N. Cabibbo, G. Da Prato, G. De Franceschi, U. Mosco:

NEW METHOD FOR PRODUCING AND ANALYSING LINEARLY POLA RIZED GAMMA RAY BEAMS.

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MA RAY BEAMS.

        In this note we propose a new method for the produc
tion and analysis of a beam of gamma rays of high energy.
The method is based on the interference effects which are
observable in high energy bremsstrahlung and electron pair
production on crystals.

        As a consequence of the interference effects in pair
production it is found that the absorption rate (inverse
of the mean free path) of very high energy photons in cry
stal matter depends on their (linear) polarization. This
suggests the possibility of using a thick crystal for the
polarization and analysis of gamma ray beams.

        The polarization is effected by preferential absor-
ption of the unwanted polarization component, and the ana-
lysis by transmission measurements, as in the case of a po
laroid filter for visible light.

        Extensive theoretical work on the interference ef-
fects of high energy electrodynamical processes in crystals

has been done by Überall[1] and refined experiments have given results which are in excellent agreement with the theory[2].

Another method for the production of linearly polarized gamma rays by means of interference effects in a crystal is based on bremsstrahlung[3]. In this case the theory is also in excellent agreement with the experimental results obtained with electrons of ~ 1 GeV[4].

As a polarimeter the device we propose is perhaps unique in the high energy region, where the application of other methods based on the angular distribution in pair production and elastic photoproduction of π^o on zero spin nuclei[5] requires very difficult experiments.

A unique characteristic of the device is that since it is both a polarizer and an analizer one can built two or more of them and cross calibrate them with each other. The polarizing power of the device can therefore be directly measured.

2) The absorption of high energy photons is mainly due to electron pair production, a process which is already known to give interference effects[1],[2]. Let us consider the case of a cubic crystal, where the momentum K of the incoming gamma rays is in the (001) plane and makes a small angle α with the (110) axis. The (001) plane is then a symmetry plane.

We find that the total cross section for pair production depends in this situation on the linear polarization of the gamma rays.

Let us denote by Σ'' and $\Sigma^\perp$ the total cross sections per unit volume of the crystal for gamma rays which are li

nearly polarized in the (001) plane and orthogonal to it.
The two polarization components will be absorbed with dif
ferent mean free paths: i.e. after having penetrated a thi
ckness x of the crystal the intensities of the two compo-
nents will be reduced according to:

$$I''(x) = I''(o) \, exp\left[-\Sigma'' x\right]$$

(1)
$$I^{\perp}(x) = I^{\perp}(o) \, exp\left[-\Sigma^{\perp} x\right]$$

If the beam was originally unpolarized ($I''(o) = I^{\perp}(o)$) we
now have a polarization:

(2) $$P(x) = \left(I''(x) - I^{\perp}(x)\right) / \left(I''(x) + I^{\perp}(x)\right) = tanh\left[\tfrac{1}{2} x (\Sigma^{\perp} - \Sigma'')\right]$$

From eq. (2) one can see that this method could in
principle produce any degree of polarization, with an ap-
propriate choice of the thickness x. This is achieved with
a loss of the original intensity which can be expressed
in terms of the polarization P(x) and of a parameter $E(\alpha, \omega)$
defined as:

(3) $$E(\alpha, \omega) = \left(\Sigma^{\perp} - \Sigma''\right) / \left(\Sigma^{\perp} + \Sigma''\right)$$

(4) $$I(x) = I''(x) + I^{\perp}(x) = I(o) \, exp\left[-E^{-1} tanh^{-1} P\right] \left(1 - P^2\right)^{-\tfrac{1}{2}}$$

In fig. 1 we plot the intensity loss as a function
of the polarization for different values of E. Large pola
rizations with acceptable intensity losses are possible if
E $\gtrsim$ 0.05.

The technique for the computation of the relevant
cross sections is essentially that given by Überall and is
described elsewhere[7]. We have made extensive computations
for the crystals of copper (FCC lattice) at 77 °K[8], and
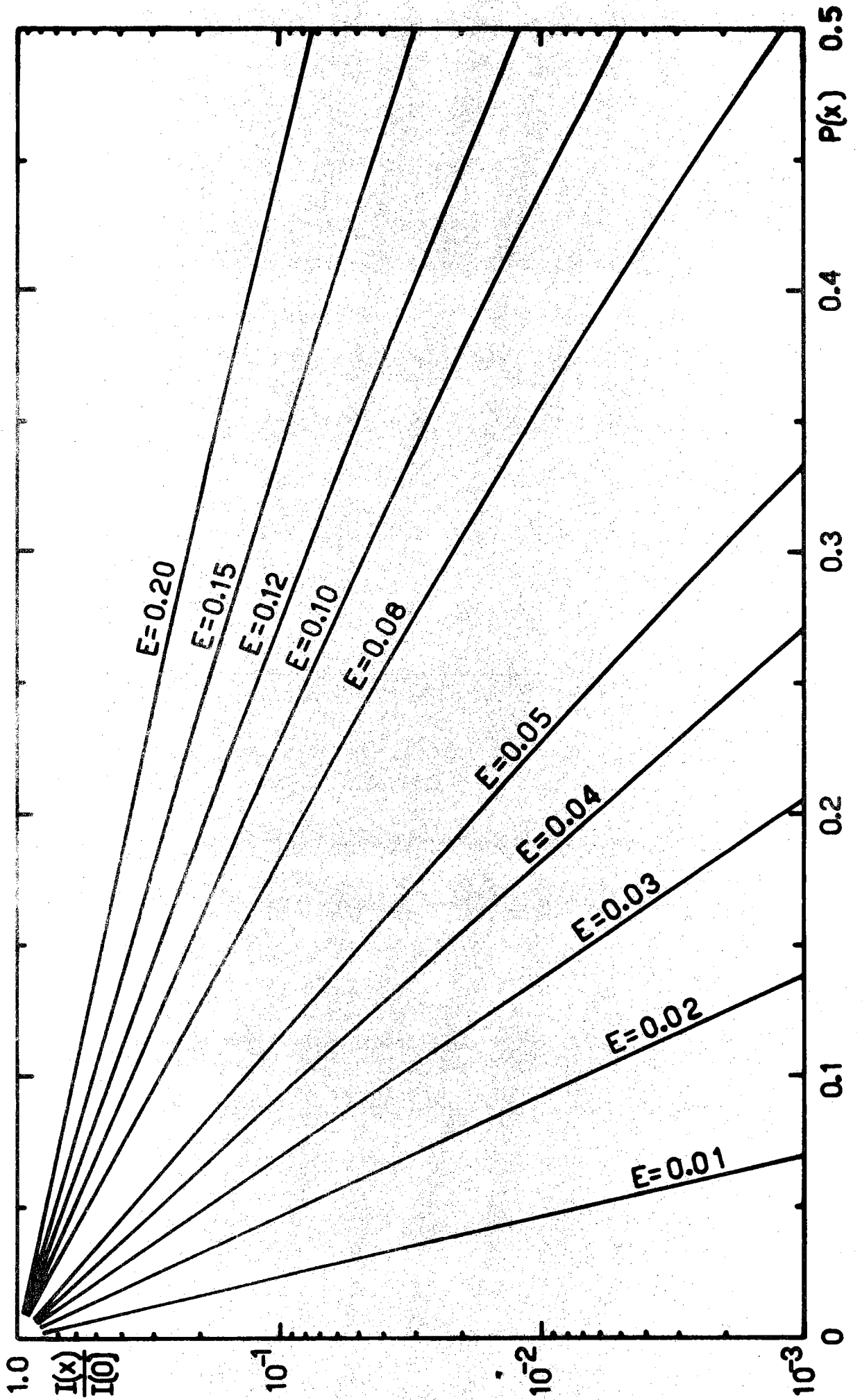
silicon (diamond lattice) at 300 °K. These crystals whe-
re chosen because they have a close packed structure and
are probably available in the large sizes required here.
Table I gives the values of E at different energies, for
the optimum value of the angle α at that energy. One can
see that the efficiency of the device increases with the
photon energy so that it's use as a polarizer starts to be
practicable for energies of the order of 6 GeV.

Table I

ω GeV	Crystal	α mrad	E
1	Cu	28	0.011
1	Si	41.5	0.0065
6	Cu	3.7	0.051
6	Si	5.5	0.034
40	Cu	0.455	0.16
40	Si	0.68	0.125

In fig. 2 we plot E as a function of the angle for
Cu with ω = 6 GeV, and E as a function of ω at α = 3.7
mrad (the optimum at 6 GeV). The dependence of E on α and
ω is not extremely critical.

3) As we said the device can be also used as a polarimeter.
Suppose that the incoming gamma rays have a linear polari-
zation $\vec{Q}$; let ψ be the angle between $\vec{Q}$ and the (001)
plane, the situation being the same as before. The transmis-
sion coefficient is then found to be:

a

Cu 77°K α=3.7

ω in GeV

b

Cu 77°K ω=6 GeV

α in m rad.
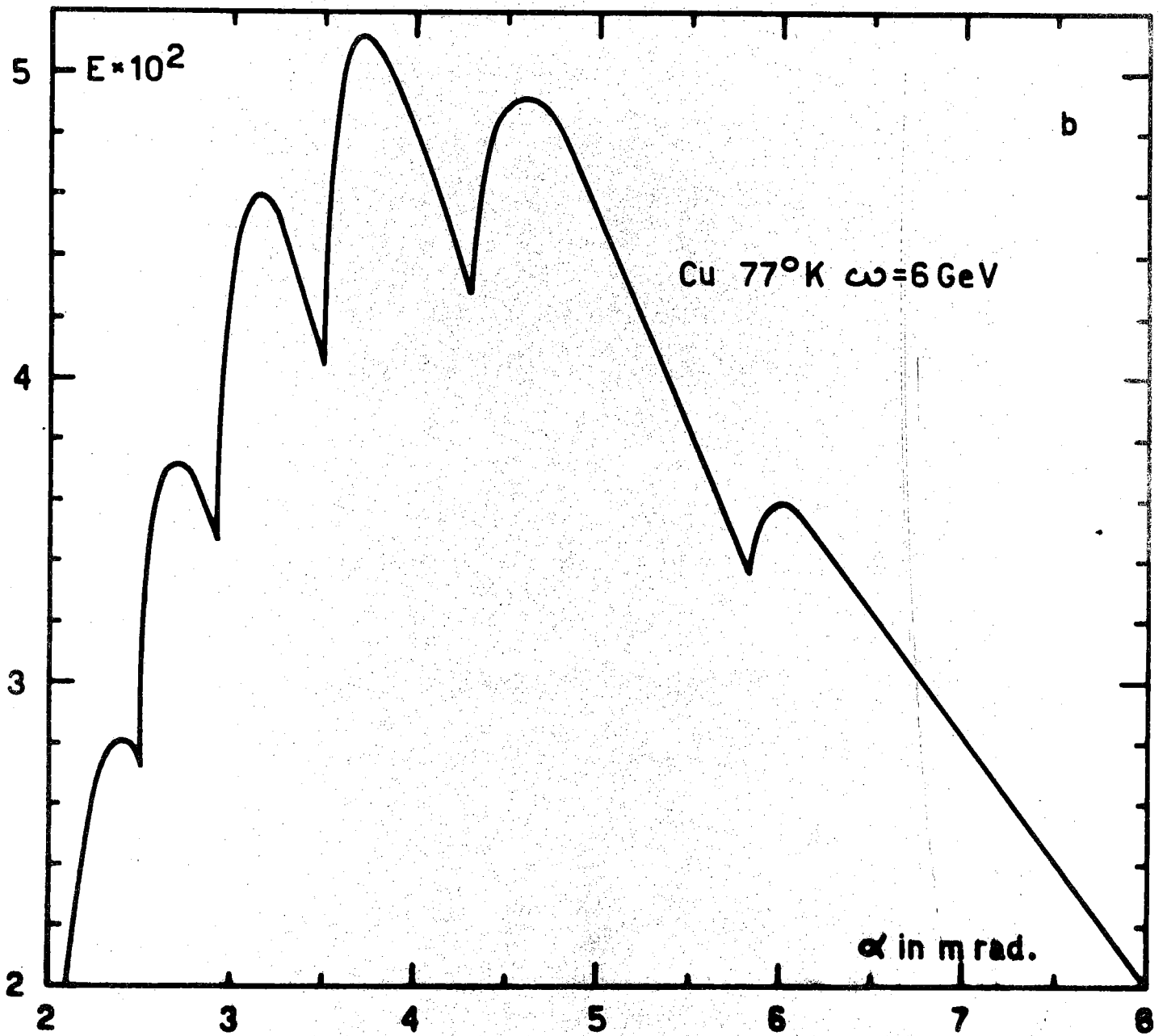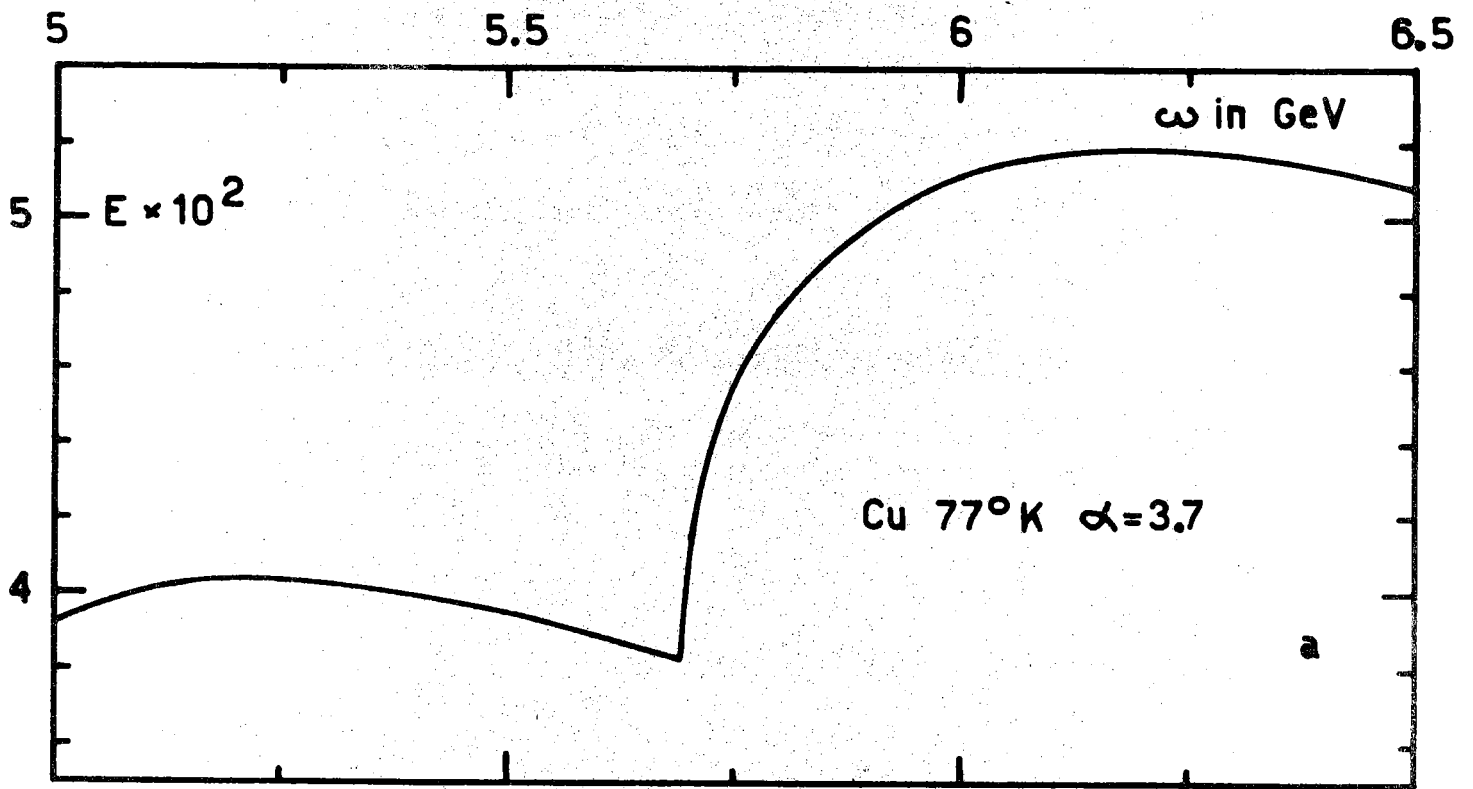
$$[I(x)/I(o)]_{\vec{Q}} = [I(x)/I(o)]_{\vec{Q}=0} \; (1 + |\vec{Q}| P(x) \cos 2\psi)$$

Knowing $P(x)$, $\vec{Q}$ can be determined by absorption measurements with the crystal in different positions obtained by rotation around the direction $\vec{k}$, so that ψ is varied, but not α .

Most of the initial energy in the beam to be analized or polarized will be absorbed in the crystal through the electromagnetic shower. This will present some problem of radiation damage to the crystal, particularly in its use as a polarizer, which need further consideration. In practical use it will be necessary to eliminate the shower secondaries through careful collimation.

We are grateful to prof. G. Diambrini and drs. Barbiellini, Bologna and Murtas for many stimulating discussions and for suggestions about the choice of the crystals to be studied, and to dr. A. Turrin and the other members of the computation group for their assistance during the numerical computations with the IBM 1620 computer.

The use of pair production on crystals (not in a trasmission experiment) for the measurement of linear polarizations had been considered previously by G. Barbiellini.

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(2) - G. Bologna, G. Diambrini, G.P. Murtas, Phys. Rev. Lett. <u>4</u>, 134 (1960).
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(3) - H. Überall, Phys. Rev. <u>107</u>, 223 (1957)

(4) - G. Barbiellini, G. Bologna, G. Diambrini, G.P. Murtas, to be published.

(5) - N. Cabibbo: Phys. Rev. Lett. <u>7</u>, 386 (1961).

(6) - Due to multiple scattering of the produced electrons, the coherence effect is limited to a lenght which is small compared with macroscopic distances, so that one can assume the decay to be exponential.

(7) - N. Cabibbo, G. Da Prato, G. De Franceschi, U. Mosco: internal report of the Frascati Laboratories.

(8) - Part of the cross section is due to the thermal and zero point motion of the nuclei, and depend on the temperature.

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