Proton extraction from the CERN-SPS by a bent crystal

The RD22 Collaboration [1]
Presented by S. Weisz, CERN
CH 1211 - Geneva 23

Abstract

An experiment is being performed at the CERN-SPS to study the feasibility of extracting protons from the halo of a 120 GeV stored beam by means of planar channeling in a 8.5 mrad bent silicon monocrystal. Two different techniques have been used to bring the protons into the crystal. In one case a kicker magnet was repeatedly energized to displace particles up to 100 microns inside the crystal front face. In the other case a continuous flux of impinging particles was obtained by powering electrostatic plates with a white noise excitation. In both cases we observed an extracted beam of channeled particles. The detection was performed with several large size scintillators, a fluorescent screen, a scintillation hodoscope, and a pair of microstrip gas chambers. Extraction efficiencies of the order of 10% were measured.

I. INTRODUCTION

Planar channeling can occur when a proton beam is sent onto a monocrystal with an incident angle relative to the main crystalline planes smaller than a given critical angle [2]. The impinging particles are confined between the atomic planes and can eventually be deflected if the crystal is mechanically bent [3]. The main features of planar channeling are now well established from the theoretical point of view [4]:

- The critical angle Ψ_p varies with the beam momentum P as $1/\sqrt{P}$. The surface acceptance, which is the probability that incident particles within the critical angle get initially channeled, does not depend on P.
- Multiple scattering on electrons can kick initially channeled particles out of the guiding potential well. The dechanneling length is proportional to P in a straight crystal.
- The curvature of the bent crystal introduces additional losses due to centrifugal forces acting on particles when entering the curved region. The reduction of the deflection efficiency is function of the ratio P/R, where R is the bending radius.

Bending efficiencies of about 50%, with a deflection of 2.4 mrad, have been measured with 450 GeV protons channeled in a silicon crystal [5]. These results were obtained on a highly parallel external beam with an angular divergence of $\pm 3\mu$rad, less than the critical angle for planar channeling at this energy $\Psi_p(450\text{ GeV}) = \pm 7\mu$rad. Extraction of 70 GeV protons from an internal circulating beam was reported with a much lower efficiency of about 1.5×10^{-4} [6].

It has been proposed to use the technique of crystal channeling to extract protons from the beam halo of both future multi-TeV colliders SSC [7] and LHC [8], allowing fixed target experiments to run in a parasitic mode. The main expected difficulty comes from a reduction of the channeling efficiency when the protons hit the crystal with small impact parameters and remain close to the surface where defaults of the crystalline structure can occur. One is also concerned about the alignment of the crystal relative to the circulating beam. The aim of the RD22 experiment [9] is to investigate these effects in the environment of a real accelerator. The experimental equipment was installed in the CERN-SPS and became operational by mid 1992.

II. EXPERIMENTAL LAYOUT

The experimental set-up, located in Straight Section 5 of the CERN-SPS, is shown schematically in Figure 1. The vacuum tank contains two silicon monocrystals, each 3 cm long, 1 cm high and 1.5 mm thick. Their upper and lower edges are clamped onto cylindrical formers to bend the crystal {110} lattice planes by 8.5 mrad. Each crystal is mounted on a goniometer which can move horizontally into the beam and which can provide angular adjustment with a resolution of up to 4 μrad. Four beam scrapers, three in the horizontal plane and one in the vertical plane, are used for a precise positioning of the beam. Protons are extracted in the horizontal plane, towards the centre of the ring. The deflected beam stays in the vacuum pipe for about 15 meters and exits through a 0.2 mm thick stainless steel window.

The three scintillators **S1**,**S2** and **S3** form a telescope to detect and count the extracted protons. The light outputs of scintillators **S4** and **S5** are attenuated to operate at high fluxes. **S4** is in the extracted beam line while **S5** is placed on the opposite side to monitor background. **TV1** is a scintillating (Cesium Iodide) screen read by a CCD TV camera providing an immediate image of the extracted beam [10]. **Hh** and **Hv** are two hodoscope planes 32 × 32 mm^2, 1 mm pitch, to measure horizontal and vertical profiles. **C1** and **C2** are pairs of Micro Strip Gas Chambers (MSGC) [11], 25 × 25 mm^2, with horizontal and vertical strips (200 μm pitch), spaced by 1 meter. Their spatial resolution is better than 100 μm. They are used to measure the direction and profiles of the extracted beam. Counter S3, the hodoscope and the MSGCs are mounted on a movable table to follow the position of the extracted beam and account for the parallax between the two crystals.

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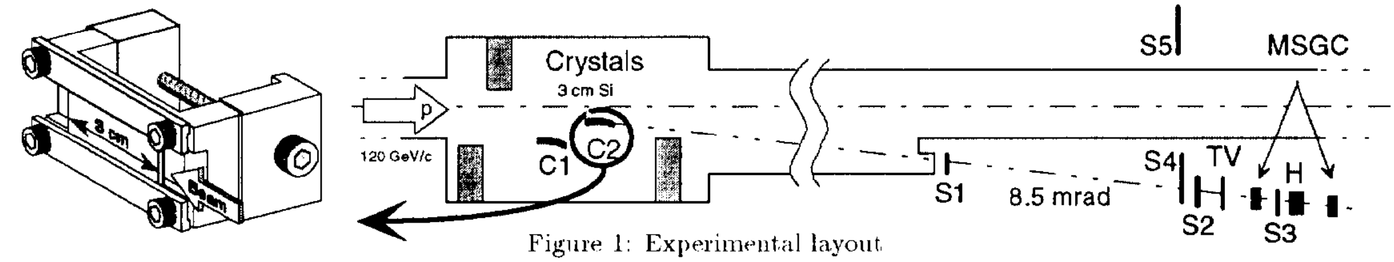

Figure 1: Experimental layout

III. KICK MODE

First evidence of extraction by crystal channeling with a circulating 120 Gev/c beam was obtained using the so called "kick mode". A fast kicker magnet was energized during one SPS revolution (23 μs) to displace horizontally the circulating beam about 100 μm at the crystal position. The inner edge of the crystal was 10 mm from the nominal closed orbit, about 3 σ of the beam size after emittance blow up, so that only a very small fraction ($\sim 10^{-4}$) of the stored protons could hit the crystal at each kick. The horizontal β function was 90 m at the crystal location, leading to an horizontal angular spread of 1.1 μrad for the proton trajectories when they first enter the crystal. This is much less than the critical channeling angle $\Psi_p(120\ \mathrm{GeV}) = \pm 14\mu$rad. The time between two consecutive kicks was long enough for the beam filamentation to refill the originally available phase space.

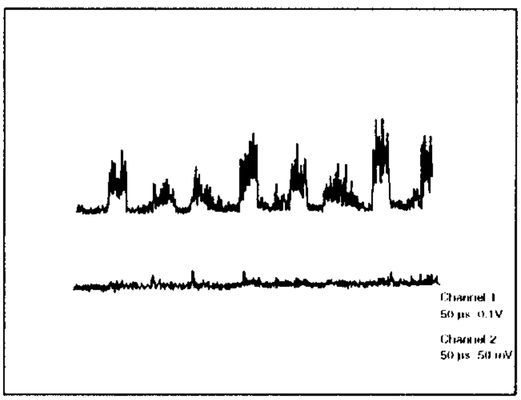

Figure 2: Extraction signal in "kick mode"

A clear signal synchronised with the kicker magnet excitation was observed in the **S4** counter after angular adjustment of the crystal (upper trace of Figure 2). The toothed pattern results from the betatron motion of the proton beam which is successively displaced towards the crystal or away from it. The lower trace of Figure 2 shows the **S5** counter which essentially recorded particles produced by nuclear interaction in the crystal. The amplitude of both traces were about equal when the crystal was not aligned and no channeling occurred.

IV. CONTINUOUS EXTRACTION

The continuous extraction was achieved by exciting an electrostatic deflector with amplitude tunable white noise. Each circulating proton received a small random horizontal kick when passing between the electrodes of the deflector, and the global effect was a continuous blow-up of the horizontal emittance of the beam. Under these conditions, the crystal received protons in a steady-state regime with impact parameters in the micron range. The hodoscope counting rate as a function of the crystal tilt angle is shown on Figure 3.

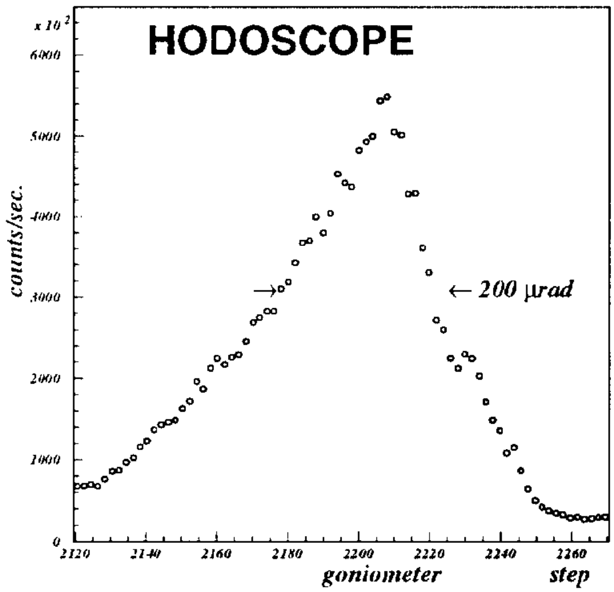

Figure 3: Hodoscope response versus crystal tilt

The distribution has a σ of $\sim 90\mu$rad, much larger than the channeling acceptance expected from the critical angle Ψ_p. The peak position corresponds to the same goniometer setting as the one that gave the maximum signal of channeled protons in the kick mode.

Our present understanding of the large angular response curve is the following: The clamping of the crystal on its bender introduces stresses and the crystal curvature is not perfectly uniform. An X-ray survey of the crystal surface, prior to its installation on the CERN-SPS, indicated that the orientation of the crystalline planes varies at the entrance and exit edges as one departs from the middle plane. By displacing the beam vertically along the crystal entrance face, we observed a shift of the peak position of the angular response curve as shown on Figure 4.

The extracted beam was observed on the TV screen and recorded by the hodoscope and the MSGCs. The horizontal profile obtained with the hodoscope is displayed on Figure 5. The width of the distribution corresponds to a beam divergence of $\sigma \sim 40\mu$rad at the crystal exit, again larger than the critical angle Ψ_p that one would expect.

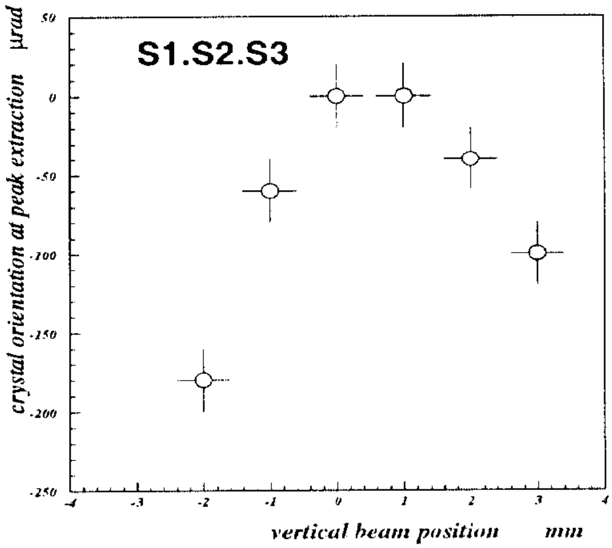

Figure 4: Peak position versus beam height

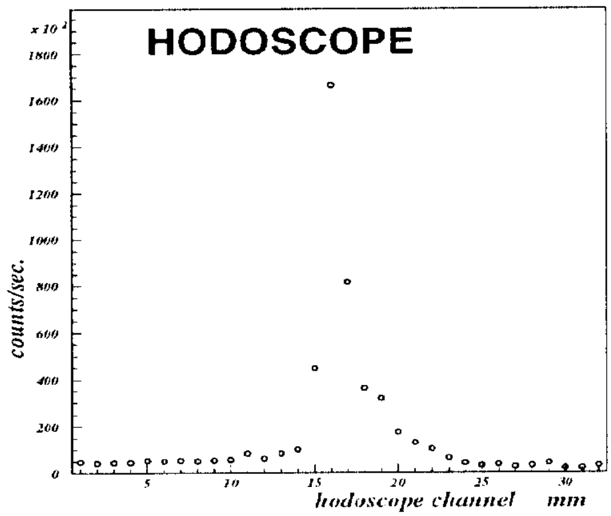

Figure 5: Horizontal profile of extracted beam

The extraction efficiency is defined as the ratio of extracted protons to the number of protons initially hitting the crystal. The number of extracted protons was deduced from the counting rates in **S1**,**S2** and **S3** while the fraction of the beam hitting the crystal was constantly monitored through the beam lifetime measurement.

Sample	Crystal 1	Crystal 2
Protons on Crystal (Hz)	$6.7\ 10^6$	$10.\ 10^6$
$S1 \cdot S2 \cdot S3$ rate (Hz)	$.61\ 10^6$	$.74\ 10^6$
Background rate (Hz)	$.27\ 10^5$	$.39\ 10^5$
Efficiency	12 ± 3 %	10 ± 3 %

Table 1: Extraction Efficiencies

The **S1**·**S2**·**S3** acceptance is limited by **S3** and defined a $1.9\ 10^{-6}$ Steradian solid angle containing the extracted beam. The background was estimated in the surrounding $6.9\ 10^{-6}$ Steradian still covered by the **S1**·**S2** coincidence. With conservative counter efficiencies of $90 \pm 10\%$, one gets the extraction efficiencies of Table 1.

V. CONCLUSIONS AND PROSPECTS

Stable continuous proton extraction from the periphery of a 120 GeV/c beam circulating in the CERN-SPS was achieved by means of particle channeling in a bent silicon monocrystal. The intensity of the extracted beam could be controlled by the strength of the excitation used to blow up the horizontal emittance. We tested successively 2 crystals and extraction efficiencies of $\sim 10\%$ were measured with both samples.

Large widths were observed for both the channeling acceptance and the deflected beam. Mechanical distortions of the crystals could explain the effects and we will investigate the problem using different bending devices during the course of 1993.

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VI. REFERENCES

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[1]ISA, University of Aarhus, Aarhus, Denmark
[2]CERN, Geneva, Switzerland
[3]Laboratori Nazionali di Frascati, Frascati, Italy
[4]Università di Lecce and INFN, Lecce, Italy
[5]Università di Pisa and INFN, Pisa, Italy
[6]Università 'La Sapienza' and INFN, Roma, Italy
[7]Università di Torino and INFN, Torino, Italy
[8]Università di Trieste and INFN, Trieste, Italy

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