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NEW METHOD FOR PRODUCING AND ANALYZING LINEARLY POLARIZED GAMMA-RAY BEAMS

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In this note we propose a new method for the production and the analysis of a polarized beam of high-energy gamma rays. The method is based on the interference effects which are observable in high-energy electron pair production on crystals. As a consequence of these the absorption rate (inverse of the mean free path) of very high-energy photons in crystal matter depends on their linear polarization. This suggests the possibility of using a thick crystal for the polarization and analysis of high-energy gamma rays. The polarization is effected by preferential absorption of the unwanted polarization component, and the analysis by transmission measurements, as in the case of a polaroid filter for visible light. Extensive theoretical work on the interference effects of high-energy electrodynamic 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^0 on nuclei of zero spin[5] requires very difficult experiments. A unique characteristic of the device is that, since it is both a polarizer and an analyzer, one can build two or more of them and cross-calibrate them with each other. The polarizing power of the device can therefore be directly measured.

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 $\vec{k}$ 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 $\Sigma^{\parallel}$ and $\Sigma^{\perp}$ the total cross sections per unit volume of the crystal for gamma rays which are linearly polarized in the (001) plane and orthogonal to it. The two polarization components will be absorbed with different mean free paths; i.e., after having penetrated a thickness x of the crystal the intensities of the two components will be reduced according to[6]

$$I^{\parallel}(x)=I^{\parallel}(0)\exp[-\Sigma^{\parallel}x],$$
$$I^{\perp}(x)=I^{\perp}(0)\exp[-\Sigma^{\perp}x]. \quad (1)$$

If the beam was originally unpolarized $[I^{\parallel}(0)=I^{\perp}(0)]$, we now have a polarization:

$$P(x)=[I^{\parallel}(x)-I^{\perp}(x)]/[I^{\parallel}(x)+I^{\perp}(x)]$$
$$=\tanh[\tfrac{1}{2}x(\Sigma^{\perp}-\Sigma^{\parallel})]. \quad (2)$$

From Eq. (2) one can see that this method could, in principle, produce any degree of polarization, with an appropriate 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

$$E(\alpha,\omega)=(\Sigma^{\perp}-\Sigma^{\parallel})/(\Sigma^{\perp}+\Sigma^{\parallel}), \qquad (3)$$

$$I(x)=I^{\parallel}(x)+I^{\perp}(x)$$
$$=I(0)\exp[-E^{-1}\tanh^{-1}P](1-P^2)^{-1/2}. \qquad (4)$$

In Fig. 1 we plot the intensity loss as a function of the polarization for different values of E. Large polarizations 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 were 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 its use as a polarizer starts to be practicable for energies of the order of 6 GeV.

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

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

$$[I(x)/I(0)]_{\vec{Q}}=[I(x)/I(0)]_{\vec{Q}=0}[1+|\vec{Q}|P(x)\cos 2\varphi].$$

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

Most of the initial energy in the beam to be analyzed or polarized will be absorbed in the crystal through the electromagnetic shower.

Table I. Values of E at different energies for the optimum value of the angle α at that energy.

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	0.456	0.16
40	Si	0.68	0.125

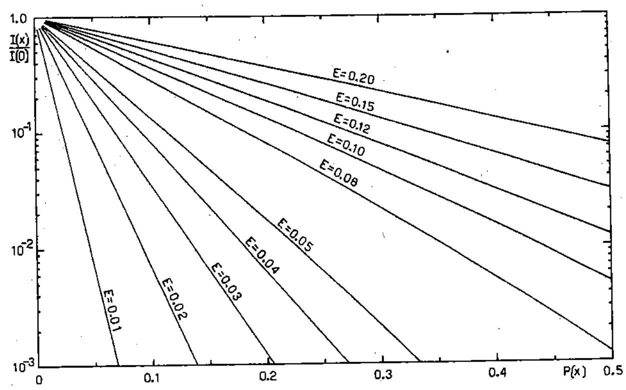

FIG. 1. Relation between the attenuation of an unpolarized beam and the obtained polarization for different values of E.

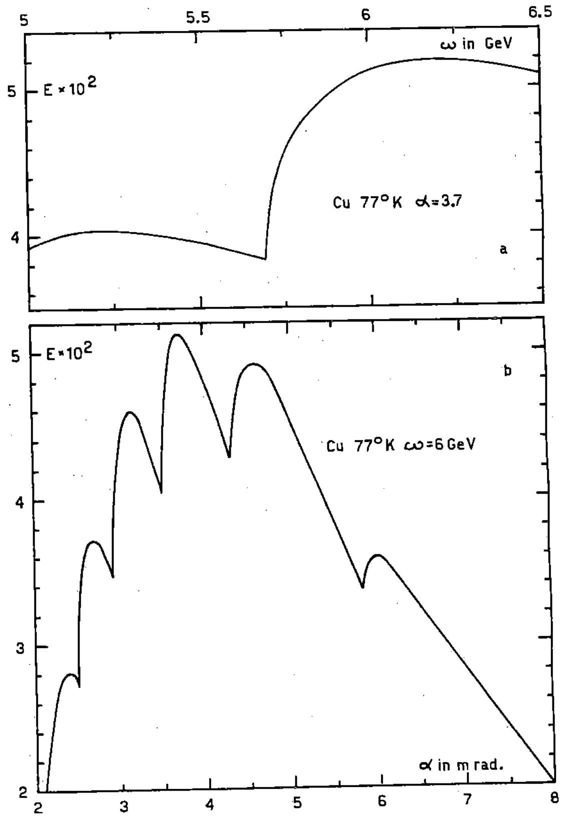

FIG. 2. (a) E as a function of ω around $\omega = 6$ GeV at the best angle $\alpha = 3.7$ mrad. (b) E as a function of the angle α for Cu with $\omega = 6$ GeV.

This will present some problems 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 Professor G. Diambrini, Dr. G. Barbiellini, Dr. G. Bologna, and Dr. G. P. 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 transmission experiment) for the measurement of linear polarizations had been considered previously by Barbiellini.[9]

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EVIDENCE FOR A $T=0$ π^+-π^- RESONANCE AT 1250 MeV*

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In recent months a great deal of attention has been given to the Regge-pole approach to elementary particle theory. If this approach, as outlined particularly by Chew and Frautschi,[1] is correct, then in some sense the existence of some unifying principle for all of the elementary particles will be indicated. One of the specific predictions of the Regge-pole approach is the existence of a spin-2 particle, having the quantum numbers of the vacuum (apart from the angular momentum), and with a mass of the order of 1.0[1] to 1.4[2] BeV. Such a particle could decay into two π mesons and should be observed as a π-π resonance with isotopic spin $T=0$. This Letter reports experimental evidence for the existence of a particle with isotopic spin, G-parity, and mass similar to those of the particle called for in the Regge pole theory.

From a run of 60 000 pictures using the 3-BeV/c separated π^- beam[3] and the BNL 20-inch hydrogen bubble chamber, at the AGS, we have so far analyzed 40% of the available two-prong reactions, and have in particular studied the reactions

$$\pi^- + p \to \pi^- + \pi^0 + p, \qquad (1)$$

$$\pi^- + p \to \pi^- + \pi^+ + n. \qquad (2)$$

Figure 1 shows the invariant-mass distributions for the π-π system, in Reactions (1) and (2). The data show a peak at about 1250 MeV in the $\pi^-\pi^+$ mass plot in addition to the ρ peak at 775 MeV. The 1250-MeV peak is not present in the $\pi^-\pi^0$ data, and we therefore identify it as $T=0$. We shall refer to this resonance, or particle, as the f^0 meson.

The width of the f^0 appears to be of the order of 100 MeV or so, full width at half maximum. This is considerably greater than our experimental resolution, which we estimate to be about 20 MeV.

Our conclusion that the 1250-MeV peak is real is based on the difference between the $\pi^-\pi^0$ and $\pi^-\pi^+$ mass plots in Fig. 1. The $\pi^-\pi^0$ mass plot, for masses above the ρ peak, is completely consistent with a phase-space distribution. The $\pi^-\pi^+$ mass plot, however, is quite inconsistent with such a distribtuion. The odds against a phase-space distribution being consistent with our data are of the order of several thousand to one, when we compare the number of events in mass intervals of 50 to 100 MeV, covering the range from 1000 to 1600 MeV, with the relative numbers of events for a phase-space distribution. (These odds are calculated by a χ^2 method.)