MANIPULATION OF NEGATIVELY CHARGED BEAMS VIA COHERENT EFFECTS IN BENT CRYSTALS

W. Scandale^a, A. Vomiero^b, E. Bagli^c, S. Baricordi^c, P. Dalpiaz^c, M. Fiorini^c, V. Guidi^c, A. Mazzolari^c, D. Vincenzi^c, R. Milan^d, G. Della Mea^e, E. Vallazza^f, A.G. Afonin^g, Yu.A. Chesnokov^g, V.A. Maisheev^g, I.A. Yazynin^g, V.M. Golovatyuk^h, A.D. Kovalenko^h, A.M. Taratin^h,

A.S. Denisovⁱ, Yu.A. Gavrikovⁱ, Yu.M. Ivanovⁱ, L.P. Lapinaⁱ, L.G. Malyarenkoⁱ, V.V.

Skorobogatovⁱ, V.M. Suvorovⁱ, S.A. Vavilovⁱ, D. Bolognini^{j,k}, S. Hasan^{j,k}, A. Mattera^{j,k}, M. Prest^{j,k}

^aCERN, European Organization for Nuclear Research, CH-1211, Geneva, Switzerland, ^bINFM-CNR, Via Vallotti 9, 25133 Brescia, Italy

°INFN Sezione di Ferrara, Dipartimento di Fisica, Università di Ferrara, 44100 Ferrara, Italy

^dINFN Laboratori Nazionali di Legnaro, 35020 Legnaro (PD), Italy

^eDipartimento di Ingegneria dei Materiali e Tecnologie Industriali, Università di Trento, 38050

Trento, Italy

^fINFN Sezione di Trieste, 34127 Trieste, Italy

^gInstitute of High Energy Physics, Moscow Region, RU-142284 Protvino, Russia ^hJoint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia ⁱPetersburg Nuclear Physics Institute, 188300 Gatchina, Leningrad Region, Russia ^jUniversità dell'Insubria, 22100 Como, Italy ^kINFN Sezione di Milano Bicocca, 20126 Milano, Italy

Abstract

We review the experimental evidences we recorded with volume reflection and planar and axial channelings with negatively charged particles beam. High deflection efficiency was observed in all cases. The experiment was carried out by the UA9 collaboration in the external lines of the CERN SPS with a secondary beam of 150 GeV/c negative particles.

INTRODUCTION

When high-energy charged particles enter a crystal with small angles with respect to the atomic planes their transverse motion is governed by the crystal potential averaged along the planes. For positive particles the planar potential is repulsive while for negative particles the planar potential is attractive. As the transverse energy of the particle is smaller than the depth of the planar potential well, the particle moves with a trajectory oscillating between neighbouring crystalline planes. As a result, the probability of close collisions with the crystal atoms is high for negative particles in the channeling states. Therefore, the dechanneling length for negative particles is much shorter than for the positive ones. For this reason channeling along the whole crystal length with the deflection of negative particles by the crystal bend angle has not been observed. Only a broadening of the angular distributions towards the crystal bend side has been observed in the previous experiments (e.g. [1]).

This article presents the mail results of the observation of planar and axial channelings as well as volume reflection in bent silicon crystals at 150 GeV/c negative particles, mainly π mesons, at one of the secondary beams of the CERN SPS. The experimental setup was the same as described in [2].

PLANAR CHANNELING AND VOLUME REFLECTION

Silicon crystals with small lengths along the beam have been used in the experiment. For planar channelling we describe the results obtained with a quasi-mosaic crystal (QM2), bent along the (111) planes and 0.84 mm long. The crystal bend angle is about 65 µrad.

The divergence of the beam incident onto the crystal measured with the detector telescope was characterized by the RMS deviations $\sigma_x=(34.4\pm0.06)$ µrad and $\sigma_y=(28.2\pm0.04)$ µrad in the horizontal and vertical planes, respectively. A high-precision goniometer was used to orient the crystal planes with respect to the beam axis with an accuracy of 2 µrad.

Fig. 1 shows the intensity distribution of the beam crossing the crystal. In regions (1) and (6) the crystal scatters particles as an amorphous material. From the right to the left of the figure, we recognize first the crystal orientations where a considerable fraction of the incident beam is captured into the bound states with the (111) planes and deflected by the crystal bend angle (channeled particles) (2). Area (3) shows the fraction of particles dechanneled during the passage through the crystal. The wider area (4), whose width is determined by the crystal bend angle, is the volume reflection area. Area (5) shows the particle fraction captured into the bound states with the bent planes in a tangency area due to multiple scattering on the atomic nuclei and therefore undergoing a smaller angular deflection.

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Figure 1: Intensity distribution of the deflection angles of particles crossing the crystal vs. the angular positions of the goniometer. The following areas are indicated: (1) and (6) amorphous-like scattering, (2) deflection due to channeling, (3) dechanneling, (4) volume reflection, (5) deflection of volume captured particles.

Fig. 2a shows the distribution of particle deflection angles at an orientation optimal for channeling. The right peak owes to channelled particles while volume-reflected particles generate the left peak. The beam fraction between the two peaks is due to dechanneling (about 14%). Deflection angle holds θ_d =(63.24±0.24) µrad and the RMS of the distribution is σ_d =(10.16±0.19) µrad. Deflection efficiency is determined by the beam fraction under the fit (hatched area) and holds P_d =(30.24±0.38)%.

Fig. 2b shows the distribution of deflection angles of particles for the crystal orientation in the middle of the VR area. Gaussian fit gives peak position, VR deflection angle, θ_{vr} =(-14.64±0.12) µrad and its RMS deviation σ_{vr} =(10.06±0.11) µrad. VR deflection angle is about 0.8 θ_c , i.e., it is smaller than for positive particles (1.4 θ_c) [3].

AXIAL CHANNELING

For axial channelling, we describe the results obtained with a strip crystal (ST10), bent along the (110) planes and 0.98 mm long. Bending angle was α =43 µrad. For 150 GeV/c π - mesons the critical angle of channeling along the (111) axis was ψ =33.8µrad, and the equalization length λ =26.3 µm. It means that the Greenenko-Shul'ga condition was satisfied. Such condition ensures highefficiency deflection for axial channelling, which is mainly driven through doughnut scattering [4].

Fig. 3 shows beam intensity distribution in the deflection angles of particles in the horizontal θ_x and vertical θ_y planes for the different orientation angles θ_v of the <111> axis with the beam direction. When the crystal is not aligned with the beam, i.e., the crystal axes and plane directions are far from the beam direction, particles undergo ordinary Coulomb multiple scattering as in an amorphous medium and the beam is not deflected. As the crystal axis becomes close to alignment with the beam,



Figure 2: Deflection angle distribution of π^{-} mesons crossing the crystal for crystal orientations optimal for channeling (a) and volume reflection (b).

particle directions are governed by the averaged potential of atomic strings and undergo multiple scattering by the atomic strings. We can see an arc in particle distribution for the orientation angle of the <111> crystal axis θ_v =-40 µrad (a).



Figure 3: Beam intensity distribution in the deflection angles of particles in the horizontal θx and vertical θy planes for the different orientation angles θv of the $\langle 111 \rangle$ crystal axis with respect to the beam: (a) $\theta v = -40 \mu rad$, (b) $\theta v = -20 \mu rad$ and(c) $\theta v = 0$. (d) The distribution obtained by simulation for the perfect alignment with the axis. The bend crystal angle $\alpha = 43 \mu rad$ is shown by the dotted line in (c) and (d).

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The arc radii are determined by the particle angles to the axis direction at the crystal entrance $|\theta_v|$ and exit $|\theta_v|+\alpha$. For the orientation angle θ_v =-20 µrad (b), the distribution becomes close to a circle, which is shifted to the bend side. However, the maximum of beam intensity is still near the incident beam direction. For nearly perfect alignment at θ_v =0 (c), the whole beam is deflected by the bend angle. As opposed to the case with positive particles, there is no leakage of π^- mesons into skew planar channels intersecting the <111> axis because the planar motion of negative particles at small angles with atomic strings of the planes cannot be stabilized [5].

The whole beam was deflected to one side with the efficiency of about 90% and with the peak position at the bend crystal angle α =43 µrad. Deflection occurs mainly due to doughnut scattering of above-barrier particles by the atomic strings of the crystal. However, due to high probability of particle recapture into bound states with the atomic strings their contribution to the deflection should be about 15% for our case according to simulation results.

CONCLUSIONS

Planar and axial channelings other than volume reflection have been demonstrated for negatively charged particles. In particular the axial regime exhibits very high efficiency though considerable performance was recorded also in the other cases. Such evidences open up interesting perspectives for the manipulation of beam in several applications of accelerators, such as crystal-assisted collimation in the new generation of high-intensity electron facilities and manipulation of antiprotons.

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