

# DEVELOPMENT OF CRYSTAL EXTRACTION STUDIES AT THE IHEP ACCELERATOR

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## Abstract

The crystal extraction of  $10^7$  proton/s on BEC experimental facility is described. Detailed computer analysis is made to explain the basic experimental results. Future high-intensity efficient extraction using a short crystal is announced.

## 1 INTRODUCTION

In 1989 at the IHEP accelerator, a crystal extraction of a 70-GeV proton beam onto the experimental set-up PROZA[1] was carried out. As a development of this method, another extraction has been realized onto the experimental set-up BEC[2]. The beam line where BEC is located, was created for formation from an internal target of the beams of negatively charged particles in the energy range of 20-40 GeV (see fig. 1).

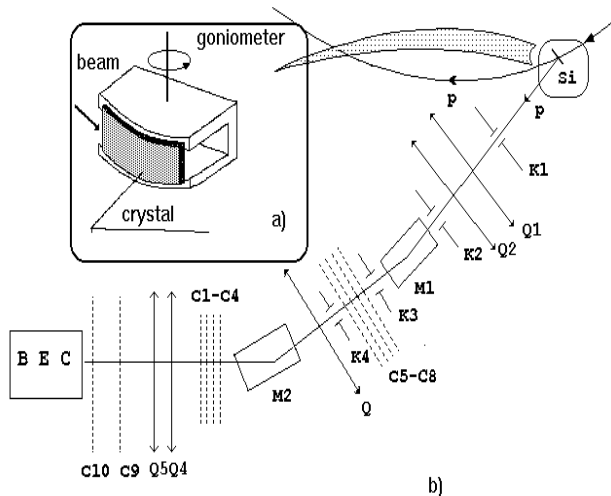


Figure 1: A bent crystal with bending device (a) and schematic of proton extraction onto BEC (b). K is collimators, Q quadrupoles, M magnets, C scintillation counters, p the orbit part, Si the crystal.

Usage in this case of the other methods of extraction of a proton beam is extremely difficult, and requires a significant reconstruction of an initial part of the beam line. Using a bent crystal, its bending angle and position inside a vacuum chamber of the accelerator can be chosen so that the line of the extraction of a proton beam is on the axis of the beam line. An opportunity of extraction into the beam line of negatively charged particles from internal targets is thus saved. The computations of proton trajectories through a

nonlinear magnetic field of an accelerator were conducted under the programs FINT and TRAEK[3]. To not restrict the accelerator acceptance, the radial position of a crystal was chosen equal to  $\approx 50$  mm from the axis of the vacuum chamber. To bring protons onto the crystal, a local distortion of a closed orbit was invoked.

For extraction, a Si crystal of orientation (111) with the sizes  $85 \times 16 \times 0.5$  mm<sup>3</sup>, bent on a angle of 89 mrad was used. The goniometer, on which crystal was established, provided its radial translation (coordinate accuracy of 0.1 mm) and turning in a horizontal plane with the step  $\approx 80 \mu\text{rad}$ .

Up to 10% of the intensity of an accelerated beam, i.e. up to  $10^{11}$  protons in a cycle, were incident on the crystal. Thus the intensity in the extraction beam line was  $10^7$  protons in a cycle and, hence, the efficiency of extraction was at the level  $\sim 10^{-4}$  (see fig. 2).

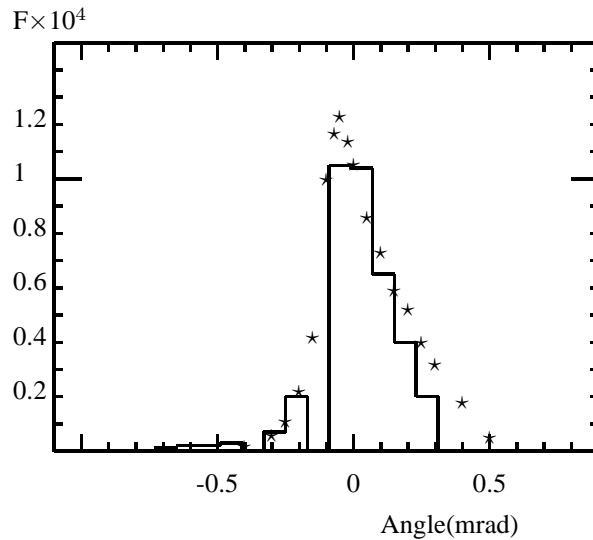


Figure 2: Histogram is the measured dependence of the extraction efficiency on the crystal orientation angle. Points (\*) are the simulation results.

The received intensity of protons was quite sufficient for fulfilment of the planned experiment on BEC. The low efficiency of extraction with the help of a crystal, bent on large angle, as simulations show, is connected not only to intensive dechanneling process of particles in such a crystal, but also to essential influence of defects, inevitably introduced at its manufacturing (destroyed near-surface layer) and bending (twists). The experiment was simulated by the program CATCH [4], which took into account a geometry

of the crystal with distortions and the effects of repeated passage of particles through a crystal. During the passage of particles through a bent crystal lattice, every step ( $\sim 1 \mu\text{m}$ ) the local crystal fields and densities of nuclei and electrons were calculated, and the scattering events generated [4]. The lattice of a crystal was considered ideal, however on its surface there could be a nonchanneling layer of the thickness of a few microns [5] (“septum thickness”), the influence of which was investigated in details. In the computation, the geometry of the holder of a crystal (scattering in it) and variable longitudinal and transverse curvatures of a crystal, existing in a geometry of fig. 1, were taken into account. Besides, the crystal twist was taken into account, as a result of which the orientation of atomic planes (111) at the entrance of a crystal becomes a parabolic function of vertical coordinate  $y$ . In our case an angle  $\theta$  of misorientation of the planes (111) is given by the expression  $\theta(\mu\text{rad})=20 \times y^2$  (mm).

The results of modeling are shown on figs. 2–4. Computed for real conditions of the experiment, the efficiency of extraction dependence on the angle of orientation of a crystal, shown on fig. 2, well agrees with the results of the experiment. Modeling has shown, that the chosen length of a crystal is optimum, while a vertical gap of the holder of 10 mm and accordingly the height of a crystal are not sufficient. Indeed, in experiment the vertical size of undisturbed beam was  $\sim 13$  mm. Moreover, the inaccuracy of the middle plane at the crystal position is  $\pm 5$  mm. Therefore the significant part of particles may be lost at the scattering on the holder. If to increase a vertical gap of the holder of a crystal up to 20 mm, the efficiency of extraction increases by 1.5-2 times.

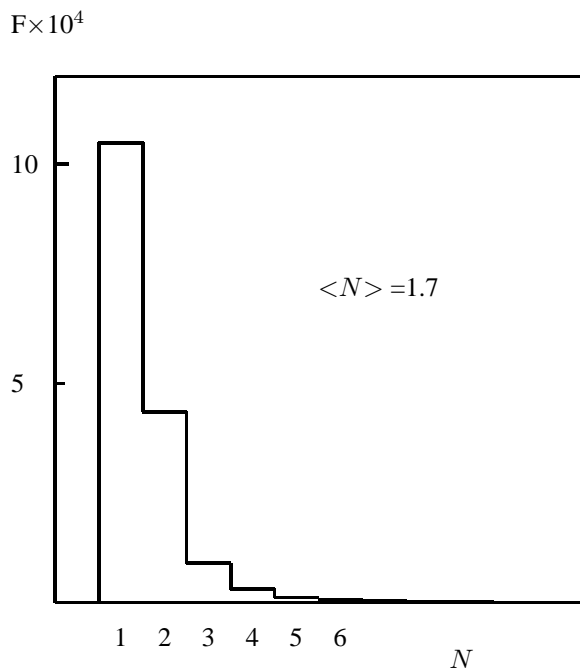


Figure 3: The number of extracted particles extracted by an ideal crystal at the  $N$ -th passage through the crystal.

Fig. 3 shows the computed efficiency of extraction by an ideal crystal (no twist, nor near-surface nonchanneling layer) as a function of the number  $N$  of particle’s encounters with the crystal. The main contribution to efficiency of extraction is from the first passage of particles through the crystal, whereas the contribution of the subsequent passages quickly drops because of a large scattering of nonchanneled particles in a crystal. The average number of passages of a particle through a crystal before a capture into the channeling state, as follows from fig. 3, is only  $\langle N \rangle = 1.7$ .

The presence of a near-surface nonchanneling layer, which in our case has a thickness of the order  $60 \mu\text{m}$ , and of a twist, changes this picture essentially. If a beam is slowly brought onto a crystal, the primary impact parameter is only a fraction of micron (the speed of this process is  $\sim 5$  mm/s, the revolution time of a particle in a ring is  $5 \mu\text{s}$ ). At such a depth, a particle hits a nonchanneling layer of a crystal and, passing in it the way  $\sim 1$  cm, scatters by  $\sim 50 \mu\text{rad}$ , that results in a secondary impact parameter at the crystal of  $\sim 60 \mu\text{m}$ . Thus, the presence in the crystal of the nonchanneling layer  $\sim 60 \mu\text{m}$  results in a complete suppression of efficiency of the first passage and partial one of the second passage. Dependence of efficiency of the extraction on a thickness of this layer, with twist and without it, is shown in fig. 4.

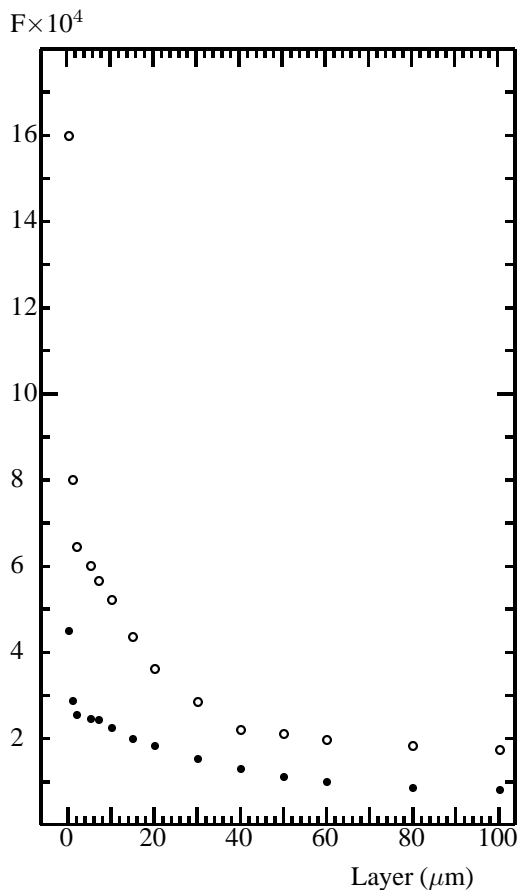


Figure 4: As simulated, the extraction efficiency as a function of the thickness of nonchanneling layer: crystal with twist ( $\bullet$ ) and without it ( $\circ$ ).

From there we see that twist has a large influence on efficiency either. The crystal with an ideal surface and without twist would ensure an efficiency of the extraction one order of magnitude higher than presently.

A radical increase of efficiency of the extraction can be reached by a use of a short crystal, bent on the small angle  $\sim 1-3$  mrad. In a long, strongly-bent crystal the dechanneling losses are almost two orders of magnitude. Besides elimination of dechanneling losses of particles, the gain in efficiency is reached also because of significant reduction of scattering over the crystal length, i.e. respective reduction of the beam divergence at the incidence on a crystal. Thus unlike in a long crystal, another mechanism of the growth of efficiency of the extraction of particles begins to work, related to the increase of the average number of encounters of particles with a crystal. Computations show that at the IHEP accelerator the efficiency of extraction of  $\sim 20-40\%$  by means of a crystal of the length of  $\sim 5$  mm, bent on the angle  $\sim 1.5$  mrad, can be achieved. Herewith, the extracted intensity may be as high as  $10^{11}$  protons/s. The experiment on realization of such an extraction is in a stage of preparation.

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