Orientational dependence of cascade processes in silicon crystals

V. A. Baskov, V. B. Ganenko,[1)] V. A. Gushchin,[1)] Yu. V. Zhebrovskiĭ,[1)] V. V. Kim, L. Ya. Kolesnikov,[1)] I. V. Konorov, B. I. Luchkov,[2)] V. A. Maisheev,[3)] A. L. Rubashkin,[1)] V. I. Sergienko, V. Yu. Tugaenko,[2)] V. A. Khablo, and O. V. Chupikov[2)]
P. N. Lebedev Physics Institute, Academy of Sciences of the USSR

(Submitted 28 September 1989)
Pis'ma Zh. Eksp. Teor. Fiz. **50**, No. 9, 395–397 (10 November 1989)

The orientational dependence of signals from a Čerenkov counter has been obtained. The Čerenkov counter recorded the electromagnetic showers emitted from a silicon crystal. These electromagnetic showers were produced by γ rays with energies 3–15 GeV. The resulting effects can be used to determine the location of the γ-ray source.

The cascade processes in oriented crystals, which are produced by high-energy γ rays, differ markedly from similar processes in amorphous substances. At certain energies and small angles Θ between the primary-particle momentum and the crystallographic axis (plane) the probability that a γ ray will produce an e^+e^- pair and that an electron will emit a γ ray may be considerably greater than the probability for these occurrences in an amorphous substance or a disoriented crystal. As a result, an electromagnetic shower develops over a shorter distance which depends on Θ, on the primary particle energy, and on the characteristics of the crystal. As the energy of the γ rays which move along the crystallographic axis is reduced, the probability that they will produce e^+e^- pairs decreases exponentially, while the probability for a multiple emission of γ rays by electrons, which move under similar conditions, remains high. The crystal produces distinctive photon showers, in which there can be many more γ rays than charged particles.[1,2] As a result, the directivity of the cascade processes relative to the angle Θ will be determined by the directivity of the radiation losses of electrons (positrons) in the crystal over a broad energy interval of primary γ rays. A directivity of this sort is observed in the orientational dependence of the emission from a tungsten crystal of the photon and charged components of the electromagnetic showers produced by 8- to 26-GeV γ rays.[3] The widths of these dependences are comparable to each other and to the width of the orientational curve of the emission of 28-geV/c electrons in the same crystal.[4]

Several methods of using single crystals to determine the directions of a γ-ray beam, which are based on the measurement of the orientational dependence of the cross section for the photoproduction of e^+e^- pairs, have been proposed.[5] At low γ-ray energies the curve for the photoproduction cross section has several coherent peaks which have an angular distribution of hundreds of milliradians from the angle $\Theta = 0$, when the crystallographic axis is pointed directly to the γ-ray source. As the energy is raised, the peaks converge and increase. At high energies ($E_\gamma \gtrsim 100$ GeV for silicon and $E_\gamma \gtrsim 25$ GeV for tungsten) the cross section has one, pronounced peak at $\Theta = 0$, which is attributable to the production of $e^+ e^-$ pairs in a strong field. The orientational curve for the cross section can be obtained by turning, in a goniometric device, the crystal with a preferred crystallographic axis in a γ-ray flux, by counting the γ-ray conversion events, and by measuring the energy of the γ rays with a detector placed behind the crystal. The direction of the γ-ray beam can be determined from the peaks in the cross section. This method, however, cannot be used effectively in γ-ray astronomy to search for cosmic γ-ray emission sources. At low γ-ray energies ($\gtrsim 1$ GeV) the accuracy of the determination from coherent peaks is no better than that of the conventional methods, and the procedure is complicated, in particular, if there is more than one source. Since the cosmic γ-ray fluxes are small at high energies ($\gtrsim 100$ GeV), the area of the detector must be large, a goal which is actually very difficult to achieve, particularly in the case of extraterrestrial γ-ray astronomy. It is necessary to develop a method which could be used over a broad range of γ-ray energies, beginning with ~ 1 GeV, and to use readily available, perfect crystals of relatively large dimensions, such as silicon, for example.

To verify the applicability of such a method to study the development of cascade processes in crystals, we have measured the emission of the charged component of a shower from a silicon crystal. A 20-mm-thick crystal, oriented relative to the ⟨100⟩ axis, was held at a temperature of 293 K. Figure 1 (the left ordinate: ●, ○, ×, ▼) shows the orientational dependence of the average amplitude of the signals from a Čerenkov counter with a lead-glass radiator of thickness one radiation length. The counter was placed behind the crystal. The divergence of the primary γ-ray beam is $|\vartheta| \leqslant 0.5$ mrad at the base. All curves have a single maximum at $\Theta = 0$, whose half-width at half-height is identical within error limits: ~ 3 mrad. With an increase in the γ-ray energy, the extent to which the maximum is exceeded increases from $\sim 30\%$ at

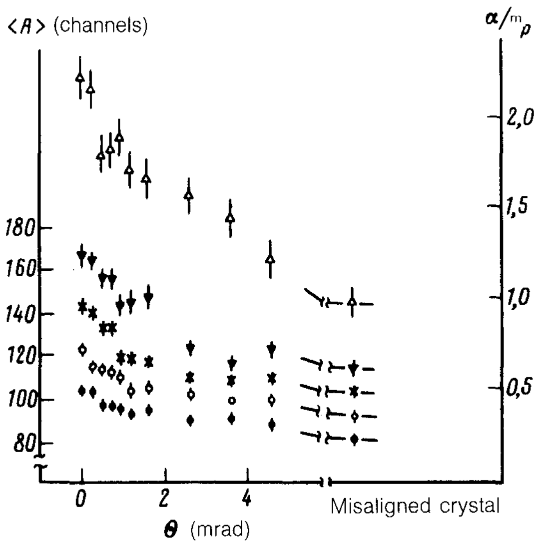

FIG. 1. Orientational dependences of the average amplitude of the signals from the Čerenkov counter (left ordinate, ●, ○, ×, ▼) and of the change in the amplitude spectrum of the signals from the counter (right ordinate, △). ●—$E_\gamma = 3$–5 GeV, ○—$E_\gamma = 5$–7 GeV, ×—$E_\gamma = 7$–10 GeV, ▼--$E_\gamma = 10$–15 GeV, △—$E_\gamma = 3$–5 GeV.

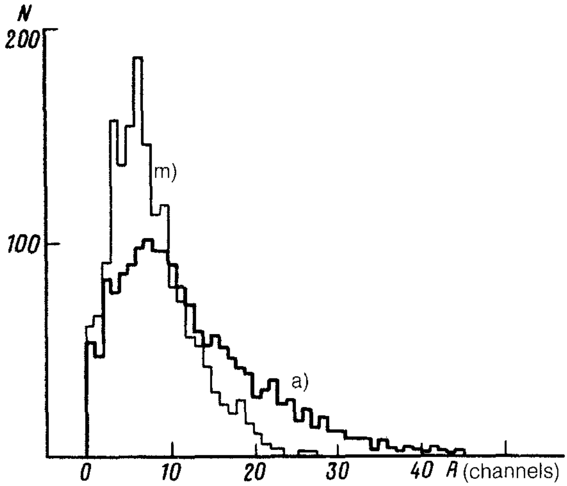

FIG. 2. Amplitude spectra of the signals from the Čerenkov counter. m) Misaligned crystal; a) the ⟨100⟩ axis of the crystal is aligned with the γ-ray beam.

$E_\gamma = 3$–5 GeV to ~50% at $E_\gamma = 10$–15 GeV; i.e., with an increase in the energy, the efficiency of this method improves. At γ-ray energy $\lesssim 3$ GeV, the maximum increases only slightly and the search for the location of the source may become complicated. Figure 2 shows the amplitude spectra—which contain an identical number of events—of the signals from the counter for the two extreme cases: m) the crystal is misaligned; a) the crystal is aligned with the γ-ray beam with energies 3–5 GeV. The shape of spectrum a) changes with respect to the shape of spectrum m): The number of events with a large amplitude increases as a result of a decrease in the number of events with a small amplitude. The magnitude of the change can be quantitatively estimated from the coefficient $\alpha = \Delta N_{\rm rs}/\Delta N_{\rm es}$, where $\Delta N_{\rm rs}$ is the number of events on the right side of the amplitude spectrum relative to the chosen channel, and $\Delta N_{\rm ls}$ is the number of events on the left side of the spectrum. In our case the maximum ratio of the coefficients of the spectra $\alpha_a/\alpha_m = 2.3 \pm 0.2$, i.e., an increase of $\gtrsim 100\%$. The orientational dependence of the ratio α/α_m is shown in Fig. 1 (the symbol Δ on the ordinate on the right side). This dependence has the same width as the neighboring dependences. The use of the spectrum-conversion method can simplify considerably, in our view, the search for the source of γ rays with energies $\leqslant 3$ GeV.

The results presented in this letter show that the directivity of cascade processes in crystals is observed over a broad range of energies of primary γ rays. This is an important consideration in the construction of γ-ray telescopes and directional spectrometers used to determine the energy of γ-rays and the vertex of their production in nuclear reactions.

[1] Physicotechnical Institute, Khar'kov.
[2] Engineering-Physics Institute, Moscow.
[3] Institute of High Energy Physics, Serpukhov.

[1] V. N. Baier *et al.*, NIM in Phys. Res. B **27**, 360 (1987).
[2] A. I. Akhiezer *et al.*, Dok. Akad. Nauk SSSR **292**, 338 (1987) [Sov. Phys. Dokl. **32**, 47 (1987)].

[3] V. A. Baskov *et al.*, Preprint FIAN No. 143, Moscow, 1988. *Proceedings of the XIX All-Union Conference on the Physics of the Interaction of Charged Particles with Crystals, 1989,* Moscow State University, Moscow.
[4] V. N. Baĭer *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **49**, 533 (1989) [JETP Lett. **49**, 615 (1989)].
[5] V. G. Zverev *et al.*, in *Elementary Particles and Cosmic Rays,* MIFI, Moscow, 1985; V. N. Baier *et al.*, NIM in Phys. Res. A **250**, 514 (1986); B. McBreen, *Proceedings of the Twentieth International Cosmic Ray Conference,* Moscow, 1987, p. 367.