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THE IMPORTANCE OF A WEAK BEND IN THE REDUCTION OF THE DIPOLE SYNCHROTRON RADIATION IN THE LEP STRAIGHT SECTIONS

by

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INTRODUCTION

In an effort to reduce the amount of synchrotron radiation entering the straight section and the interaction region, the last bending magnet before the crossing (the weak field magnet) is of lower strength than the main magnets. Previously, it has been assumed [1,2] that a strength of 10 % of that of the main magnets would provide a sufficient reduction in the amount of radiation.

This report examines the importance of a weak bend and presents one possible way of estimating its absolute value.

PHOTON FLUX

The number of photons generated with an energy ε by passing through a unit length of bending magnet is given by [3]

$$\frac{\delta^2 N}{\delta\varepsilon\,\delta s} = \frac{P_\gamma}{2\pi\rho\,\varepsilon_c^2}\,\frac{\varepsilon_c}{\varepsilon}\,S_b(\varepsilon/\varepsilon_c)$$

where ε_c is the critical energy defined as follows :

$$\varepsilon_c = \tfrac{3}{2}\,\hbar c\,\gamma^3/\rho$$

Here ρ is the bending radius, and the other symbols have their usual meaning. $S_b(\varepsilon/\varepsilon_c)$ is the universal function defined by Sands [4] and P_γ is the power loss of a circulating electron beam of current I, given by

$$P_\gamma = \frac{4\pi}{3}\,\frac{r_e E_o \gamma^4 I}{e\rho} = \frac{\delta P_\gamma}{\delta s}\,2\pi\rho$$

where r_e is the classical radius of the electron, of rest energy E_o. At a LEP energy of 86 GeV,

$$\frac{\delta P_\gamma}{\delta s} = 563.8\ W m^{-1}$$

$$\varepsilon_c = 400\ keV$$

If B_o is the strength of the 100 % magnet, and B_x the strength of the weak-field magnet, then

$$\frac{B_x}{B_o} = \frac{\rho_o}{\rho_x} = x \quad , \quad \frac{\delta P}{\delta s\,(B_x)} = \frac{\delta P}{\delta s\,(B_o)} \cdot x^2$$

Also $\quad \varepsilon_c(B_x) = \varepsilon_c(B_o) \cdot x$

Hence, it can be shown that

$$\frac{\delta^2 N}{\delta \varepsilon\, \delta s} = \frac{\delta P}{\delta s\,(B_o)} \cdot \frac{1}{\varepsilon_c(B_o)} \cdot \frac{1}{\varepsilon} \cdot x \cdot S_b\left(\varepsilon/\varepsilon_c(B_x)\right)$$

$$= 8.81 \cdot 10^{15}\ x/\varepsilon \cdot S_b\left(\varepsilon/\varepsilon_c(B_x)\right) \quad \ldots\ldots\ldots\ldots \quad (1)$$

This expression gives the energy spectrum from a bending magnet of relative strength, x, and is plotted in Fig. 1 for 100 % and 10 % magnets [5].

INTEGRAL PHOTON NUMBERS

To simplify the problem of calculating the total number of photons produced, we introduce low and high cut-off energies. The beam is separated from the experimental area by at least 2 mm of aluminium vacuum chamber wall; this introduces a low energy cut-off of 8 keV, below which the attenuation by the wall is $> 10^{15}$. The high energy cut-off is taken as 10 ε_c above which a negligible number of photons are produced.

The following approximate expression for $S_b(\varepsilon/\varepsilon_c)$ has been found :

$$S_b(\varepsilon/\varepsilon_c) = .73 + .1 \cdot \ln \varepsilon/\varepsilon_c \qquad .01 \le \varepsilon/\varepsilon_c \le .24$$

$$S_b(\varepsilon/\varepsilon_c) = .53 - .04 \cdot \ln \varepsilon/\varepsilon_c \qquad .24 \le \varepsilon/\varepsilon_c \le .60$$

$$S_b(\varepsilon/\varepsilon_c) = .40 - .29 \cdot \ln \varepsilon/\varepsilon_c \qquad .60 \le \varepsilon/\varepsilon_c \le 4$$

$$S_b(\varepsilon/\varepsilon_c) = 0 \qquad 4 \le \varepsilon/\varepsilon_c \le 10$$

Taking the length of the bending magnets as 23.16 m we have, from Equ. (1)

$$\frac{\partial N}{\partial \varepsilon} = K \cdot x/\varepsilon \cdot S_b(\varepsilon/\varepsilon_c) \quad \ldots\ldots\ldots\ldots \quad (2)$$

where $K = 2.1 \cdot 10^{17}$

We now integrate equation (2) to find the total number of photons produced from a bending magnet, for fixed X-values, within an energy range 8 to $\mathcal{E}$ keV

$$N/X = \int_{8}^{\varepsilon} \frac{1}{\varepsilon} S_b(\varepsilon/\varepsilon_c)\,\delta\varepsilon$$

The resulting curves, for various values of ε_c , are shown in Fig. 2.

The curves in Fig. 2 show that the variation in the total number of photons, above a ~ 10 keV threshold, as a function of the relative fieldstrength (B_x/B_o) is small. The total number of photons at x = 1 is only ~ 20 times higher than at x = .1 . The corresponding radiated power is, however, a strong function of the relative fieldstrength and scales as $(B_x/B_o)^2$.

RADIATION ENTERING THE STRAIGHT SECTION

The radiation entering the straight section could cause problems in two respects : damage radiation sensitive materials (superconduction equipment) and contribute to the general background.

In the first case, it is the absolute power and the dissipated energy that should be minimised. The background, however, is measured in spurious hits/bunch and is sensitive to the absolute number of photons. This is especially true for experiments with gas filled detectors.

It can probably not be avoided to place radiation sensitive equipment on all sides of the vacuum chamber and threrefore in the direct synchrotron radiation. In this case the scattered radiation can be ignored since the reduction in power is large due to scattering. The scattered power represents typically only a few % of the direct radiation. In order to avoid any direct radiation from the full field magnets to enter the straight section the weak bend should be 30 % of the full field bend (or 20 % and 50 % longer).

However, in considering the background, the situation is very different if one continues to regard the total number of photons as the important parameter. In this case, all photons reaching the central part of the intersection should have scattered at least once. The scattering reduces the energy of the photons and according to ref. 6 the intensity is reduced by typically 10^{-3} (in the extreme forward direction).

Since the scattering efficiency in the forward direction is 6 times higher for a 300 keV photon compared to a 100 keV photon, it is of interest to reduce the average energy of the initial photon flux.

It is clear from the above discussion that a weak bend will drastically reduce the total photon power and, to a less degree, the total number of photons entering the straight section.

In order to make the best estimate of the strength of the weak bend, we can use equation (2) to minimise the total number of photons hitting a length d of the vacuum chamber.

As seen from the simplified arrangement in Fig. 3, an angle Θ_d can be defined as the angle of which no direct radiation from B_o can reach the area between I and d, hence

$$\Theta_d = \frac{r}{296-d}$$

Similarly, the angle Θ'_d is defined such that

$$\Theta'_d = \frac{r-\alpha(B_x)(296-d)}{(323-d)}$$

For $\alpha(B_x) \leq \Theta d$, the total flux of energy $\mathcal{E}$ entering the region I to d, from the B_o and B_x magnets is then

$$\frac{d\Phi}{d\mathcal{E}} = \frac{\Theta'_d}{\alpha(B_o)} \cdot \frac{K \cdot S_b(\mathcal{E}/\mathcal{E}_c(B_o))}{\mathcal{E}} + \frac{x \cdot K \cdot S_b(\mathcal{E}/\mathcal{E}_c(B_x))}{\mathcal{E}}$$

and for $\alpha(B_x) > \Theta d$

$$\frac{d\Phi}{d\mathcal{E}} = 0 + \frac{\Theta_d}{\alpha(B_x)} \cdot \frac{x \cdot K \cdot S_b(\mathcal{E}/\mathcal{E}_c(B_x))}{\mathcal{E}}$$

The resulting curves of the integral photon numbers as a function of the strength of the weak-field magnet for various values of d are shown in Fig. 4a-c.

The peak at low x-values represents the contribution from the B_o-magnet. It can be argued that the higher energy of these photons and higher scattering efficiency should increase the importance of the B_o-magnet. This does, of course, strengthen the case for a weak bend but does not change its value, since the angle Θd remains the same.

CONCLUSION

It has been shown that the "effective" synchrotron radiation from a bending magnet of various strength can be represented by the curves in Fig. 2.

Using this data the absolute value of the weak bend has been estimated by mimimising the number of photons falling on a certain length (d) of vacuum chamber near the interaction point. For d = 50 m the minimum occurs at 5 % and for a complete protection of the straight section a 30 % weak bend is necessary.

This report concludes that a weak bend of ~ 8 % (in combination with collimators) would give a real and necessary reduction of the synchrotron radiation background coming from the bending magnets.

REFERENCES

1) LBL - 4288, SLAC - 189 (1976)

2) The LEP Study Group, CERN/ISR-LEP/78-12 (1978)

3) E. Keil. CERN/ISR-LEP/76-23 (1976)

4) M. Sands, SLAC-121 (1970)

5) Program SYNSPECT, ID = IS490 KEIL

6) DESY PET-78/03 (1978).

FIGURE CAPTIONS

Fig.1 Photon energy sprectra from a LEP bending magnet.

Fig.2 Integral photon number from a bending magnet of critical energy $\mathcal{E}_c$, divided by the relative strength of the magnet, vs. fractional energy $\mathcal{E}/\mathcal{E}_c$

Fig.3 Arrangement of the weak-field and main-field bending magnets.

Fig.4a-c The total photon flux from a bend consisting of one weak-field magnet (B_x) and one main-field bending magnet (B_o) as a function of B_x/B_o.

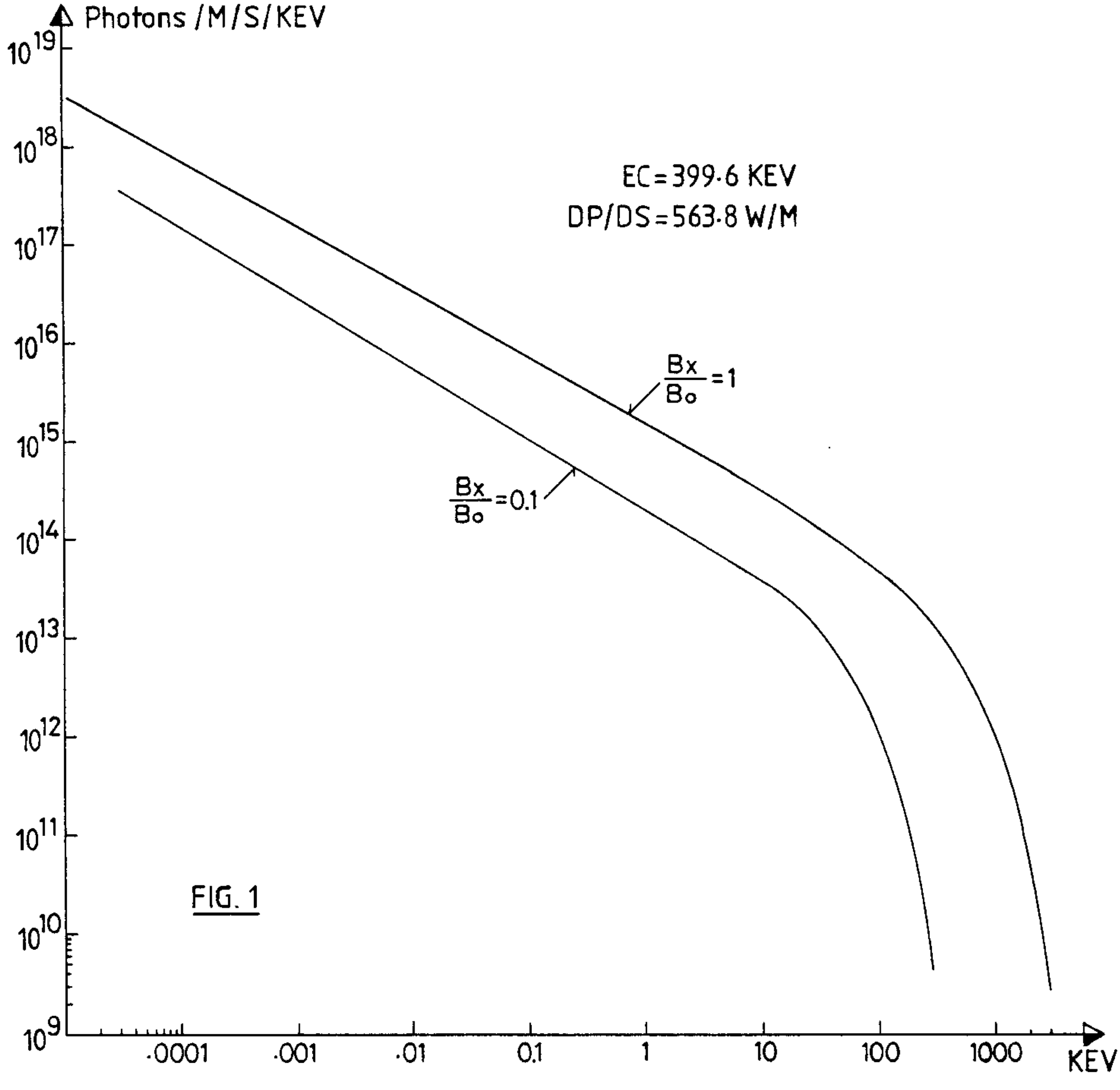
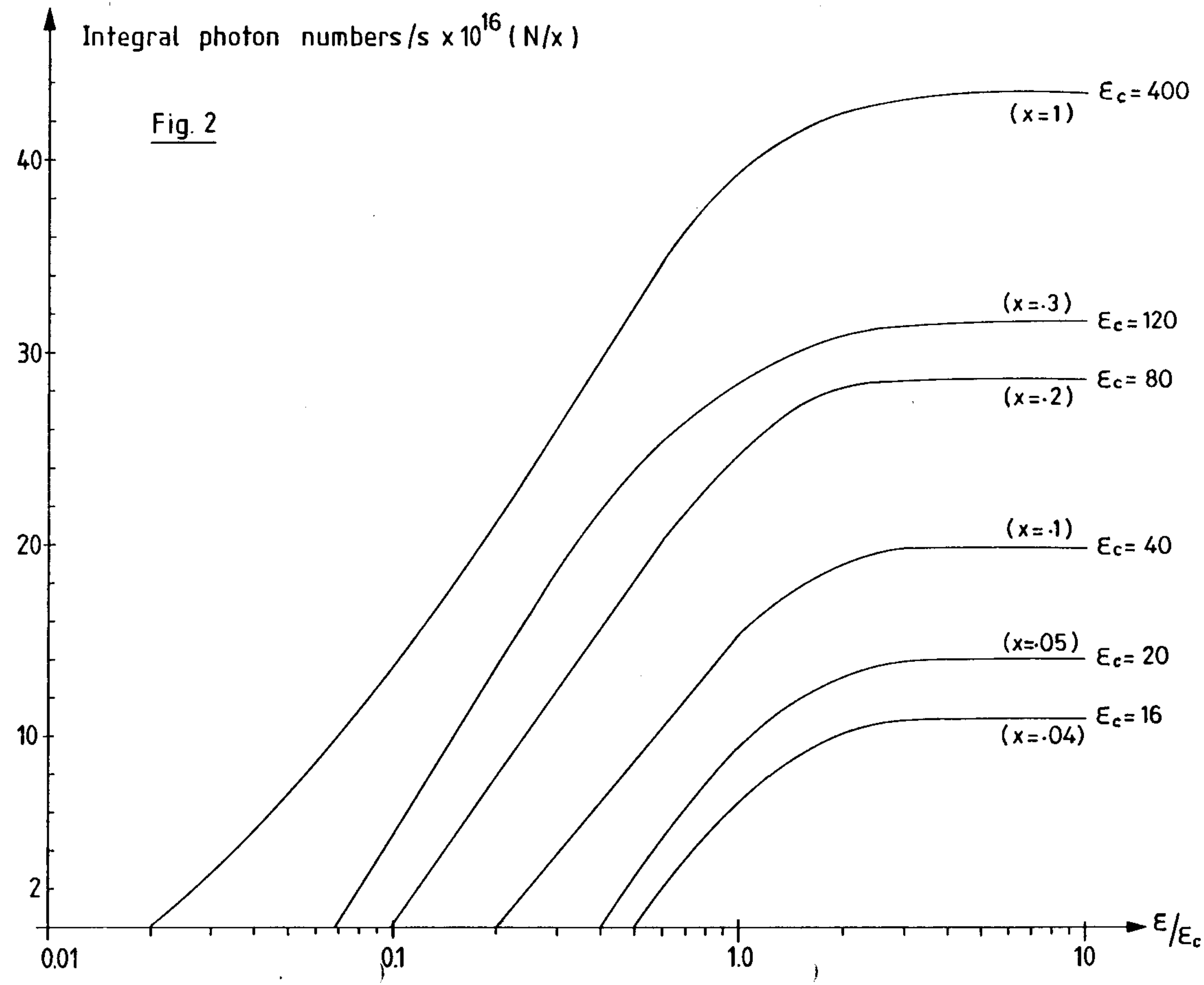

Photons /M/S/KEV
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
EC = 399·6 KEV
DP/DS = 563·8 W/M
$\frac{Bx}{Bo} = 1$
$\frac{Bx}{Bo} = 0.1$
·0001
·001
·01
0.1
1
10
100
1000
KEV

FIG. 1

Fig. 2



Integral photon numbers/s x 10^{16} (N/x)
40
30
20
10
2
0.01
0.1
1.0
10
$\varepsilon/\varepsilon_c$
ε_c = 400
(x = 1)
(x = .3)
ε_c = 120
ε_c = 80
(x = .2)
(x = .1)
ε_c = 40
(x = .05)
ε_c = 20
ε_c = 16
(x = .04)

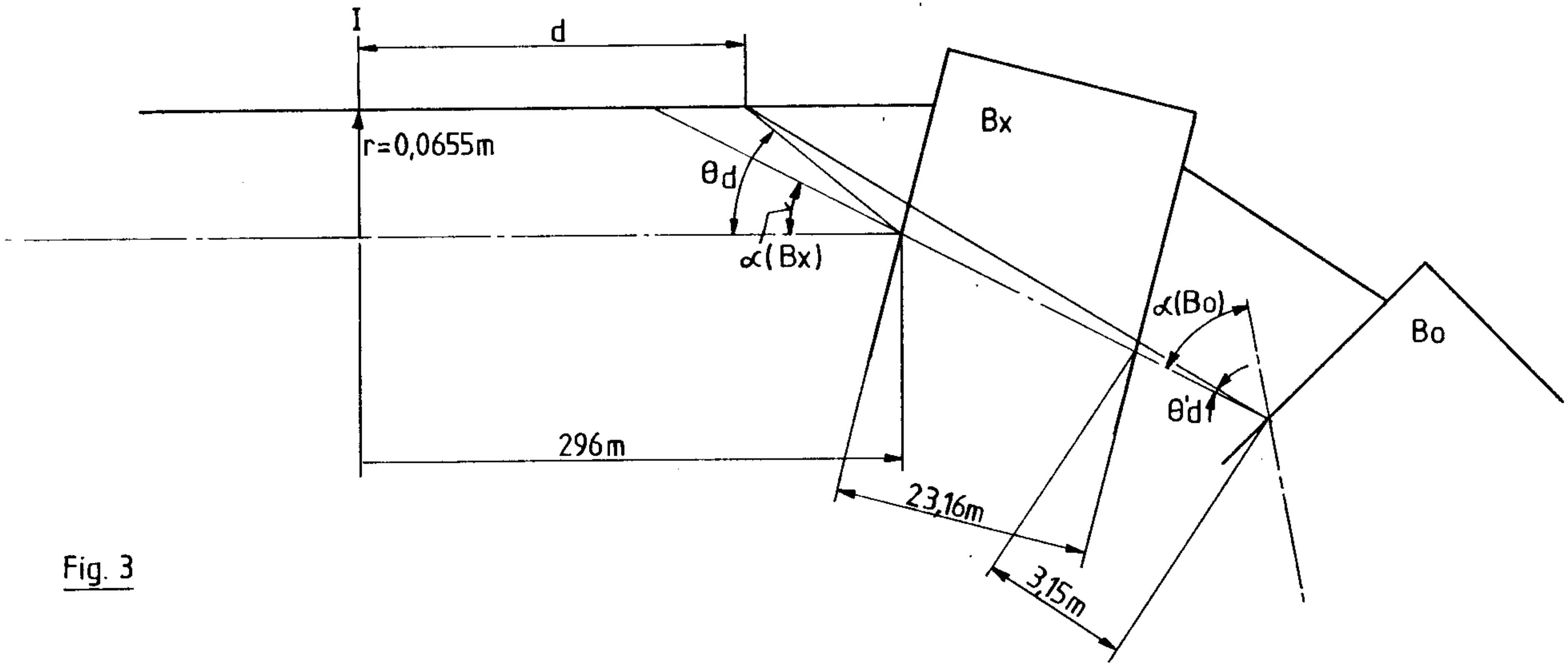
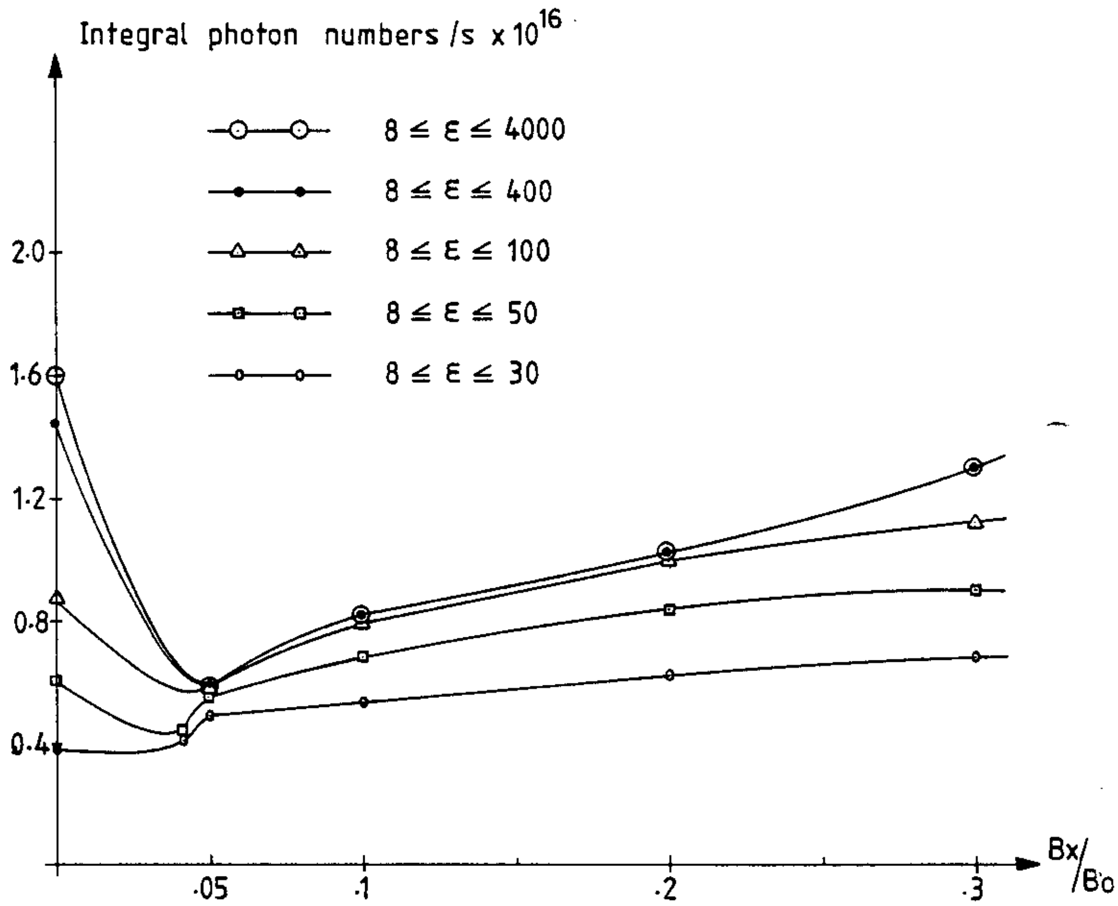


Fig. 3

Fig. 4 (a)

d = 50 m



Integral photon numbers /s x 10^16
8 ≤ ε ≤ 4000
8 ≤ ε ≤ 400
8 ≤ ε ≤ 100
8 ≤ ε ≤ 50
8 ≤ ε ≤ 30
2·0
1·6
1·2
0·8
0·4
·05
·1
·2
·3
Bx/Bo

Fig. 4 (b)

d = 100 m

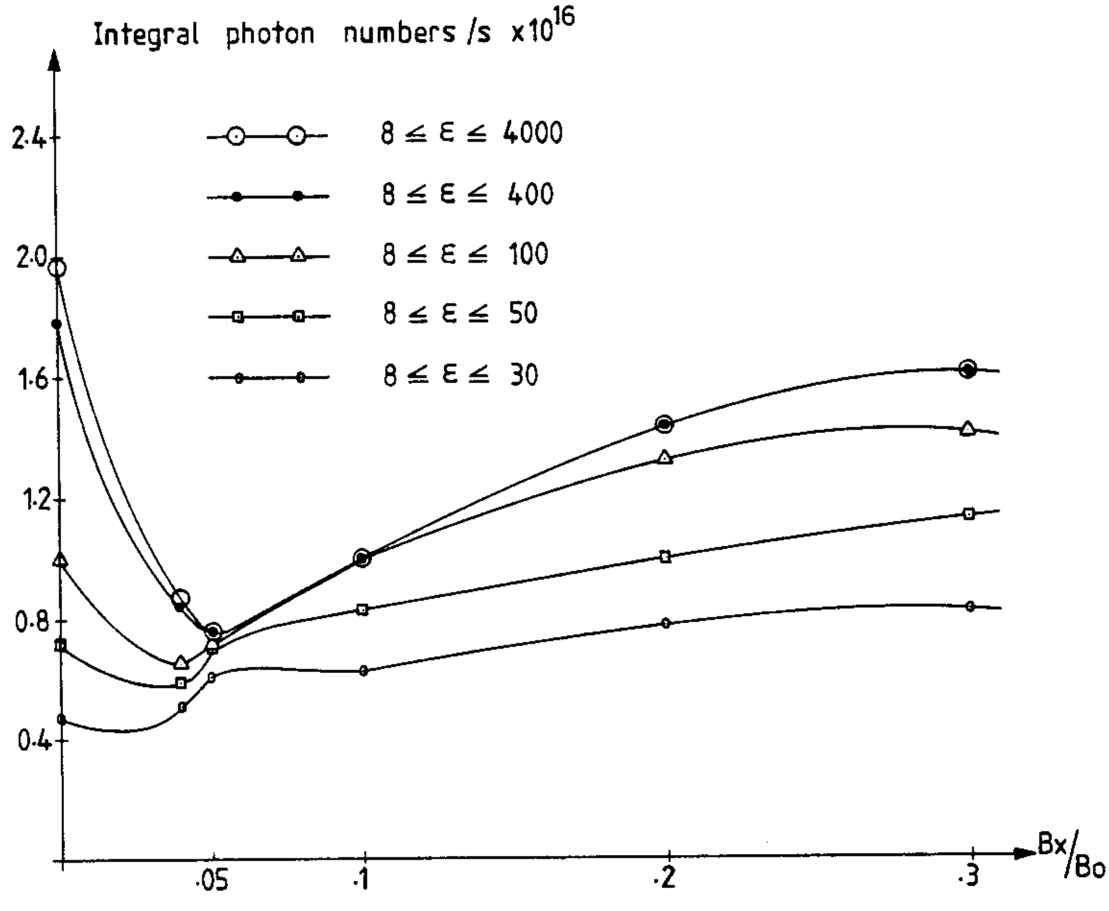
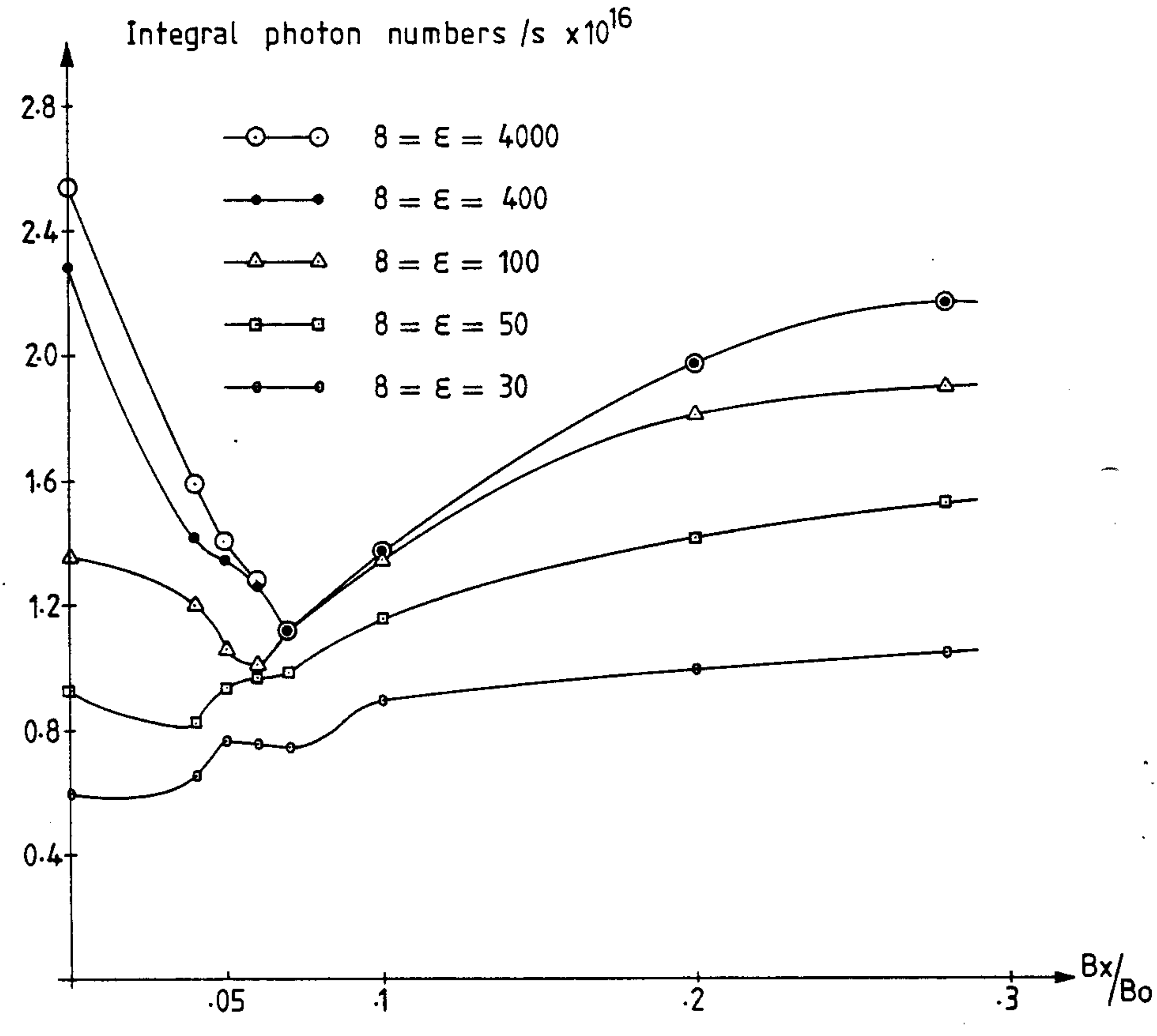

Integral photon numbers /s x10^16
8 ≤ ε ≤ 4000
8 ≤ ε ≤ 400
8 ≤ ε ≤ 100
8 ≤ ε ≤ 50
8 ≤ ε ≤ 30
2.4
2.0
1.6
1.2
0.8
0.4
.05
.1
.2
.3
Bx/Bo

Fig. 4 (c)

d = 150


Integral photon numbers /s x10[16]
2·8
2·4
2·0
1·6
1·2
0·8
0·4
8 = ε = 4000
8 = ε = 400
8 = ε = 100
8 = ε = 50
8 = ε = 30
·05
·1
·2
·3
Bx/Bo