Separation of high-energy electrons and hadrons with the help of oriented tungsten crystals

V. A. Baskov, B. B. Govorkov, V. V. Kim, V. I. Sergienko, V. A. Khablo, and V. I. Yumatov
P. N. Lebedev Physics Institute, Russian Academy of Sciences, 117924, Moscow, Russia

B. I. Luchkov and V. Yu. Tugaenko,
Engineering-Physics Institute, 115409, Moscow, Russia

(Submitted 21 July 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56**, No. 5, 233–236 (10 September 1992)

Oriented crystals make it possible to improve the separation of high-energy electrons and hadrons. Experimental results on the degree of separation of 26-GeV/c electrons moving along the $\langle 111 \rangle$ crystallographic axis of tungsten crystals from electrons with momenta in other directions are reported.

The electromagnetic showers which are generated by electrons with energies $E \geqslant 10$ GeV in the strong fields in oriented crystals differ substantially from the electromagnetic showers generated in an amorphous medium or disoriented crystal. The radiation length X_0' in an oriented crystal is not a constant quantity. It decreases with increasing energy of the electrons, and it depends on the type of crystal (on the potential of the axis or plane). The reason for this situation is a sharp increase in the cross sections for electromagnetic processes—for radiation by electrons and for the production of e^+e^- pairs by γ rays—at these energies.[1,2] Experimental results[3–8] show that the yield of charged particles and the energy evolution in a detector behind an oriented crystal of silicon, germanium or tungsten is higher than those from disoriented crystals by a factor of 2–5, depending on the crystal thickness.

In this letter we discuss the possibility of using oriented crystals to separate high-energy electrons and hadrons on the basis of the particular features of the development of electromagnetic showers in oriented crystals. For a disoriented tungsten crystal, the ratio of the nuclear interaction length ($\lambda = 7.8$ cm) to the electromagnetic interaction length ($X_0 = 0.35$ cm) is essentially constant at $\eta = 7.8/0.35 = 22.3$ in the GeV energy range. In an oriented crystal, the radiation length is shorter (by one or two orders of magnitude, depending on the electron energy and the particular crystal). As a result, there is a corresponding increase in η (Ref. 9). This circumstance means that the separation of hadrons and electrons can be improved substantially.

The Kaskad installation of the accelerator of the Institute of High Energy Physics has been used for research on the development of electromagnetic showers in oriented tungsten crystals.[10] The crystal was held in a goniometer which could insert the crystal into the beam and withdraw it from the beam. It could rotate the crystal at steps of 17 and 48 μrad around the horizontal and vertical axes, respectively. A scintillation counter 2 cm thick was placed behind the crystal. This counter was intended for detecting the charged-particle multiplicity in the showers emerging from disoriented and oriented crystals. The output signal from the counter was subjected to pulse-height analysis; the average number of charged particles in the shower was determined

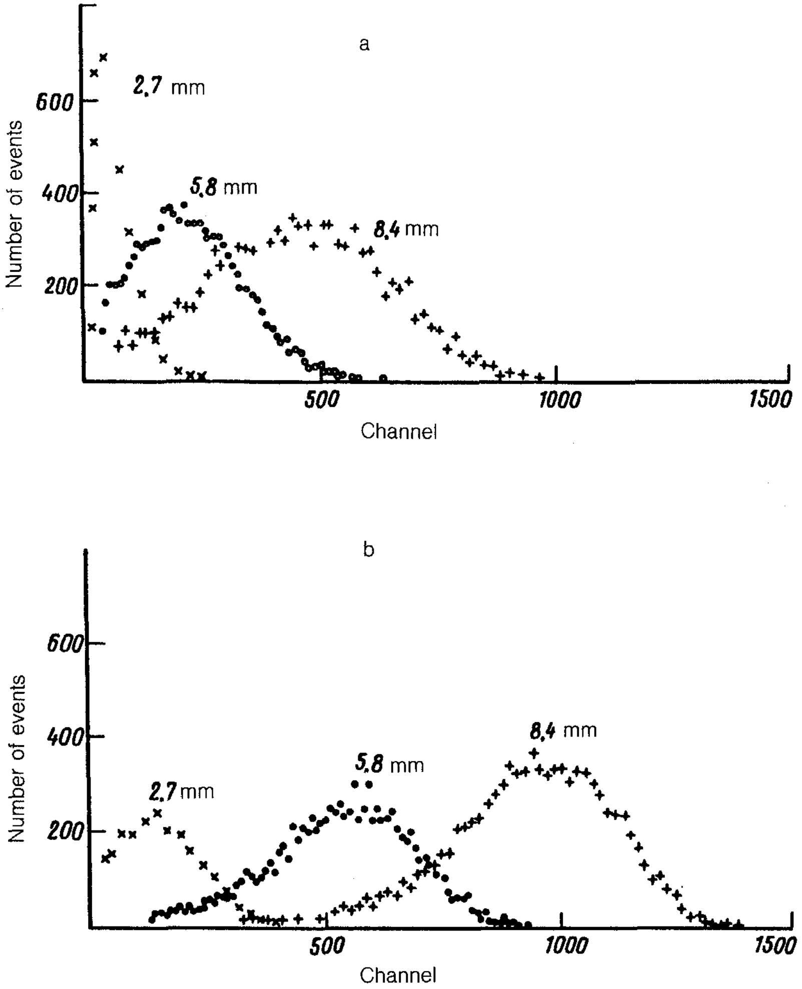

FIG. 1. Pulse-height spectra from a scintillation counter. (a)—Disoriented crystals ($\theta \geqslant 30$ mrad); b—oriented crystals ($\theta = 0$ mrad). The number of events in each channel of the spectrum is normalized on the basis of the total number of events (the thicknesses of the tungsten crystals are written above the spectra).

from the pulse height. The counter was first calibrated in an electron beam without a target. In these experiments, tungsten crystals with thicknesses of 2.7, 5.8, and 8.4 mm were used at a temperature of 293 K. The crystals were oriented along the ⟨111⟩ axis. The degree of mosaic structure of all the crystals was 1 mrad.

Figure 1, a and b, shows pulse-height spectra obtained from the scintillation counter in the cases of (a) disoriented and (b) oriented crystals. We see that the charged-particle multiplicity is higher by a factor of more than 2 when the crystal is oriented. This effect makes it possible to separate electrons moving in a specified direction (in the case at hand, along the ⟨111⟩ axis) from electrons moving in other

TABLE I. Rejection factors (R) and efficiencies (ϵ_0) in the detection of electrons by a scintillation counter behind a tungsten crystal as a function of the crystal thickness t_W.

$t - \vec{w}$(mm)	2,7	5,8	8,4
$R(1\sigma_{\langle i \rangle})$	0,454±0,027	0,202±0,030	0,192±0,033
ϵ_0(%)	80,3±1,5	85,8±2,6	87,3±2,0
$R(2\sigma_{\langle i \rangle})$	0,267±0,021	0,033±0,023	0,036±0,022
ϵ_0(%)	69,3±1,4	67,2±2,2	75,3±1,8
$R(3\sigma_{\langle i \rangle})$	0,144±0,016	0,004±0,014	0.001±0,013
ϵ_0(%)	56,2±1,2	36,4±1,4	46,5 + 1,3
$R(4\sigma_{\langle i \rangle})$	0,072±0,012		
ϵ_0(%)	42,9±1,0		
$R(5\sigma_{\langle i \rangle})$	0.041±0,009		
ϵ_0(%)	31,0±0,8		

directions. The rejection factor R is defined as the ratio of the efficiency with which the scintillation counter detects electrons which have passed through the disoriented crystal ($\theta \geqslant 30$ mrad) to the efficiency with which the same counter detects electrons which have passed through a crystal oriented along the $\langle 111 \rangle$ axis ($\theta = 0$ mrad): $R = \epsilon_p / \epsilon_0$. Here θ is the angle between the electron's momentum and the $\langle 111 \rangle$ axis. The detection efficiencies are defined as $\epsilon_p = \Sigma_{i=j}^{m} N_{i(p)} / \Sigma_{i=1}^{m} N_{i(p)}$ and $\epsilon_0 = \Sigma_{i=j}^{1} N_{i(0)} / \Sigma_{i=1}^{1} N_{i(0)}$, where N_i is the number of events in channel i of the pulse-height spectrum, $\Sigma_{i=1}^{m} N_{i(p)}, \Sigma_{i=1}^{1} N_{i(0)}$ are the total numbers of events in the pulse-height spectra for the disoriented and oriented crystals, respectively, and m and l are the numbers of channels spanned by the spectra. In the pulse-height spectrum for the case of the disoriented crystal, we determined the average channel index $\langle i \rangle = \Sigma_{i=1}^{m} i \cdot N_{i(p)} / \Sigma_{i=1}^{m} N_{i(p)}$ and the standard deviation $\sigma_{\langle i \rangle}$. The threshold channel j was separated from the mean channel by a certain number of standard deviations $j = \langle i \rangle + n\sigma_{\langle i \rangle}$ ($n = 1,2,3,\ldots$). Table I shows the rejection factors and the detection efficiencies for electrons as a function of j and the crystal thickness. We see that the rejection improves with increasing thickness of the crystal and with increasing index of the threshold channel, j.

For a tungsten crystal 2.7 mm thick, and for an electron momentum of 26 GeV/c, the radiation length of the oriented crystal, determined from the average number of charged particles leaving the crystal with the help of the scintillation counter, is 0.18 ± 0.01 cm ($\eta = 43.3$), and the effective thickness of the crystal reaches 5.2 ± 0.3 mm. The electron detection efficiency in this case is higher by a factor of $1/R$ than that in the case of the disoriented crystal, for a given crystal thickness. One could define the degree of separation of the hadrons and electrons or the hadron-electron rejection factor as $R_h = \epsilon_h / \epsilon_e$, where ϵ_h and ϵ_e are the hadron and electron detection efficiencies, respectively. If there is a source of hadrons with an admixture of electrons, the efficiency at which the electrons are detected by a detector behind a crystal oriented toward the source will then increase, while the efficiency with which the hadrons are detected will remain essentially constant. We should stress that this separation method will be most effective when the energies of the particles are hundreds of GeV or higher, at accelerators presently under construction (the LHC, the SSC, the VLÉPP, etc.).

We wish to thank E. I. Tamm and S. I. Nikol'skiĭ for support of this study and A. A. Sadovskiĭ for assistance.

[1] V. N. Baĭer, V. M. Katkov, and V. M. Strakhovenko, *High-Energy Electromagnetic Processes in Oriented Single Crystals*, Nauka, Novosibirsk, 1989.

[2] A. I. Akhiezer and N. F. Shul'ga, Zh. Eksp. Teor. Fiz. **85**, 94 (1983) [Sov. Phys. JETP **58**, 55 (1983)].

[3] K. Elsener, S. P. Moller, J. B. B. Petersen, and E. Uggerhoj, Phys. Lett. B **212**, 537 (1988).

[4] V. A. Baskov, V. B. Ganenko, V. A. Gushcin *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **50**, 395 (1989) [JETP Lett. **50**, 428 (1989)].

[5] K. Elsener, M. Hage-Ali, K. Maier *et al.*, Phys. Lett. B **227**, 483 (1989).

[6] V. A. Baskov, V. B. Ganenko, V. A. Gushchin *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **52**, 740 (1990) [JETP Lett. **52**, 99 (1990)].

[7] V. A. Baskov, V. B. Ganenko, B. B. Govorkov *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **52**, 1082 (1990) [JETP Lett. **52**, 480 (1990)].

[8] K. Elsener, M. Hage-Ali, K. Maier *et al.*, Phys. Lett. B **242**, 517 (1990).

[9] V. A. Baskov, B. B. Govorkov, V. V. Kim *et al.*, Kratk. Soobschch. Fiz. (1992) (in press).

[10] V. A. Baskov, V. V. Kim, I. V. Konorov *et al.*, Prib. Tekh. Eksp., No. 5, 58 (1990).

Translated by D. Parsons