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V.I. Baranov[1], V.M. Biryukov[1], A.P. Bugorsky[1], Yu.A. Chesnokov[1], V.I. Kotov[1], M.V. Tarakanov[1], V.I. Terekhov[1], S.V. Tsarik[1], O.L. Fedin[2], M.A. Gordeeva[2], M.P. Gur'yev[2], Yu.P. Platonov[2], A.I. Smirnov[1]

Highly Efficient Deflection of the Divergent Beam by Bent Single Crystal

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Serpukhov, IFVE

[1]Institute for High Energy Physics, Protvino, 142284 Moscow Region, Russia

[2]Sanct-Petersburg Institute of Nuclear Physics St. Petersburg, Russia

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Abstract

Baranov V.I. et al. Highly efficient deflection of the divergent beam by bent single crystal: IHEP Preprint 95-15. – Protvino, 1995. – p. 5, figs. 4, refs.: 3.

We have investigated the proton beam deflection in the geometry where the first crystal formed a divergent beam and the second one shaped this beam into the parallel one. In spite of the aberration influence a high bending efficiency was obtained.

Аннотация

Баранов В.И. и др. Высокоэффективное отклонение расходящегося пучка изогнутым монокристаллом: Препринт ИФВЭ 95-15. – Протвино, 1995. – 5 с., 4 рис., библиогр.: 3.

В настоящей работе мы исследовали отклонение пучка протонов в схеме, когда один монокристалл формировал расходящийся пучок, а второй кристалл преобразовывал его в параллельный. Несмотря на влияние аберраций, была достигнута высокая эффективность отклонения.

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Nowadays the bent single crystals of silicon are applied for bending low-divergent (as compared to the channeling angle $\theta_L \sim 0.02 \div 0.002$ mrad at 100 GeV – 10 TeV) high-energy particle beams [1]. The CERN experiment [2] has demonstrated that the efficiency of bending proton beam of 450 GeV energy and the divergence less than 3 μrad is up to $\sim 50\%$.

In [3] a method to focuse a beam with a bent monocrystal in the plane of bending was proposed. The focusing (parallel to point) was due to the difference of the crystal bending angles, the end face of which had a special shape. Another important application of a focusing crystal may be related to the reverse motion of particles – transformation of the beam diverging from a point-like source into a parallel. To do this, the crystal entry face must have a special shape. The problem of focusing a divergent beam is typical for steering secondary particle beams, and in particular for their extraction from colliders.

To extract most of the secondary particles produced in the target located in the vacuum chamber of the accelerator (at the crystal focal point, Fig.1), certain conditions must be fulfilled. It is known that most of the produced secondaries exit in the angular range

$$\pm\,\theta \;=\; \frac{0.4\ \mathrm{GeV/c}}{\mathrm{P}}, \tag{1}$$

where P is momentum. The acceptance of the focusing crystal is

$$\pm\,\varphi \;=\; \frac{H}{2F}, \tag{2}$$

where H is the crystal thickness, F is the focus distance, should be about $\pm\theta$.

High efficiency of particle trapping into channeling mode may be obtained, if the target size Δx in the bending plane is

$$\Delta x \;\leq\; 2\theta_L F. \tag{3}$$

Then the particles entering the crystal are aligned w.r.t. the crystal planes within θ_L, and the trapping efficiency η may be close to the theoretical limit $\sim 70\%$. Under practicable conditions of the experiment the defects of the focusing device may lower η essentially.

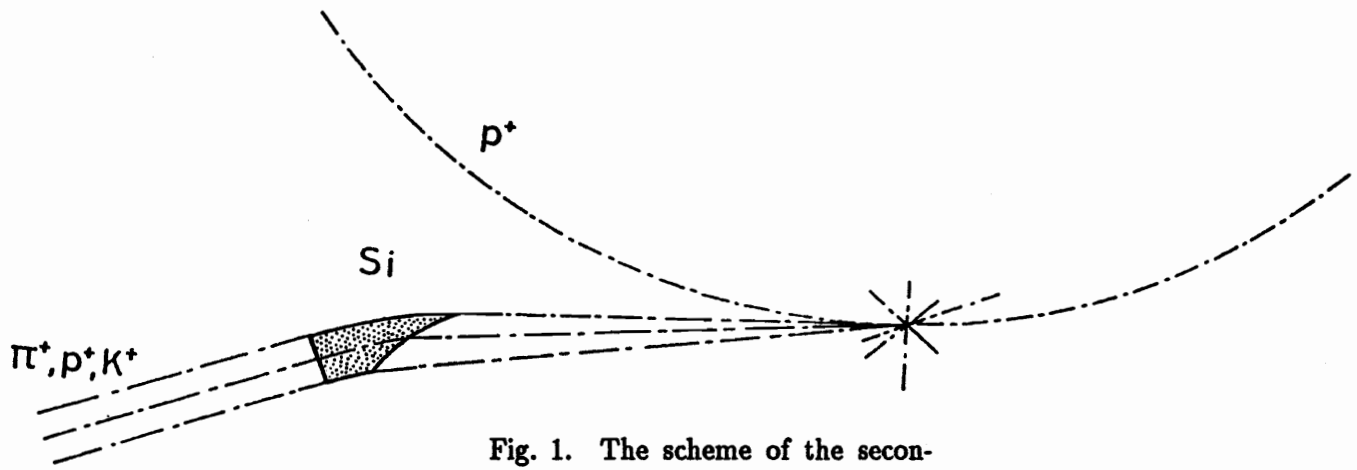

Fig. 1. The scheme of the secondary-particle beam extraction from accelerator with the focusing crystal.

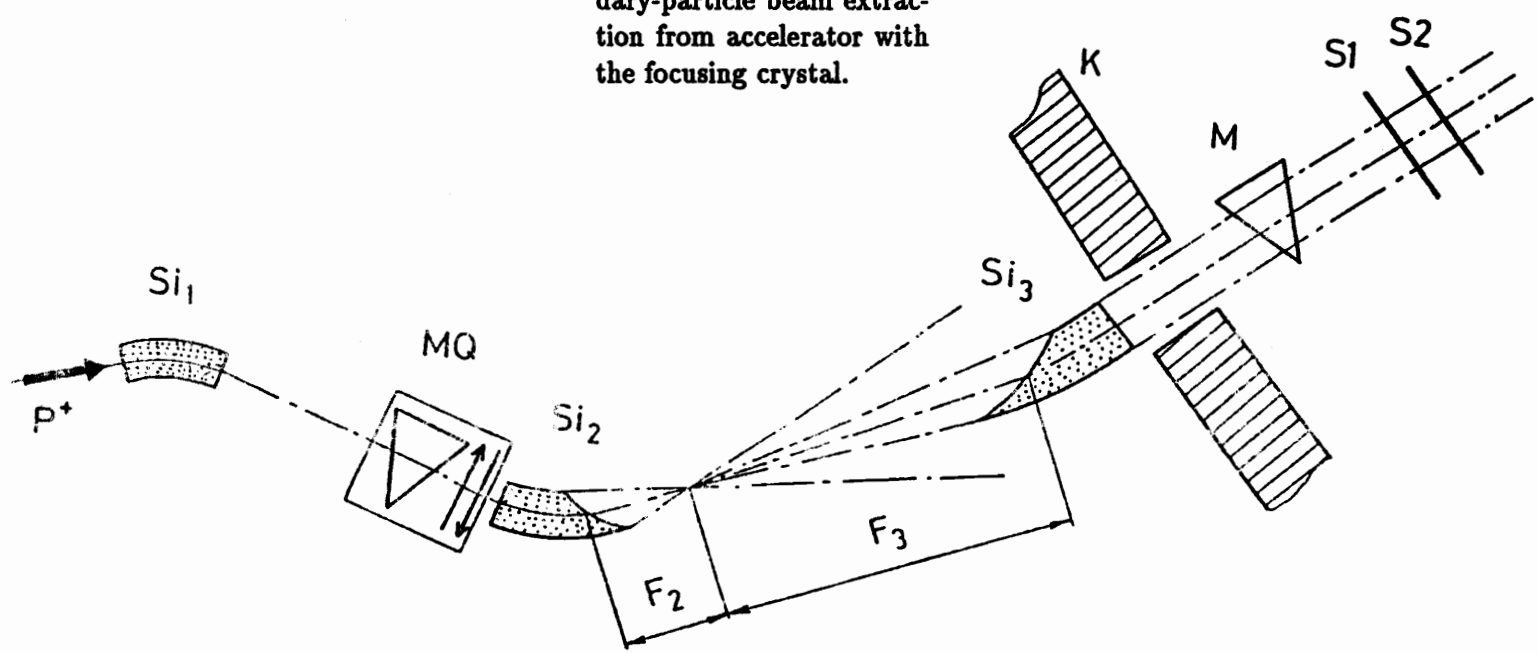

Fig. 2. The scheme of experiment.

The above conditions for the efficient extraction of secondary particles can be easily met at TeV energies. The estimates for the LHC collider (energy of protons is 7 TeV) show that in this way one can extract secondary particles with intensity of up to $\sim 10^8$/s.

The experimental investigation of the efficiency of capture and deflection of the beam diverging from a point-like source was made with the extracted 70 GeV proton beam of IHEP accelerator. The experimental scheme is in Fig.2. The crystal Si_1 (with usual flat faces) bent by 60 mrad was exposed to the 70 GeV proton beam of $10^{11}/s$ intensity and bent the beam with moderate intensity $\sim 10^7/s$ toward the magnet-optics system $MQ - M$, where two other crystals were placed. The beam formed with the forward part of the magnet system was brought onto the crystal Si_2 with had the focusing end face. This crystal was 2 mm thick, 15 mm high, 70 mm long and 18 mrad bent. The crystal focused the beam at the distance of 0.5 m into a narrow vertical strip with the crossover width $\simeq 80$ μm FWHM and divergence ± 2 mrad. The beam formed in this way was used as a source of protons. In order to focus and deflect this divergent beam, the crystal Si_3 with 2.5 m focus distance was used. It was $2 \times 20 \times 30$ mm^3 in size and was bent by 6 mrad (the first and second crystals had orientation (111), the third was cut along the planes (110)). This crystal had the acceptance of $\varphi = \pm 0.4$ mrad. According to preliminary measurements, it gave for the parallel-to-point focusing the crossover size $\sim 200\mu$m FWHM (the ideal value is $\Delta x = 2\theta_L F = 125\mu$m). The crystals were aligned to the beam successively. Each of them had an independent goniometer.

The effect of focusing the beam from the divergent to parallel was detected by measuring the intensity of the beam deflected by the third crystal while the latter was rotated around the vertical axis crossing its entry face. The intensity obtained in this angular scanning is shown in Fig.3. The scan FWHM approaches to $2\theta_L$ ($\simeq 4\theta_L$ at the base), which attests a good quality of focusing. According to measurements with the remoted scintillation counters S1 and S2, the crystal Si_3 at the best angle deflected $(15 \pm 2)\%$ of the protons incident on its face, which is by a factor of ~ 2 lower than the calculation for the ideal focusing.

The high-efficiency bending of the divergent beam is confirmed with the data of developing the beam profile on the nuclear emulsion, which was placed downstream the crystal Si_3 under its optimal alignment. This profile is shown in Fig.4. The wide beam (excess over the background) corresponds to the divergent beam formed by the crystal Si_2. The dip on the right is the shadow of the crystal Si_3, due to the capture of beam fraction in the channeling mode. From the ratio of areas one can find that $\sim 30\%$ of particles are trapped in channeling mode. On the left of the figure the contribution of particles bent by Si_3 is seen, superimposed on the broad profile of the beam divergent from the crystal Si_2. The bent-beam fraction, according to the figure, is 14% of incident particles. This agrees well with the scintillation counters measurements. The reduction of the number of bent particles by a factor of 2.2, as compared to the particles trapped in the channeling mode, is explained by dechanneling. It is also seen from the figure, that the efficiency of particle bending is not uniform over the crystal thickness (at the edges it is higher than in the middle). Apparently, this is due to defects of crystal Si_3. For focusing the beam with this crystal from parallel to point, there was observed a characteristic split of the

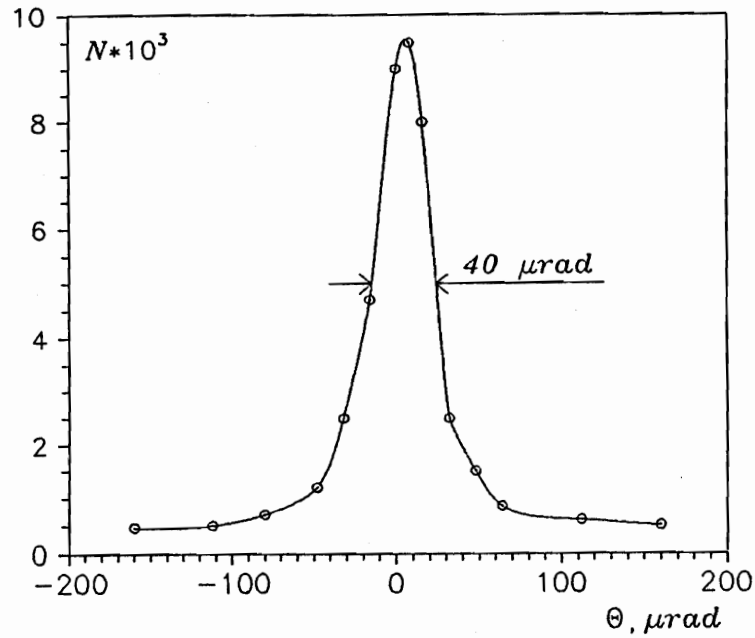

Fig. 3. Angular scan of intensity for the beam bent with the third crystal.

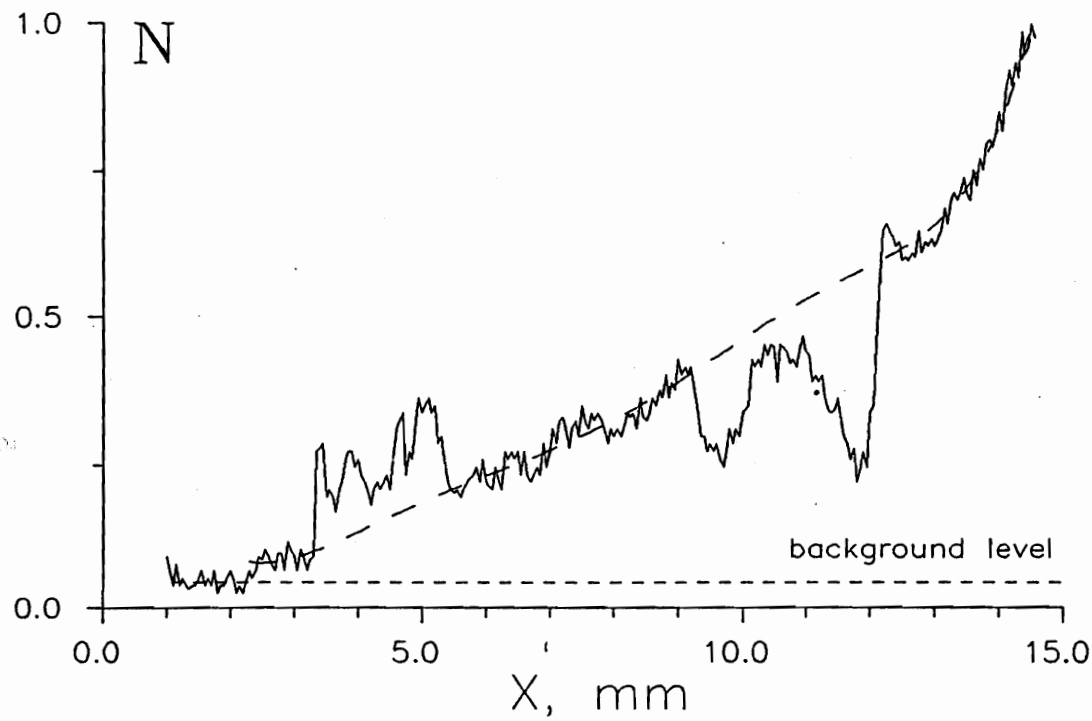

Fig. 4. Beam profile on the nuclear emulsion downstream the third crystal.

beam profile some distance downstream the crossover, similar to that of the profiles in Fig.4.

At the energies above $\sim$ 500 GeV and for the same crystal size, the fraction of the bent particles will be close to 30%, as in this case the particle losses in the process of deflection are insignificant because of the dechanneling length growth. The obtained efficiency is high despite the defects of both Si_2 (the source) and Si_3. In further studies we suppose to use microstrip detectors to measure precisely the characteristics of the incident and bent beams. We hope that detailed information will allow us to improve the quality of focusing crystals and to bring the bending efficiency closer to the theoretical value.

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В.И.Баранов и др.
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ГНЦ РФ, Институт физики высоких энергий
142284, Протвино Московской обл.

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