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Deflection of 100 MeV positron beam by repeated reflections in thin crystals

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The phenomenon of the deflection of a charged particle beam due to channelling in a bent crystal is thoroughly investigated and successfully applied for the extraction of the beam in high-energy accelerators, at the energies of about 10 GeV and higher. However, a big practical interest lies in the task of bending and extracting charged particles with energies below 1 GeV, for example, for the production of ultrastable beams of low emittance for medical and biological applications. That is why a novel crystal technique, namely thin straight crystal targets, is investigated in this article, using crystals as elements for extraction and collimation of the circulating beam in a ring accelerator. The advantages of reflection in straight crystals in comparison with bent crystal channelling consist in the small length of straight crystals along the beam that reduces the amount of nuclear interactions and improves the background. Experimental results were obtained for the bending of a 100 MeV positron beam with using five sequential straight crystals.

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The phenomenon of the deflection of a charged particle beam due to channelling in a bent crystal is thoroughly investigated and successfully applied for the extraction of the beam in high-energy accelerators, at the energies of about 10 GeV and higher (see, for example, Refs. [1–3]). However, a big practical interest lies in the task of bending and extracting charged particles with energies below 1 GeV, for example, for the production of ultrastable beams of low emittance for medical and biological applications. However, for low energy, i.e. below 1 GeV, the bent crystal channelling is not efficient. With usual channelling bent crystals (about 1 mm in length) only 10% efficiency was achieved for the deflection of sub-GeV energy particles [4] in a beam line.

More serious problems arise when a circulating beam is extracted from a circular accelerator, since crystals required for this task must have large transverse dimensions exceeding the crystal length. In addition, the bending angle of the crystal must be $\gtrsim 1$ mrad in order that the deflected beam could be easily separated from the circulating one. Potentially, quasimosaic bent crystals [5] or thin flat crystals [6, 7] can be used for this purpose; nevertheless, in both cases, the particles deflection angle must be increased by several times.

That is why a novel crystal technique, namely thin straight crystal targets, is investigated in this article, using crystals as elements for beam deflection. The advantages of reflection in straight crystals in comparison with bent crystal channelling consist in the small length of straight crystals along the beam that reduces the amount of nuclear interactions and improves the background. This work is devoted to the experimental results obtained using the new crystal method – fan-type reflector for bending a particle beam with the use of thin straight crystals.

The method is based on particle reflection from very thin straight crystal plates, whose thickness is equal to an odd number of half-waves of particle path oscillations during channeling: $L = (n + 1/2)\lambda$, where $\lambda \cong \pi d/\theta_c$, $d = 2.3$ Å – interplanar distance in silicon. The effect of particle deflection by a thin crystal is shown on Fig. 1.

The deflection angle equals approximately the doubled critical angle for channelling $\theta_c = ((2U_0)/pv)^{(}1/2)$, where $U_0 \sim 20$ eV is the potential of the planar channel in silicon; p and v are the momentum and velocity of the incident particle, respectively. Several oriented crystal plates unfolded like a fan can be used to increase the deflection angle (Fig. 2).

In order to ensure maximum beam deflection in this construction each successive crystal is deflected through an angle of about $2\theta_c$. As a result, the total deflection angle may be as large as $2\theta_c N$, where N is the number of crystal plates. If the spread of the fan and the plate thickness are nonoptimal, the beam is deflected through

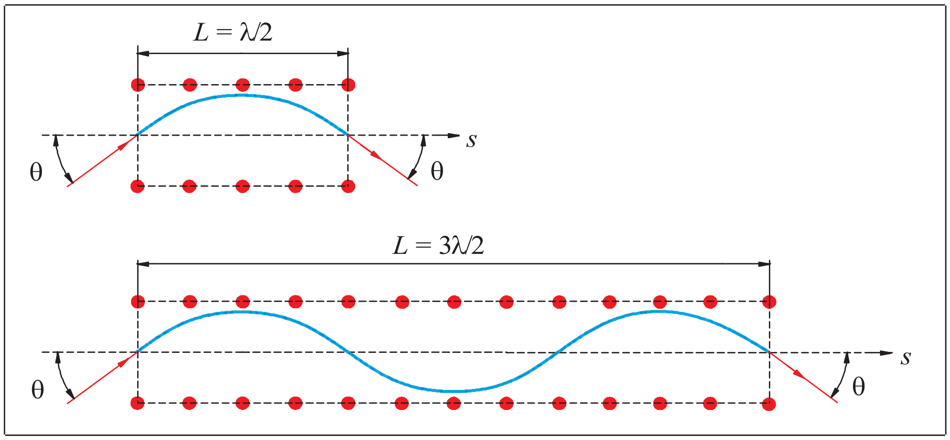

Fig. 1. Effect of particle trajectory bending in a thin crystal

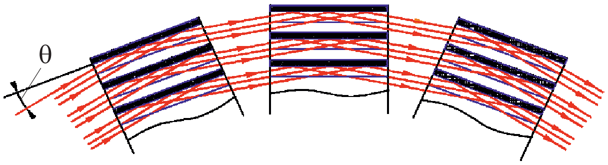

Fig. 2. Fan-type reflector for bending the particle beam with the use of thin straight crystals. The reflection of particles trajectories from nuclear planes is schematically shown

a smaller angle, and the obtained pattern is more difficult to interpret.

The results of the first Monte-Carlo simulations of beam bending by fan-like reflector are reported in [8]. In [9] preliminary experimental results for 50 GeV proton beam bending with such a technique are given. In Fig. 3 the real device is shown which was used in the experiment. The device in Fig. 3 was cut out with the help of precise machining from one piece of silicon and bent further with the help of glueing the bottom part to a metal cylindrical mirror. Thus each subsequent crystal plate is turned on an angle of 1 mrad compared the previous one, which is checked by a laser. So the full bending angle of the beam is about 5 mrad, according to simulation by the method in [8].

The necessary experimental setup was realized in the beam test facility (BTF) area at LNF (Fig. 4) [10]. A low emittance beam of 100 MeV positrons was obtained using a special iron collimator. The beam divergence achieved was about ±0.5 mrad which is appropriate for efficient particle deflection observation, because of the critical channelling angle $\theta_c = 0.7$ mrad for 100 MeV positrons.

The effect of beam deflection by the crystal device was registered by a scintillator hodoscop [10] and a GEM detector [11]. In Fig. 5 the beam profile is shown in the aligned and disaligned crystal position. As seen from the pictures, the crystal system in the aligned position deflected a significant fraction, i.e. about 30%, of the beam at 15 millimeters distance. This value concides with expectations, corresponding to a ~5 mrad deflection of a beam. The efficiency measured is a factor of 2 lower then simulations for an ideal device with optimal thickness of each crystal plate. Further work is in

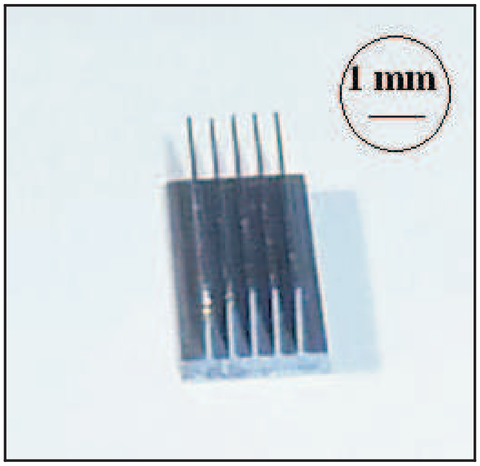

Fig. 3. The fan-like reflector used in the experiment

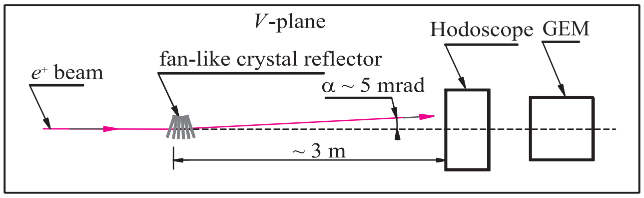

Fig. 4. Schematic diagram of the experiment

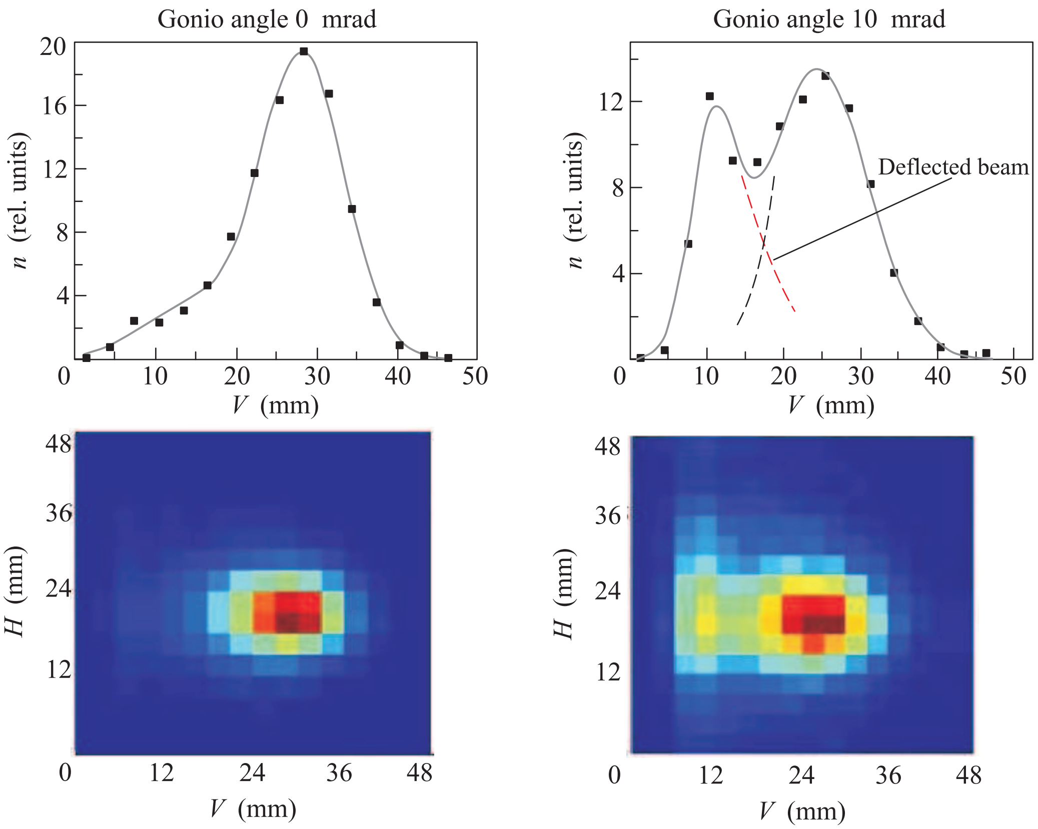

Fig. 5. Beam profile downstream the disaligned crystal (left) and the aligned crystal (right), measured by hodoscope (top picrutes) and GEM detector (bottom pictures)

progress for the optimisation of the crystal device. Also the installation of a goniometer with a crystal into the vacuum is planned for decreasing the Coulomb scattering of the beam.

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