# The main results of four years experience on extraction of protons by bent crystal from the 70 GeV IHEP accelerator.

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*Abstract*

The main experimental results of using bent crystals for extraction of 70 GeV protons from the IHEP accelerator for physical research are reported.

## 1 INTRODUCTION

Development of experimental research programs in the Institute for High Energy Physics requires an extraction from the accelerator such particle beams the parameters of which (intensity, duration of extraction, quality of the time structure, etc.) can not be obtained with the known, for example resonant, methods of beam extraction. From this point of view the method of a beam extraction by bent crystals is the new and original one. It does not require septum-magnets with strong magnetic fields, power supplies as well as other large scaled equipment in an accelerator. In the IHEP in 1989 for the first time for strong-focusing accelerators an extraction of 70 GeV protons by the crystal of Si bent by 80 mrad was done for physical research on the experimental setup PROZA [1, 2]. But it was the second step. The first one was done in 1984 in Dubna (for the weak-focusing accelerator) when the possibility of extraction a 4–7 GeV beam by a crystal bent by 35 mrad was shown [3]. This method excites a great interest of the experimental physicists and preparation on extraction of a maximum energy beam by bent crystals is in progress now on the SPS [4][1], Tevatron [5].

## 2 EXPERIMENTAL RESULTS

### 2.1 Efficiency

The very first results of a beam extraction by a bent crystal from A-70 were reported in [1]. Intensity recorded in a beam line at $10^{11}$ accelerated protons spilled onto the crystal, was $4 \cdot 10^6$ particles, i.e. efficiency of extraction was $4 \cdot 10^{-5}$. Later on (see, for example [2]) an efficiency of $8 \cdot 10^{-5}$ was obtained.

Installation of a crystal in the lattice of the A-70 one can see in fig.1 where the position of it inside the vacuum chamber of block 25 as well as the closed orbit bumps to be used for deflection of an accelerated beam onto a bent crystal and internal targets are shown.

The new values of efficiency one can find in [7] where the dependence of it as well as number of particles into a beam line versus an intensity of a beam interacting with

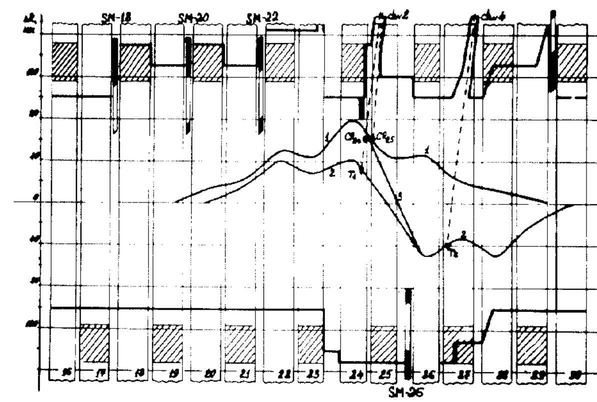


Figure 1: The cheme of extraction for protons and secondary particles from the accelerator.

a crystal are given. It was shown that in the best case an extraction efficiency reaches $\sim 1.5 \cdot 10^{-4}$.

The latest figure of an efficiency $\sim 0.7\%$ was obtained [8] when the thin target [9] was used for scattering particles from the edge of a beam distribution. This value of efficiency would allow one to get an extracted beam intensity to be enough for experiments being prepared at SPS, LHC [4] and Tevatron [5].

### 2.2 Beam parameters

Time structure of an extracted beam is the most important characteristic determining an efficiency of the physical experiment. Fig.2 [7] gives an impression about duration and quality of beams when accelerated protons and secondary particles are extracted simultaneously for different experiments towards various beam lines. The traces a) and d) of the oscillogram are the time structure of a 70 GeV proton beam extracted to the PROZA setup (beam line 14) by the bent crystal [2] and FODS-2 (beam line 22) in the nonresonant slow extraction mode [10, 11]. The traces b) and c) are the time structure of a 40 GeV secondary particle beam extracted to the setups GAMS, MIS JINR (beam line 4) and HYPERON (beam line 18) from internal targets installed respectively into magnetic blocks 27 and 35 of the accelerator. Fig.2 confirmes the possibility investigated earlier of protons extraction to the PROZA setup by a bent crystal simultaneously with extraction of particles for different experiments by other methods of ex-

[1] In 1993 the 120 GeV proton beam was extracted from the SPS [6].

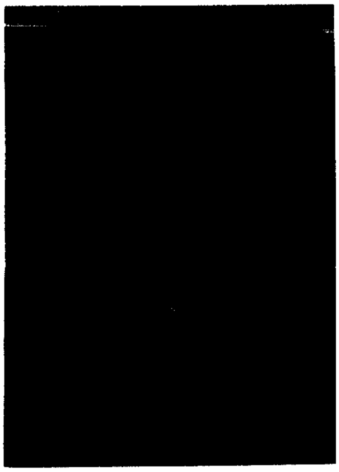

Figure 2: The oscillograms of simultaneous extraction of accelerated protons and secondary particles for different experiments. Time scale: 200 ms/div.

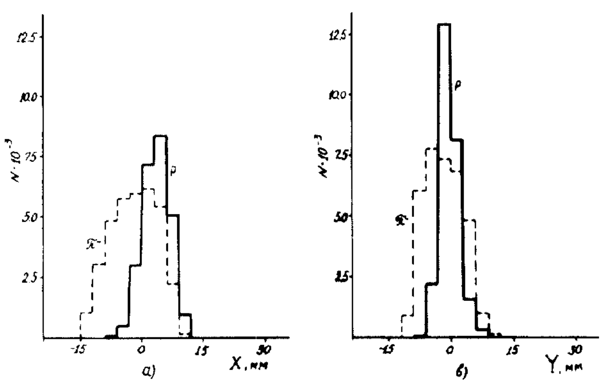


Figure 3: Spatial distributions of the 70 GeV protons and 40 GeV $\pi^-$-mesons in the target region of the experimental setup PROZA.

traction in the same accelerator cycle. A high quality of the extracted beam time structure is due to use of the thin internal target [9] scattering the beam before moving it onto the crystal.

A proton beam was formed on the target of an experimental setup with the existing focusing elements of beam line 14 forming negative hadron beams (mainly the $\pi^-$-mesons) of a momentum $\leq 40$ GeV/c.

A possibility to compare, in the target region of the experimental setup PROZA, spatial and angular distributions of the 70 GeV proton beam extracted by a bent crystal and the 40 GeV $\pi^-$-meson beam from internal target of block 24 is presented in figs.3 and 4. Fig.3 gives a spatial distribution, fig.4 gives an angular one in horisontal and vertical planes (a and b, respectively). It is seen that the transverse distribution of the proton beam is about 2 times narrower than that of the pion beam, the proton beam has a less angular divergence as well. Such parameters of the formed beam satisfy the requirements of polarization research on the experimental setup PROZA [7].

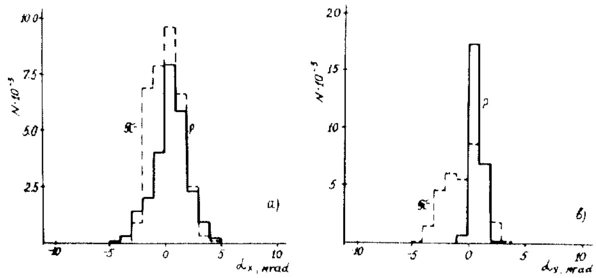


Figure 4: Angular distributions of the proton and $\pi^-$-meson beams.

### 2.3 *Improvement*

In 1991 we were able to find out a new phenomenon helping us to increase the bent crystal extraction efficiency: preliminary scattering a beam by a thin target installed upstream of the crystal [8]. The result was: intensity of an extracted onto experimental setup beam was doubled and reached $\sim 10^7$ protons/pulse while, according to estimations, the proton density on the crystal input decreased by $\sim 17$ times. It means that the extraction efficiency value in this regime reached $\sim 1\%$. Direct comparison of the estimations with the results derived from experimental characteristics of the IHEP accelerated beam shows their satisfactory agreement.

Computer simulation shows that the anglular divergence of beam particles having large betatron amrlitudes in the case of using a thin target significantly decreases approaching the critical crystal channeling angle at 70 GeV $\psi_c \sim \pm 25\mu$rad [12].

Investigation of a thin target influence on the bent crystal extraction efficiency is continued in the IHEP.

## 3 DEVELOPMENT

### 3.1 *Extraction of 50 GeV protons*

During one of the runs in 1992 an extraction of 50 GeV protons to one of the experimental setups (SIGMA [13], beam line 2) for methodical experiments was realized. The scheme of beam lines 2 and 14, having a common head part, as well as some experimental results are given in ref.[14]. Main figure is: an obtained efficiency of extraction is $\sim 4.6 \cdot 10^{-5}$ that corresponds to the efficiency value obtained before [2] and confirms keeping up geometrical conditions of a beam extraction from the A–70 at 50 GeV.

Preliminary scattering a beam by a thin target gives an extraction efficiency increase at 50 GeV energy level also. But, on comparing to the case of intensity doubling at 70 GeV, an increase of intensity into beam line 2 only by 30% was fixed.

Analisis of the data received in [14] shows that numerical values of main characteristics of the 50 and 70 GeV proton beams (maxima of intensity, its "initial" levels $(N_{in})_E$ and gradients of increase) are approximately proportional to the primary beam energy. These dependencies show, for example, that at the Tevatron energy 800 GeV one can extract by bent crystal $\sim 10^8$ protons [15] which satisfies the new experiment requirements (see, e.g., ref.[4, 5]).

### *3.2 Extraction towards the setup WES (beam line 4)*

For beam line 4 a crystal deflector is to be set into block 27 (see, for example, fig.1) at 6.55 m from its edge downstream. The bending angle of a crystal is $\sim$ 85 mrad [16].

Peculiarities of extraction conditions:

— working zone of a crystal deflector is in the region of positive coordinates relatively to the central orbit (in opposite to the block 27 targets generating secondaries on negative coordinates);

— local distortion of the closed orbit is formed by two bumps since the one existing bump does not allow to steer a beam onto a crystal at more distant coordinates than the ones of internal targets.

Such scheme of steering allows a requirement of a mutual beam and crystal alignment to be significantly weakened as well as to make easy a remote controled goniometer construction.

One should point out that, with appearance of a proton beam into beam line 4, the experimental possibilities are extended not only for the setup WES (which used only secondary beams earlier) but also for other setups of this beam line: GAMS, ISTRA, MIS JINR.

## 4 PERSPECTIVES

Development of the IHEP experimental base connected with the UNK construction and designing new experimental facilities supposes an extention of the test zones complex of the existing accelerator to prepare apparatus for operation with a beam of the UNK energy region. A more effective use of the A-70 extracted beam can be reached if, besides of existing methods of extraction of protons and secondaries, one will use bent crystals.

As it was pointed out before, even under direct steering a beam onto a crystal the experimental value of an extraction efficiency $\sim 10^{-4}$ have been obtained. It means that, in order to get about $10^6$ particles onto the target of an experimental setup, one should move $\sim 10^{10}$ protons of an accelerated beam onto a crystal. Note, that such an intensity value is by two orders of magnitude lower of that which to be steered onto internal targets for generation of the secondary particle beams. Intensity of $\sim 10^{10}$ protons/cycle is contained practically into a halo of an accelerated beam encircling its dense part (see, for example, [17]). This particles can be extracted easily from the IHEP accelerator by bent crystals some of which are installed in the places marked in fig.5 with the black points.

## 5 CONCLUSION

Experience of extraction by bent crystals accelerated protons for physical experiments, for the first time gained at

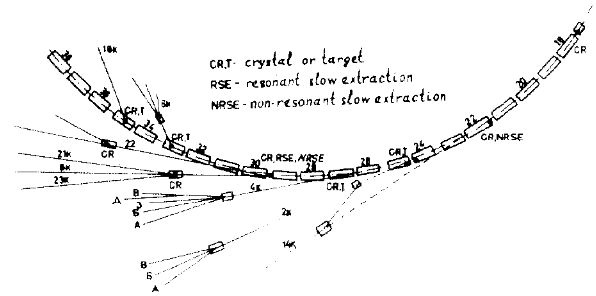


Figure 5: Perspective of the bent crystals use for extraction of accelerated protons from A-70.

the IHEP, allows one to make conclusion about its reliability, high stability of beam parameters, compatibility of it with other methods and modes of particles extraction. Simplicity of using bent crystals, possibility of mounting them in any region of the accelerator vacuum chamber as well as a possibility of using the existing beam lines suggest an expedience of their use for beam extraction both on the IHEP accelerator and on other machines of higher energies.

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