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STEERING OF THE CHARGED PARTICLE TRAJECTORIES BY A BENT CRYSTAL

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ядерных исследований
БИБЛИОТЕКА

Водопьянов А.С. и др.

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Управление траекториями заряженных частиц с помощью изогнутого монокристалла

Впервые экспериментально показано, что с помощью изогнутого монокристалла можно управлять траекториями заряженных частиц. Протоны с энергией 8 ГэВ, захваченные в процесс плоскостного каналирования изогнутым монокристаллом кремния, отклонялись на угол до 26,0 миллиардиан. Радиус траектории частицы составлял около 38 см, что соответствует среднему значению поперечного электрического поля, воздействующего на частицу, около $0{,}5 \cdot 10^{10}$ В/см. Это эквивалентно магнитному полю с индукцией около 72,0 Т.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1979

Vodopianov A.S. et al.

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Steering of the Charged Particle Trajectories by a Bent Crystal

The first experimental evidence has been obtained for steering the charged particle trajectories by a bent silicon crystal. In the process of planar channeling, the 8 GeV proton beam has been deflected up to 26 mrad relative to the incident beam direction. This corresponds to the bending radius of a range of 38 cm. The effective transversal component of the electrical field is equal to 270 MV/cm.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1979

The statement has been made in paper [1] that a bent single crystal may be used for steering the charged particle trajectories. The particles entering the crystal and captured by the channeling process can follow the shape of the crystallographic planes until the bending radius of the crystal is greater than some critical radius. The calculated value of the critical radius for the charged particle is given by:

$$R = M \cdot v^2 / Z \cdot e \cdot E_c ,$$

where M and v are the particle relativistic mass and velocity, respectively, $Z \cdot e$ is the charge of the particle. The meaning of E_c is the average electrical field intensity defined on such a distance from the plane of the crystal lattice (in the case of planar channeling for positively charged particles) where the trajectory of the particle no longer remains stable due to the interaction with individual atoms. The value of E_c is equal to $0.5 \cdot 10^{10}$ V/cm for the case of 8 GeV protons incident upon a silicon crystal, and the critical radius in this case is equal to 2 cm.

The purpose of the present studies was to check the hypothesis stated in Ref.1. The experiment was performed by using the 8 GeV external beam of the JINR High Energy Laboratory accelerator. The beam pulses with a pulse time of 0.3-0.4 sec contained, on the average, 10^5 protons and had an angular divergence of ± 0.3 mrad. The beam size in the position of the crystal was about 20 mm. The experimental setup is shown in Fig.1. The trajectories of the particles incident onto the target crystal were read out by 20 drift planes. The system of coincidence and anticoincidence counters triggered the spectrometer to select the particles that passed through the crystal volume. The precision goniometer with polar and azimuthal degrees of freedom was used to rotate the crystal with an accuracy of 0.001° . The apparatus was connected on-line with a computer which could store up to 500 events per beam pulse on the magnetic tape.

The front part of the 2.0 cm long silicon crystal was prepared as a totally depleted semiconductor detector. Simple technique was employed for the controllable bending of the back part of the crystal in the vertical plane. The bent plane of the crystal coincided with the crystallographic plane (111). The accuracy of measurement of the bending angle of the crystal was about 5 per cent. The side view of the bending device is shown in Fig.2.

Figure 3 presents typical spectra of the particle energy losses for the crystal oriented randomly with respect to the primary beam direction and when the crystallographic plane (111) was oriented along the beam direction. As is seen from Fig.3, the channeled particles may be identified through their anomalous low energy losses. This gives the possibility to orient the crystal and to select a fraction of the particles involved in the channeling process.

Measurements were performed for crystal bending angles of 0, 0.5, 1.0, 2.0, 3.0, 4.5, 12.5, and 26.0 mrad. It was found that the channeled fraction of the beam followed the geometry of the bent crystallographic plane for all crystal bending angles. It was also observed that the number of dechanneled particles did not change significantly with increasing the crystal bending angle.

The angular distribution in the vertical plane for the particles outgoing from the crystal bent at 4.5 mrad is presented in Fig.4. The main broad peak is due to the protons multiply scattered by the silicon crystal. The narrow right peak corresponds to the deflected part of the beam. In order to select only the channeled particles for the analysis, we chose the events with energy losses in a range of $(0.2-0.7)\Delta E$ where ΔE is the most probable energy loss deposited by the particles in a randomly oriented crystal.

Furthermore, to reduce the number of multiple-scattered events, the scattering angle in the horizontal plane was limited by a value of ±0.1 mrad. Figure 5 presents the angular distribution of the selected events. This figure confirms that the right peak corresponds to the true channeled particles. Figure 6 presents the angular distribution of the outgoing particles in the vertical plane; the picture was obtained with the selection of the nonchanneled events. This figure also confirms that the right peak in Fig.4 is due to the deflection of the particles by the bent crystal.

Figure 7 shows the angular distribution of the outgoing particles for the variety of crystal bending angles. The events were selected on the same criteria as in Fig.5. It is clear that the angular peak position is consistent with the crystal bending angle. It should be noted that for an angle of 26.0 mrad the value of effective transversal field intensity may be estimated as much as 270 MV per centimeter.

Therefore, in the present investigation the first experimental evidence for steering the charged particle trajectories by the bent single crystal has been obtained. This new phenomenon can find applications in high-energy physics.

The authors would like to express their gratitude to Prof. N.N.Bogolubov, Prof. D.D.Kiss, Prof. A.M.Baldin, Prof. R.Wilson and Prof. L.Lederman for their support and interest during this work.

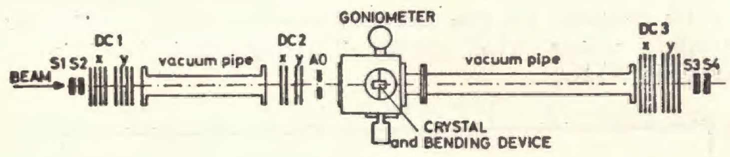


Fig. 1. Schematic drawing of the experimental setup: S1, S2, S3, S4, A_0-scintillation counters. DC1, DC2, DC3 - drift chamber modules.

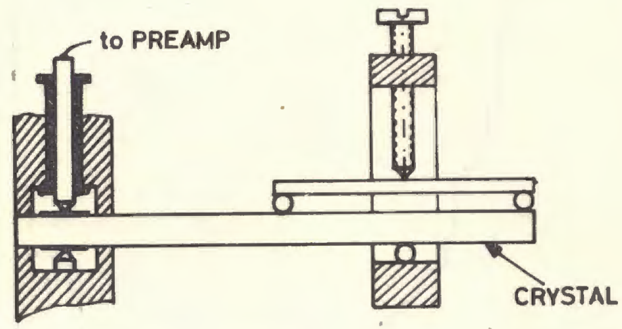


Fig. 2. Side view of the single crystal with the installed bending device.

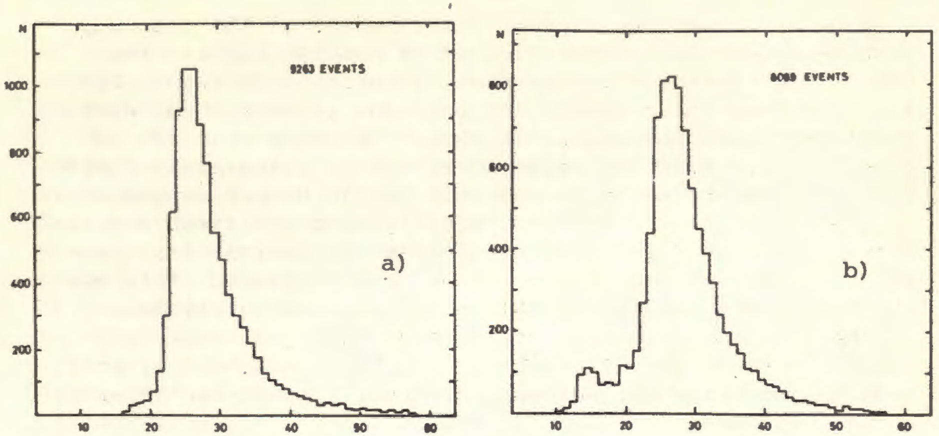


Fig. 3. Energy loss distribution of the events obtained by the silicon semiconductor detector: a) crystal oriented randomly with respect to the primary beam direction; b) crystallographic plane (111) oriented along the beam direction (planar channeling).

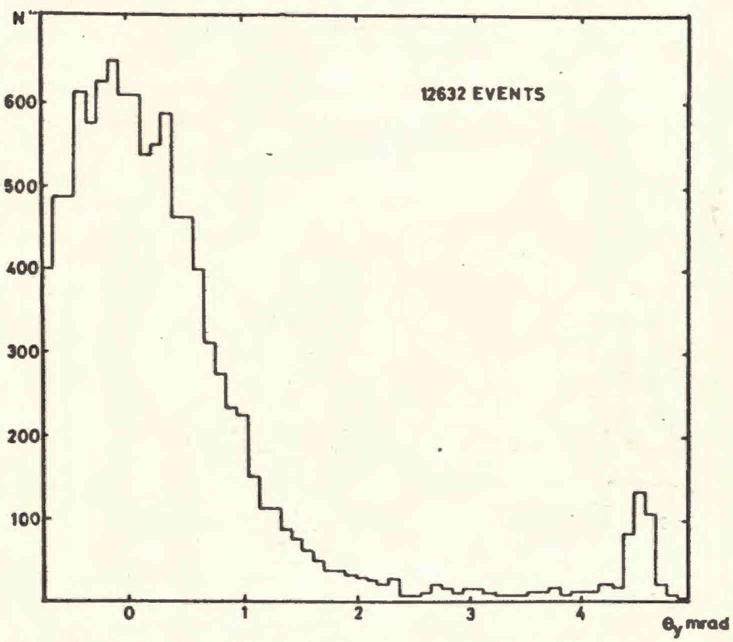


Fig. 4. Angular distribution in the vertical plane for the protons outgoing from the crystal bent at 4.5 mrad.

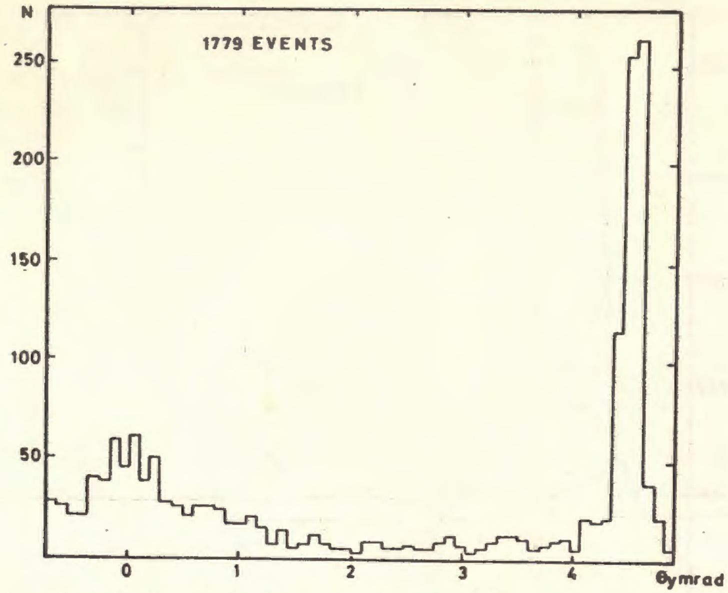


Fig. 5. The same as in fig. 4 except for the fact that the channelled particles were selected.

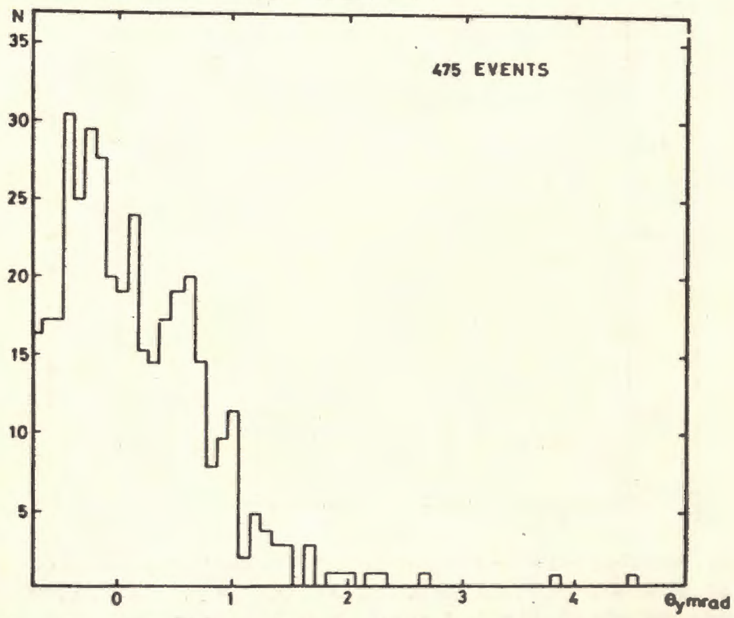
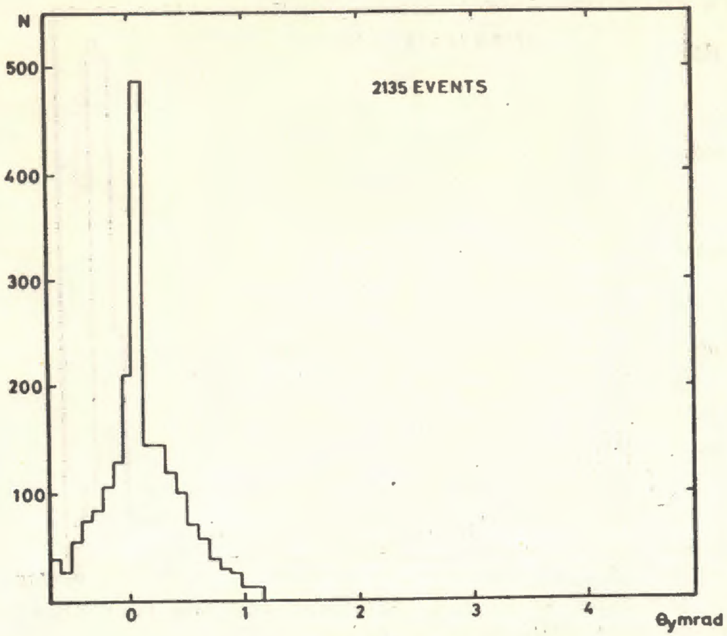
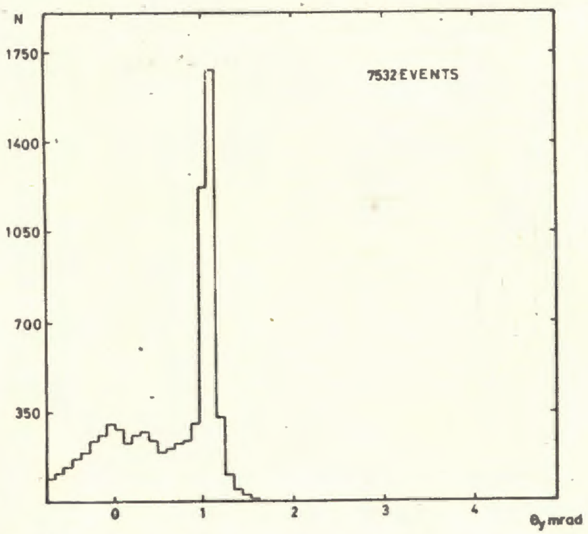


Fig. 6. The same as in fig. 4 except for the fact that the nonchannelled particles were selected.

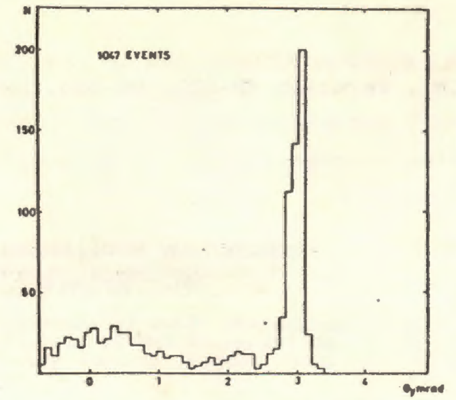


a)

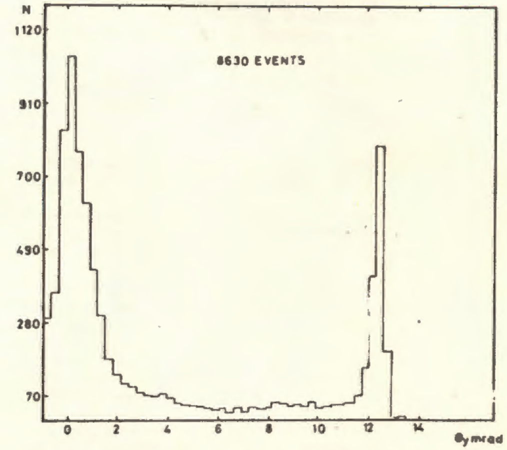


b)

Fig. 7. Angular distribution in the vertical plane for protons at various crystal bending angles. The channelled particles were selected. a - 0 mrad, b - 1.0 mrad, c - 3.0 mrad, d - 12.5 mrad, e - 26.0 mrad.



c)



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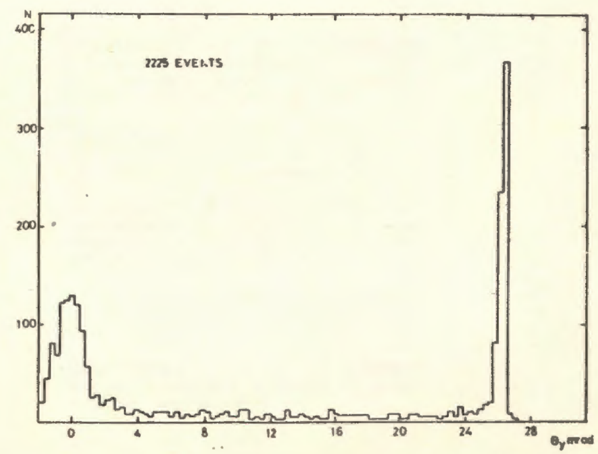

e)

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