Electromagnetic showers generated in an oriented tungsten crystal by γ rays of 8–27 GeV

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An experimental study has been made of the development of electromagnetic showers generated along the ⟨111⟩ axis of a tungsten crystal 1.0 mm thick by γ rays with energies of 8–27 GeV.

An electromagnetic shower generated in a crystal by a high-energy γ ray (or electron) moving at a small angle θ with respect to a crystallographic axis (or plane) may be very different from a shower in an amorphous medium.[1,2] The radiation length of an oriented crystal is not a constant, as it would be for an amorphous medium; specifically, it may decrease. The magnitude of the decrease depends on the energy of the primary particle, the characteristics of the crystal, and the orientation of the crystal. As a result, the shower develops over a shorter distance than it would in a corresponding amorphous medium.

Experiments on the development of showers generated by electrons and sites in crystals are described in Refs. 3–7.

In the present letter we are reporting experimental data obtained at the Kaskad installation[8,9] at the Institute of High-Energy Physics. A 28-GeV electron beam generates γ rays with energy of 8–27 GeV in a tracer system.[10] These γ rays propagate along the ⟨111⟩ axis of a tungsten crystal 1 mm thick cooled to 77 K by liquid nitrogen. The angle (θ) between the ⟨111⟩ axis and the momentum of each γ ray is determined within an error no greater than 0.1 mrad. The showers emerging from the crystal are studied with a composite Čerenkov total-absorption shower spectrometer positioned behind the crystal. This spectrometer consists of several lead–glass counters 1 radiation length thick, placed one behind another.[4]

Figure 1 shows cascade curves of the development of the electromagnetic showers emerging from the tungsten crystal and developing further in the shower spectrometer. Two curves of the development of an electromagnetic shower, for the cases of oriented and disoriented crystals, are shown for each of three intervals of γ-ray energy: 8–10, 19–22, and 25–27 GeV. We see that as the energy of the γ rays increases, the peaks on the cascade curves move away from the crystal into the shower spectrometer. In the case of the oriented crystal, the cascade curve changes; specifically, it changes in shape and shifts toward the point at which the shower begins to develop. With increasing energy of the γ rays, this shift increases.

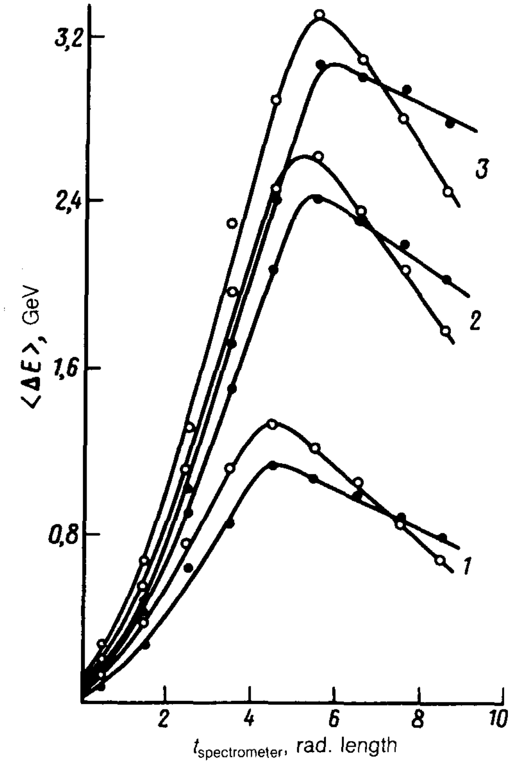

FIG. 1. Cascade curves of the development of electromagnetic showers generated by γ rays as these showers emerge from a tungsten crystal and develop further in a shower spectrometer (the crystal thickness is 1.0 mm, the orientation is along the ⟨111⟩ axis, and the temperature is $T = 77$ K). Filled circles—Disoriented crystal; open circles—oriented crystal. *1*—$\langle E_\gamma \rangle = 9$ GeV; *2*—20.5; *3*—$\geqslant 26$ GeV.

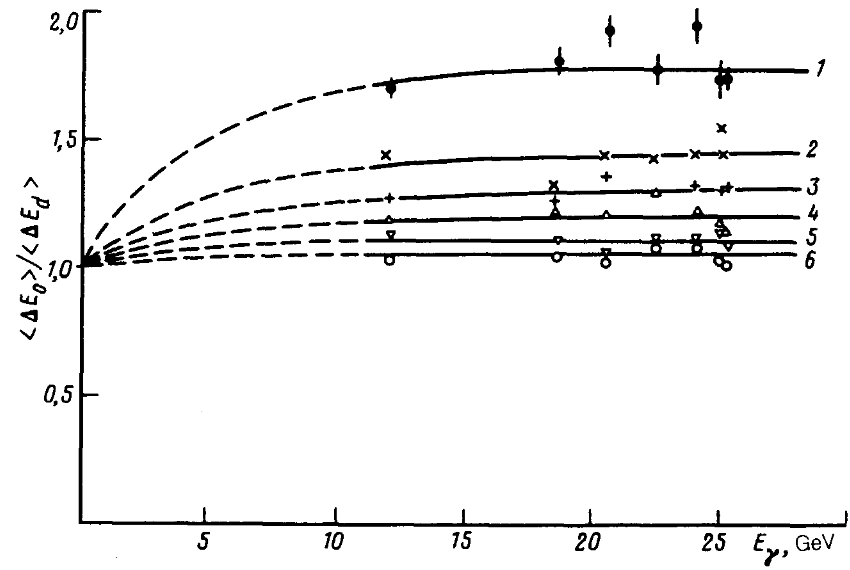

FIG. 2. Ratio of the average shower energy evolution in the case of an oriented crystal ($\langle \Delta E_0 \rangle$) to that in the case of a disoriented crystal ($\langle \Delta E_d \rangle$) versus the γ-ray energy E_γ for various shower development depths in the shower spectrometer (the number of the spectrometer counter is shown at the right).

Figure 2 shows the ratio $\eta = \langle \Delta E_0 \rangle / \langle \Delta E_d \rangle$ as a function of the γ-ray energy and the depth of the shower development in the shower spectrometer ($\langle \Delta E_{0,d} \rangle$ is the average energy evolution of the shower in each counter of the shower spectrometer for the cases of the oriented and disoriented crystals). The ratio η increases with increasing γ energy. For all energies this ratio is at a maximum in the first counter, reaching $\eta \approx 1.8$ at $\langle E_\gamma \rangle = 25$ GeV. By way of comparison, we have $\eta \simeq 4.3$ for showers generated by electrons with an energy $E_e = 26$–28 GeV under similar conditions.[4]

The distinctive features of shower development in oriented crystals might find some interesting applications. Some possibilities are in determining the spatial position of a source of γ rays[11] and in developing compact γ-ray spectrometers.[7]

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