Angular and energy distributions of the $\gamma$ rays emitted in the channeling of relativistic positrons


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Experimental results are reported on the angular distributions of the $\gamma$ rays emitted in the planar channeling of 10-GeV positrons in a silicon single crystal 113 $\mu$m thick. The spectral-angular emission density of the $\gamma$ rays emitted at various angles from the crystal is plotted against the energy.

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Although several experiments have been carried out on the radiation emitted by channeled high-energy particles, no data have been reported on the angular characteristics of the emitted $\gamma$ rays.

This letter reports a study of the angular and spectral characteristics of the radiation emitted by positrons channeled by the (110) plane of a silicon single crystal 113 $\mu$m thick.

The experiments were carried out with the Kristall apparatus. The spectrometer can measure the angles at which the positrons enter the crystal within about 6 $\mu$rad (this is the standard deviation). A drift chamber with a built-in converter determines the vertical projection of the angle at which the $\gamma$ rays are emitted from the crystal within about 4 $\mu$rad (again, the standard deviation). The $\gamma$ energy is determined by a CsI(Tl) crystal. Under the working conditions, the detector has a resolution of about 3% (the width of the distribution at half-maximum) for 100-MeV $\gamma$ rays.

Figure 1 shows the emission spectral density vs the $\gamma$ energy for events in which the positrons enter the crystal in the angular interval 0–40 $\mu$rad. The critical angle for channeling by the (110) plane of the silicon single crystal for 10-GeV positrons is about 60 $\mu$rad. We detected $\gamma$ rays with emission angles in the interval $\pm 1$ mrad in both projections. Also shown in Fig. 1 is the measured emission spectral density for an aluminum target (the dot-dashed curve). This curve agrees satisfactorily with calculations (0.12 cm$^{-1}$) carried out by the method of Ref. 7. The peak for $\gamma$ rays with an energy of about 60 MeV corresponds to emission in transitions between adjacent transverse-energy levels of the positrons (the first harmonic of the emission) and can be described well in the approximation that the emission is determined exclusively by the acceleration of the particle (the dipole approximation). For 10-GeV positrons, the deviation from the dipole approximation is seen in the appearance of a significant
FIG. 1. Emission spectral density vs the $\gamma$ energy. The distributions are normalized to a single incident positron.

probability for emission in the second and third harmonics, i.e., for transitions between more remote levels (the peaks at energies of about 120 and 200 MeV). The ratio of the emission spectral densities in the first and second harmonics is about $1.5 \pm 0.1$. The ratio of the spectral densities for $\gamma$ rays at 60 and 90 MeV (the minimum between the first and second harmonics) is $2.1 \pm 0.2$.

The values found in the experiments of Ref. 3 were $1.5 \pm 0.2$ and $2.0 \pm 0.2$, respectively, in good agreement with our results. The ratio of the spectral emission densities in the first and second harmonics also shows that the emission is quite different from a dipole emission. The results agree well with the calculations by the method of Ref. 8, as can be seen from the dashed curve in Fig. 1.

We studied the spectral-angular emission density vs the $\gamma$ energy for particles with angles of incidence in the interval 0–40 $\mu$rad for several $\gamma$-emission angular intervals (Fig. 2). It was mentioned in Ref. 8 that the collimation of a $\gamma$ beam at low angles with respect to the projection of the particles' momentum onto the crystallographic plane causes a prominent feature in the positron emission spectrum corresponding to $\gamma$ rays with an energy corresponding to the maximum energy for each harmonic. The collimation of a $\gamma$ beam, even in a single projection, changes the shape of the energy dependence of the emission spectral density. The ratio of the emission spectral densities for 60- and 120-MeV $\gamma$ rays emitted at angles in the interval 0–10 $\mu$rad (Fig. 2A) is now $2.6 \pm 0.5$; i.e., there is some relative decrease in the emission spectral density at the maximum energy of the second harmonic. Because of the nondipole nature of the emission, higher-harmonic emission contributes slightly to the spectral density for $\gamma$ rays with energies of about 60 and 120 MeV. This higher-harmonic emission occurs at large angles with respect to the projection of the positron's momentum onto the crystallographic plane. The relative level of the higher-harmonic emission is higher near 120 MeV than near 60 MeV, so that the collimation of the $\gamma$ beam around the forward direction causes a more pronounced suppression of the emission for $\gamma$ rays with energies of about 120 MeV. The ratio of the spectral densities for 60- and 90-MeV $\gamma$ rays for emission collimated in the forward direction (Fig. 2A) is $5.3 \pm 1.5$. This result
FIG. 2. Spectral-angular emission density vs the γ energy. The distributions are plotted for events in which the γ rays are emitted in the following angular intervals: A—0–10 μrad; B—0–20; C—20–40; D—40–60; E—0–50; F—50–100 μrad.

implies that for emission at small angles with respect to the crystallographic plane there is in fact a suppression of the emission with energies below the maximum for the
FIG. 3. Distribution of events in the angle in which the $\gamma$ ray is emitted from the crystal. The distributions are plotted for $\gamma$ rays in various energy ranges. The boundaries of these ranges are specified at the right in each part of the figure. The dashed curves are a Gaussian approximation of the experimental data. The standard deviation for the curve is shown at the left in each part of the figure.

harmonic at which the transition occurs. In order to obtain even narrower peaks in the emission spectrum it would apparently be necessary to select particles with $\gamma$ emission angles collimated with respect to the projection's momentum onto the crystallographic plane. The emission spectral density in Fig. 2A for 60-MeV $\gamma$ rays is $49 \pm 5$ times greater than the corresponding value for the aluminum target. The difference for the distribution in Fig. 1 is by a factor of $36 \pm 1$.

Figure 3 shows distributions of the $\gamma$ rays in the emission angle with respect to the (110) plane for particles with entrance angles in the interval 0–40 $\mu$rad. We see that for these (channeled) particles the $\gamma$ rays are emitted in a narrow angular interval (within less that $\pm 100 \mu$rad) at all the energies studied. The distribution in Fig. 3B is the narrowest. In plotting this distribution we selected $\gamma$ rays with the energy corresponding to the maximum for the first harmonic. The width of this distribution is determined primarily by the nondipole nature of the emission and by the anharmonicity of the potential in which the positron moves. Even for dipole emission in a harmonic potential, however, the width of the corresponding distribution (Fig. 3B) should be
nonzero, determined primarily by the distribution of the channeled positrons in the transverse energy.

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Spontaneous transition to a stochastic state in a four-dimensional Yang-Mills quantum theory

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The quantum expectation values in a four-dimensional Yang-Mills theory are represented in each topological sector as expectation values over the diffusion which develops in the "fourth" Euclidean time. The Langevin equations of this diffusion are stochastic duality equations in the $A_4 = 0$ gauge.

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I. We wish to outline a new approach to calculating quantum expectation values in a four-dimensional Yang-Mills theory $[YM(R^4)]$ in the $A_4 = 0$ gauge.\(^{11}\) In this approach, $YM(R^4)$ is represented as the result of a stochastic quantization of some three-dimensional theory whose Lagrangian is a Chern-Simons 3-form (see Appendix 3 in Ref. 1). Specifically, with an external source in $YM(R^3 \times [t', t''])$ we consider a matrix element

$$< A'', t'' | A', t' > = < A'' | \exp (- \hat{A} | \hat{A}' - t' ) | A' >$$

$$= \int D A_j \exp \{ - \frac{1}{2} \int_{t'}^{t''} \int d^3 x (\dot{A}_i^a, \dot{A}_j^a + B_i^a B_j^a) + \int d^4 x J_i^a(x) A_i^a(x) \},$$

\(A(t') = A', \ A(t'') = A'' \) (1)

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