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OBSERVATION OF RADIATION FROM 10 GEV POSITRONS AT VOLUME REFLECTION IN BENT SILICON MONOCRYSTAL

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Abstract

Afonin A.G., Baranov V.T., Britvich G.I. et al. Observation of Radiation from 10 GeV Positrons at Volume Reflection in Bent Silicon Monocrystal: IHEP Preprint 2008–11. – Protvino, 2008. – p. 7, figs. 5, refs.: 9.

The experimental results of radiation of 10 GeV positron beam in bent silicon single crystals are presented. The comparison with theoretical calculations is considered.

Аннотация

Афонин А.Г., Баранов В.Т., Бритвич Г.И. и др. Наблюдение излучения 10 ГэВ позитронов при объемном отражении в изогнутом монокристалле кремния: Препринт ИФВЭ 2008–11. – Протвино, 2008. – 7 с., 5 рис., библиогр.: 9.

Представлены экпериментальные результаты по излучению 10 ГэВ пучка позитронов в изогнутом монокристалле кремния. Приводится сравнение результатов измерений с теорией.

1. Introduction

Process of volume reflection of charged particles in bent single crystals [1, 2] which represents the coherent scattering of these particles was observed for proton beams in the recent experiments (see [3] and references herein). These experiments show a good agreement between predicted characteristics of process and measured ones [4]. At volume reflection particles cross a row of bent crystallographic planes and the behavior of its transversal velocity has nonperiodic oscillation character. On the basis of consideration of this motion in Ref. [5] the new type of intensive coherent radiation for electrons and positrons was predicted for these conditions. Due to high value of a Lorentz factor γ this radiation is more significant for light leptons than for other particles.

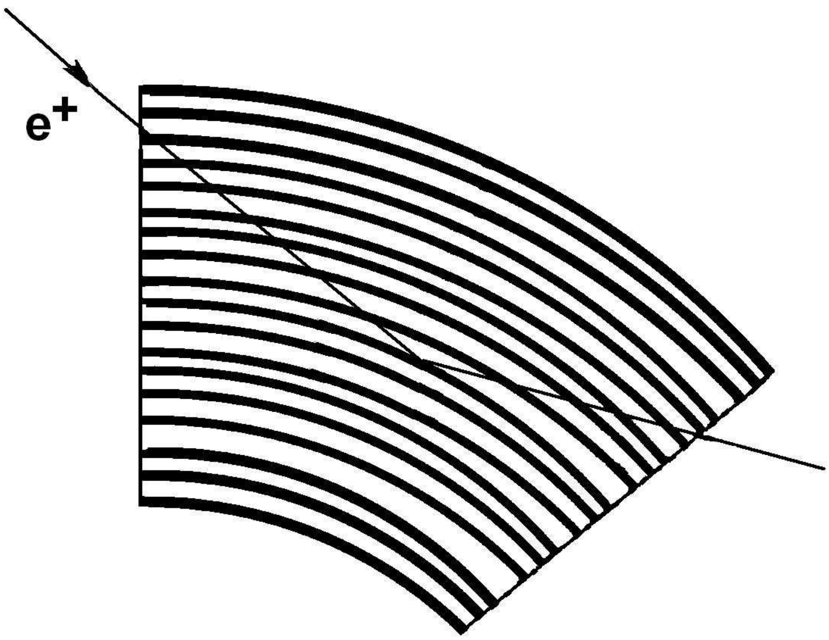

Figure 1. Scheme of volume reflection process in bent single crystals.

Fig. 1 illustrates the process of volume reflection of ultrarelativistic particle moving in the system of bent crystallographic planes. At approaching to tangent direction the transversal particle velocity becomes close to zero due to this particle undergos reflection (coherent scattering). Besides, at motion in this area particle crossed the row of the crystallographic planes and because of this the behaviour of its transversal velocity has aperiodical oscillating character (see Fig. 2). As result the process of volume reflection for positrons and electrons should be accompanied by intensive γ-radiation.

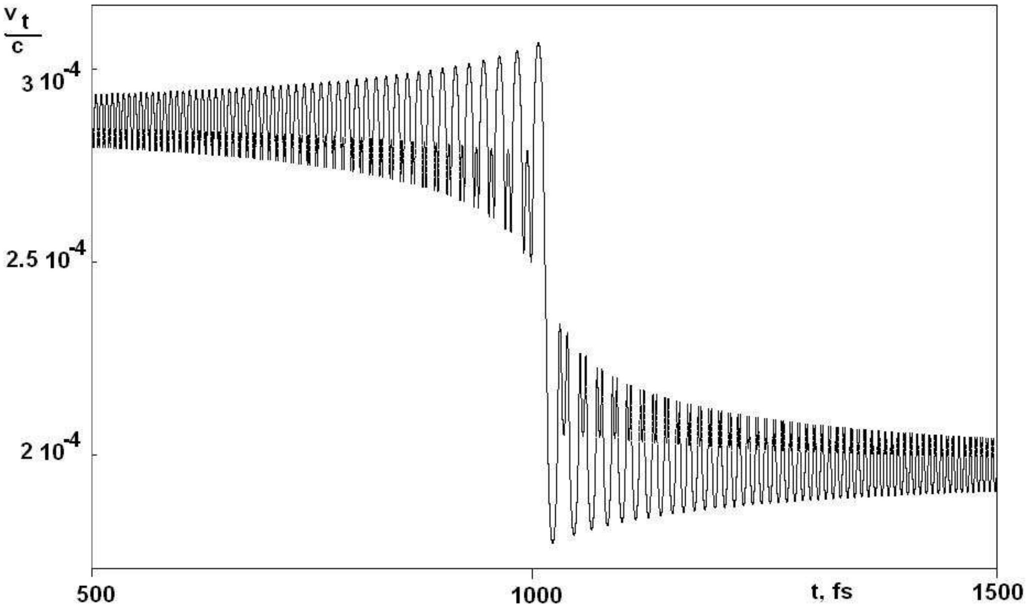

Figure 2. Behaviour of the transversal particle velosty (divided on c) as a function of time (in femptoseconds). (Time t=0 corresponds to enter point in single crystal.)

In straight single crystals the character of radiation (of electrons and positrons) for a planar case depends mainly on the angle θ with respect to crystallographic planes. In the case when $\theta \gg \theta_b = U/m_e$ (U is the potential barrier and m_e is the electron mass) the radiation has coherent bremsstrahlung character and when $\theta \ll \theta_c$ the radiation has synchrotron-like character (at a condition that particle energy is high enough). Type of radiation one can describe also in values of parameter $\rho = 2\gamma^2 \langle v_t^2 - v_m^2 \rangle / c^2$, where $\langle v_t^2 - v_m^2 \rangle$ is the squared mean deviation of the transversal velocity from its mean value v_m and c is the velocity of light. Then the coherent bremsstrahlung and synchrotron-like radiations correspond to the cases when $\rho \ll 1$ and $\rho \gg 1$, respectively. The case $\rho \approx 1$ is intermediate, when one type of radiation is transformed in another one. In straight thin crystals the character of particle radiation may be defined by angle θ which approximately conserves the initial value at motion of a particle.

However, in a bent single crystal the planar angle with respect to planes is changed at particle motion. Because of this, the type of radiation of a moving particle is also changed. Thus, far from reflection point $\rho \ll 1$ and in this area radiation of particles represents the coherent bremsstrahlung in bent single crystal [7]. At approaching of a particle to the reflection point ρ-parameter increased. Let us estimate ρ-parameter near the reflection point. If a bending radius is significantly more than critical radius of channeling [8] then the mean angle of volume reflection $\theta_{vr} \approx \sqrt{2}\theta_{ch}$, for positrons and $\theta_{vr} \approx \theta_{ch}$ for electrons where $\theta_{ch} = \sqrt{2U/E}$ is the critical angle of channeling and E is the particle energy. It means that $\rho \sim \gamma\theta_b$ and $\rho \sim 0.5\gamma\theta_b$ for positrons and electrons, respectively, and hence radiation becomes close to synchrotron like at the condition $\gamma \gg 1/\theta_b$ for positrons and $\gamma \gg 2/\theta_b$ for electrons. The corresponding to $\rho = 1$ value of energy ≈ 12 GeV and ≈ 24 GeV (for positrons and electrons) for (110) and (111) planes of a silicon single crystal.

It is well known that the case of particle motion when $\rho \sim 1$ is more difficult for adequate mathematical description of radiation processes. In Ref. [5] calculations of radiation energy losses for this case were performed based on relations from [6]. These calculations (carried out for energies 10 and 200 GeV) predict high increasing of radiation energy losses for thin (about 1 millimeter) silicon single crystals in comparing with amorphous (or nonoriented) sample of the same thickness.

This paper is devoted to preliminary results of observation of 10 GeV positron radiation at volume reflection in a bent silicon single crystal.

2. Experimental setup

Experiment was carried out on 22 beam line of IHEP accelerator. Fig. 3 illustrates the experimental layout.

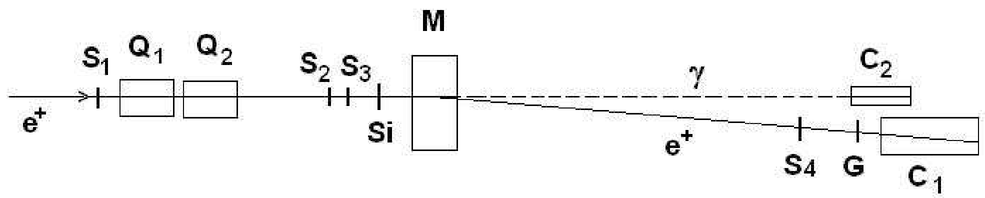

Figure 3. Experimental layout.

10 GeV positron beam (after acceptance in beam line and momentum analysis) pass through the first aperture scintillator counter S_1 and then it is focused by quadrupoles Q_1 and Q_2 on calorimeter C_1 (or C_2 at switch off magnet M). The silicon single crystal Si was mounted on one axis goniometer (see Fig. 3). For this experiment we take the silicon quasimosaic crystal with diameter ≈ 15 mm and ≈ 0.65 mm of a thickness (along direction of the beam). This crystal was manufactured in Saint Petersburg Nuclear Physics Institute using technology described in [9]. The (111) plane of crystal, with bending radius 1.3 meter, was selected as working one. The two thin scintillator counters S_2 and S_3 (with the size equal to 0.5 mm in horizontal direction) stand very close side by side and they define the rectangular area 0.5×15 mm^2 (horizontal and vertical) in the transversal plane with respect to direction of beam. This area corresponds to working area of a bent single crystal. The magnet M separates in space the γ and e^+ beams after interaction in the single crystal. Energies of γ-quanta and positrons were measured with the help of calorimeters C_1 and C_2. The hodoscope G was located before C_1-calorimeter for

measuring of a horizontal coordinate of every positron. The scintillator counter S_4 means for starting of the hodoscope.

The calorimeter C_1 was fabricated from lead glass of square cross section with 20 cm side. The calorimeter C_2 represents BGO single crystal with 15 cm along the beam direction and it has a form of rectilinear hexahedron in transversal cross section with the side equal to 2.55 cm (or in other words, the diameter of circumscribed circle is 5.1 cm). The hodoscope G provides space resolution about 5 mm.

3. Experimental results

The preliminary orientation of the single crystal was realized with the help of 50 GeV proton beam (in 22 beam line). The small size (about some millimeters) of proton distribution on hodoscope G was obtained. Despite on not high resolution of the hodoscope the channeling effect was clear fixed for small (about 10%) fraction of beam and hence the crystal was oriented.

Main measurements were carried out in 10 GeV positron beam with the mean total intensity $\sim 10^4$ particle per cycle through S_1 counter. The positron fraction in the beam was about 95 %. For every particle passing through S_1, S_2, S_3 counters signals from C_1 and C_2 calorimeters and hodoscope G were registrated for further data analysis.

Initially we found the orientation dependence of radiation intensity. For measurements we selected events with the follow signals in detectors: 1) energy losses in C_2 corresponds to γ-quanta in the range from 100 MeV till 500 MeV; 2) energy losses in C_1 is more than 5 GeV; 3) horizontal beam size of the positron beam (in G hodoscope) is less than ± 10 mm. The first condition corresponds approximately to expected energies of γ-quanta from volume reflection process. The second condition corresponds to registration of high energy positron, and the third one means that particles have horizontal angle divergence less than ± 0.1 mrad.

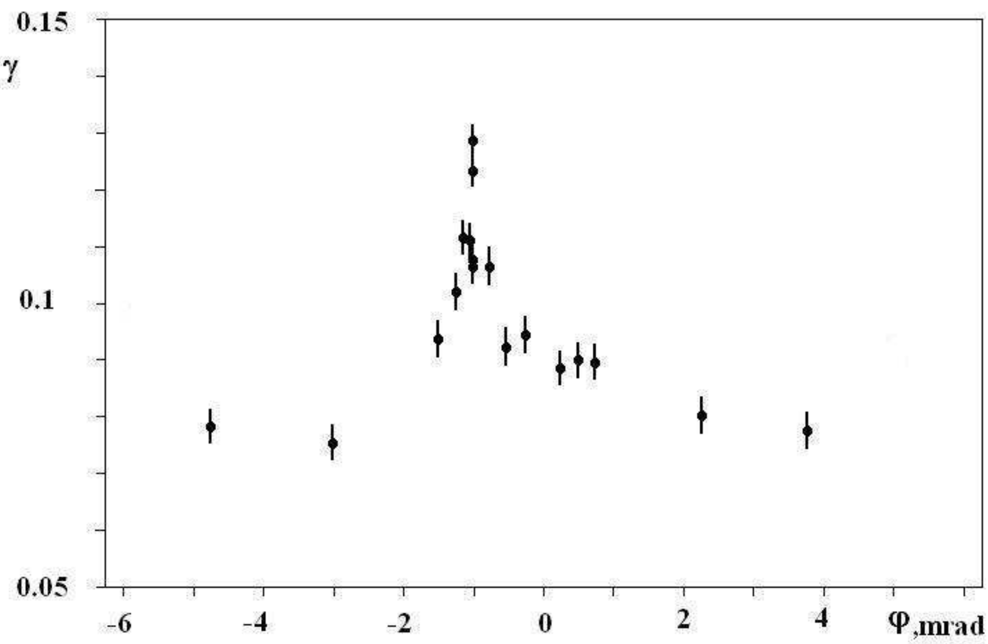

Figure 4. Measured orientation dependence of positron radiation.

Fig. 4 illustrates the result of these measurements. One can see that the orientation curve has a clear maximum. In the maximum number of γ-quanta exceeds in ≈ 1.7 times the similar number for far orientations. However, it relation is in some times less than expected. This fact we explain by background due to material in beam line (few air gaps and vacuum foils). Note that the value $\varphi = 0$ corresponds to the found orientation for channeling regime from measurements with the proton beam. From Fig. 4 it follows that the maximum of orientation dependence takes place for ≈ -1 mrad, instead predicted value $-(0.3 - 0.4)$ mrad that may be due to a small difference in geometry of positron and proton beams.

At $\varphi \approx -1$ mrad (in the maximum of orientation curve) γ-spectrum was measured. Besides, the γ-spectrum was also measured in the minimum of orientation curve. Both measurements were carried out at above mention conditions, but in the first condition the region of energies of γ-quanta was extended to 1 GeV. The difference of these spectra represents γ-spectrum due to coherent interaction of the positron beam with bent crystallographic planes at volume reflection process. The results of experiment is shown in Fig. 5.

Fig. 5b illustrates the measured radiation energy losses $E_\gamma dN_\gamma/dE_\gamma$ of positrons in single crystal. This result was obtained from difference of γ-spectra (see Fig. 5a) however for better using of statistics (for visualization of presentation) every 7 channels (in γ-spectra) were combined in one channel (in energy losses spectrum). In this figure the calculated theoretical curve is also shown. One can see valuable difference between theory and measurements. We think that this difference one can explain by radiation flow through lateral walls of C_1-calorimeter. For comparison one can point that theoretical value of energy losses for amorphous silicon (or nonoriented crystal) is ≈ 0.007 and it is practically independent of γ-quantum energy. This fact demonstrates high value of measured radiation energy losses in thin single crystal.

4. Conclusion

The presented here experimental results show on valuable radiation process of 10-GeV positron beam at volume reflection in bent single crystals. Such type of radiation can be applied at accelerators for production of intensive γ-quantum beams and positron sources.

Acknowledgments

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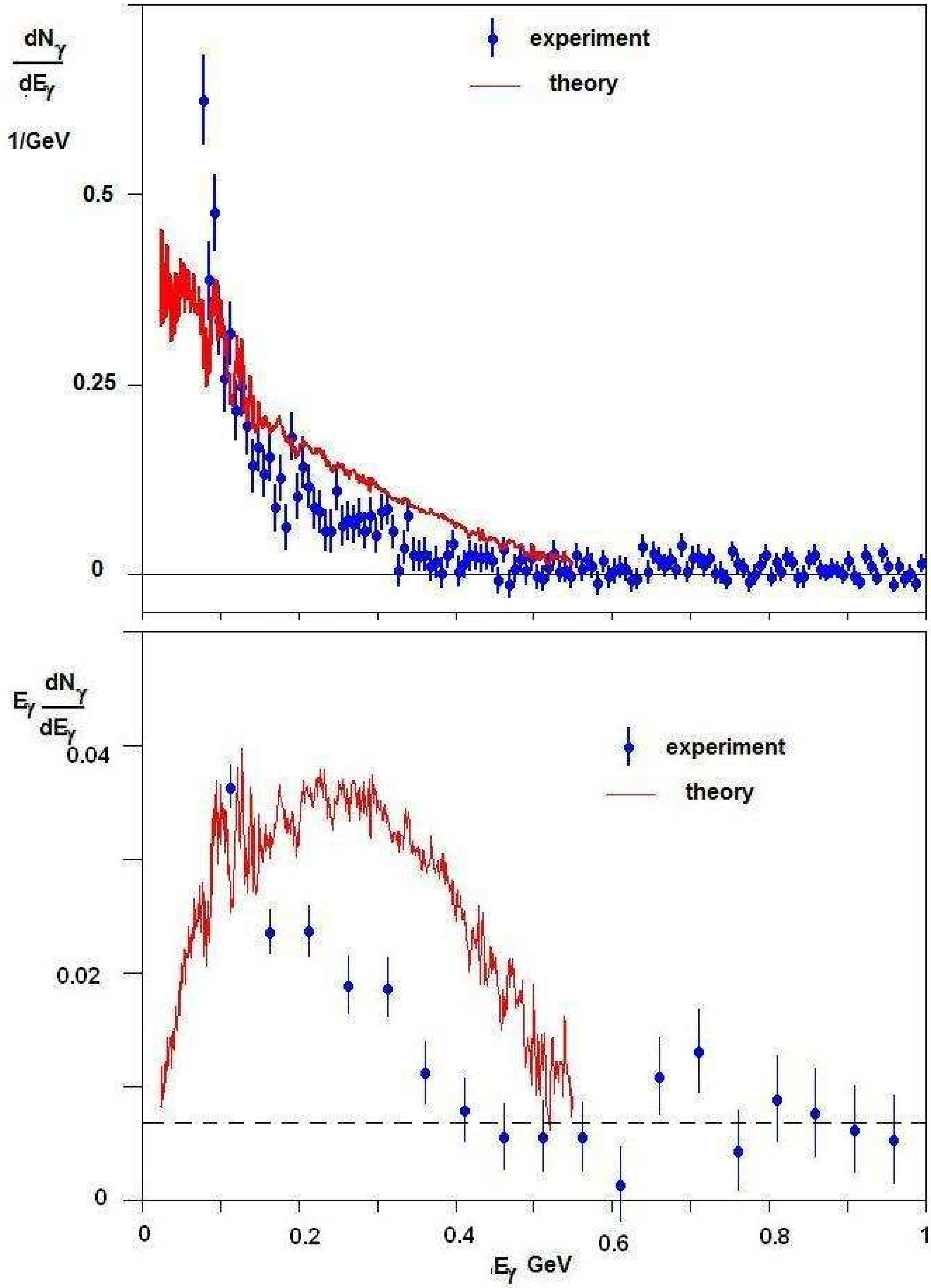

Figure 5. The coherent part of γ-quanta spectrum (a) and corresponding energy losses of positrons (b) in silicon single crystal. Points are experiment and solid line is calculation. The dashed curve is calculated energy losses in nonoriented single crystal.

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