Experimental study of radiation of channeled relativistic positrons

I. I. Miroshnichenko, J. J. Murray,[1)] R. O. Avakyan, and T. Kh. Figut

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The energy spectra of electromagnetic radiation produced as a result of interaction of high-energy positrons with crystals under conditions of planar and axial channeling were measured for the first time. A new physical effect was observed—radiation of channeled relativistic positrons—which was theoretically predicted by the Soviet physicist M.A. Kumakhov.

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It was shown recently in a number of theoretical studies[1-4] that channeling of relativistic particles causes a strong spontaneous radiation of γ-rays. The spectral density of this radiation in the neighborhood of the maximum greatly exceeds the density

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of bremsstrahlung. This singularity and the high degree of monochromaticity and polarization of this radiation may open unexpected possibilities for its practical application. The attempts[5,6] to observe experimentally the spontaneous radiation did not give an unambiguous result.

In this paper we measured for the first time the energy spectra of electromagnetic radiation by passing channeled high-energy positrons through diamond single crystals. The experiment was performed in November and December 1978, using the positron beam from the Stanford Linear Accelerator (USA) at energies of 4, 6, 10, and 14 GeV.

In the experiment we used diamond crystals of thickness 0.7×10^{-3} X and 5.2×10^{-3} X (X is the radiation length).

The positron-shaping system provided an angular divergence of the beam $\leqslant 10^{-5}$ rad. The photons, which were emitted by passing the positrons through the crystal, were recorded by a total absorption γ-ray spectrometer with a 20 X-thick NaI(Tl) crystal. An appropriate system of scintillation detectors and a coincidence-anticoincidence technique were used to separate useful and background events and to control the multichannel analyzer, which was used for analyzing the γ-ray spectra recorded by the NaI(Tl) counter. A LSI-II microcomputer was used for recording and analyzing the data. The measurements were carried out at an average intensity of the positron beam not greater than 1 positron per accelerator pulse.

In the experiment we used a goniometer whose vertical axis of rotation was perpendicular to the 011 plane of the crystal; the 100 plane was oriented perpendicularly to the positron beam. The orientation of the diamond crystal was based on the well-known effects of coherent bremsstrahlung of electrons in the crystal targets.[7] The accuracy of orientation of the crystal was 1.15×10^{-5} rad. We performed calibration measurements of the bremsstrahlung spectra of an amorphous target (diamond equivalent) and of the coherent bremsstrahlung spectra of the diamond crystal. The absolute cross sections of the normal and coherent bremsstrahlung are in agreement with the theoretical cross sections. Figure 1 shows the emission spectra for the planar channeling of 4-GeV positrons. It can be seen in Fig. 1 that in the low-energy region

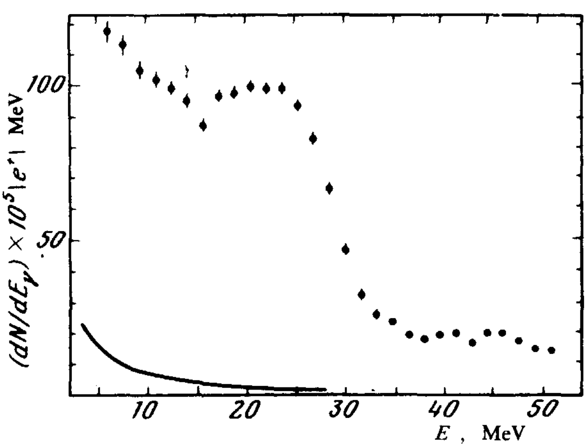

FIG. 1. Emission spectrum produced as a result of planar channeling of 4-GeV positrons. The solid line represents the emission spectrum for an amorphous target.

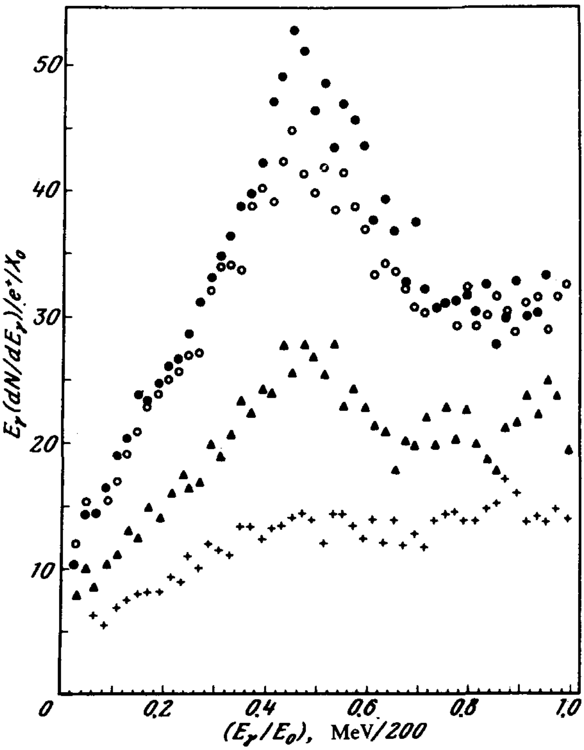

FIG. 2. Emission spectra produced as a result of planar channeling of 10-GeV positrons as a function of the angle θ between the crystal plane and the positron momentum: ●, $\theta = 0$ rad; ○, $\theta = 4.6\times10^{-5}$ rad; ▲, $\theta = 9.2\times10^{-5}$ rad; +, $\theta = 11.5\times10^{-5}$ rad.

the number of photons increases substantially compared with the normal bremsstrahlung; moreover, the number above the amorphous level increases several hundred fold with increasing energy. Note that the total number of photons in the emission spectrum of the 10-GeV positrons, after passing through a crystal of thickness 5.2×10^{-3} X, is equal to approximately the number of positrons.

We measured the emission spectra as a function of the angles of orientation of the crystal plane relative to the positron momentum. The results of these measurements for the 10-GeV positrons are shown in Fig. 2 as dependences of $E_\gamma(dN/dE_\gamma)$ on the energy of the photons for different angles of orientation. We can see a clearly defined peak whose intensity is highly sensitive to the angle of orientation of the crystal plane

TABLE I.

Positron energy	Maximum radiation energy
4 GeV	23 MeV
6 GeV	42 MeV
10 GeV	90 MeV
14 GeV	120 MeV

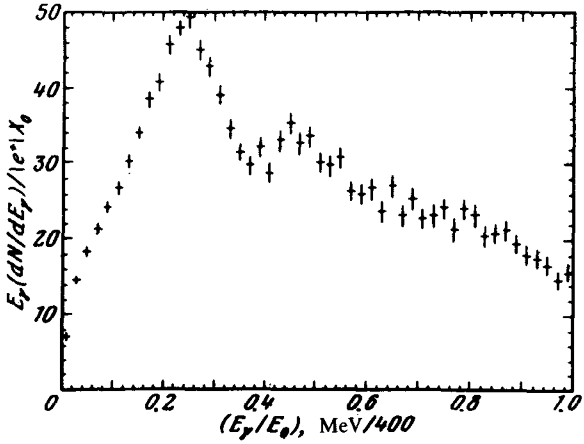

FIG. 3. Emission spectrum produced as a result of planar channeling of 10-GeV positrons.

relative to the positron momentum. The intensity of this peak, which is maximum when the position of the crystal corresponds to the planar channeling of positrons, decreases with increasing angle, when the angle exceeds the critical value the intensity of this peak is equal to zero. Thus, this radiation, which is uniquely connected with the channeling process, may be interpreted as a new physical effect-radiation of channeled

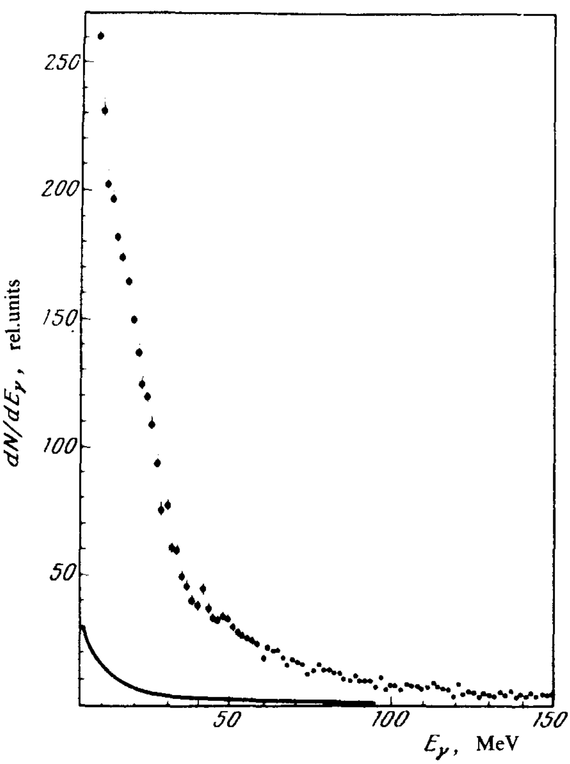

FIG. 4. Emission spectrum produced as a result of axial channeling of 4-GeV positrons: E_γ is the photon energy and E_0 is the positron energy.

relativistic positrons, which was theoretically predicted by the Soviet physicist M.A. Kumakhov.

The maximum radiant energy measured experimentally is in good agreement with the value predicted theoretically, and the energy behavior can be satisfactorily reproduced by the $E^{3/2}$ dependence (see Table I). The shape of the spectral distribution of radiation is consistent with that predicted theoretically.

Thus, a new physical effect—radiation of channeled relativistic positrons—has been observed experimentally. Notice the singularity of the measured spectral distributions in Fig. 3 which shows the emission spectrum $E_\gamma(dN/E_\gamma)$ for planar channeling of the 10-GeV positrons in a crystal of thickness 0.7×10^{-3} X. In addition to the main spontaneous-radiation peak, whose position is consistent with that calculated theoretically in the dipole approximation, there is a second, less intensive peak at a higher energy. In view of this, it would be of interest to examine this effect in terms of the theory which takes into account the higher order transitions.

The emission spectra for axial channeling of positrons are qualitatively different from those for planar channeling (see Fig. 4). The emission spectrum has no clearly defined peaks characteristic of planar channeling. The intensity of the photons exceeds by several factors the corresponding intensity in the spectra of the planar channeling.

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[1)]Stanford Linear Accelerator Center, Stanford, California 94305.

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