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C. Thornton Murphy
for the E853 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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EXTRACTION FROM THE TEVATRON USING CHANNELING WITH A BENT CRYSTAL

C. THORNTON MURPHY
Fermi National Accelerator Laboratory, Batavia, Illinois 60510 USA
for the Experiment 853 Collaboration*

ABSTRACT

We present the goals, plans, and first results from Fermilab Experiment 853, an experiment to test the feasibility and efficiency of extracting a low-intensity beam from the halo of the Tevatron using channeling in a bent silicon crystal. The motivation of the experiment is to apply this method of extraction at the SSC. An early result of the experiment in which noise was introduced to the RF voltage amplitude to generate halo is presented. Results from a similar experiment at the SPS of CERN are discussed.

1. Introduction

The idea of extracting halo beam with a bent crystal from the SSC was first written by C. R. Sun[1]. Further discussions of the idea[2,3,4] led to a proposal[5] that the East Campus footprint of the SSC be modified to make this possibility feasible at a later time. A proposal for an experiment which would use such a beam to do fixed-target B-physics has been submitted to the SSC[6]. These efforts led to a proposal for an experimental feasibility study of this extraction method in a superconducting accelerator very similar to the SSC, namely, in the Tevatron. This experiment (E853) has been approved for 72 hours of dedicated study time during the Fermilab Collider Run Ib and is the topic of this paper.

2. The SSC Motivation

Although extraction of beam from the SSC to either fixed target experiments or test-beam targets is not in the initial scope of the SSC, the idea of extracting the natural halo to make low-intensity beams has intrigued people for the last decade[1,2,3]. Since this halo will eventually be absorbed on "scraper" collimators, why not put it to better use? The specific idea proposed was to install a copy of the abort insert planned for the West Utility Straight Section in the unused East Utility Straight Section, but with a bent crystal replacing the abort kicker magnets. A crystal bent by about 100 microradians would channel whatever halo beam was incident on it up into the field-free hole in a string of Lambertson magnets. From there, the beam would exit the accelerator and enter an experimental hall about 3000 m downstream, separated laterally from the accelerator by 160 m. Details of the SSC extraction concept and Monte Carlo simulations of it are given in an earlier paper[7] and the references therein.

3. Goals and Plan for the Tevatron Experiment

Protons have already been extracted with bent crystals from the circulating

*Fermilab, SSC Laboratory, University of Virginia, UCLA, University of Texas at Austin, University of New Mexico, University of Wisconsin, CEBAF, SUNY at Albany, JINR at Dubna, IHEP at Serpukhov, and PNPI at Gatchina

beam at Dubna, Serpukhov, and the SPS at CERN. The goals of Experiment 853 go further than what was achieved in the earlier experiments. With 10^{12} protons circulating, the goal is to extract 10^6 protons/s and prove that:

1. The luminosity lifetime is not seriously shortened.
2. The crystal can be aligned to the beam quickly.
3. No intolerable backgrounds are created at the collider experiments.
4. Diffusion created by RF modulations creates halo with adequate "step size" , or "jump", to clear the edge region of the crystal (called the "septum"), where it would be bent by only part of the total bend angle of the crystal.

The plan for the experiment is shown in Figs. 1, 2, and 3 and is somewhat explained by the captions. The experiment will take place in the C0 straight section, normally the scene of the proton abort line. However, during the collider runs, the abort line is not used at 800 GeV, so one of the abort kicker magnets has been replaced by the crystal insert. The crystal is mounted at the upstream end of a 1-m beam pipe which ends with articulating bellows. Two precision motors (x,y) at each end of the pipe allow for the alignment of the crystal with four degrees of freedom. The most critical parameter is the alignment of the vertical angle of the crystal with the beam angle, which must be done to within 10 microradians to match the critical angle of the crystal with the beam angles.

Fig. 2 shows the core of the beam with respect to the crystal. The intention is to pump beam from the outer edge of the core of the beam into the horizontal halo, where it will eventually intercept the crystal on some turn following the appropriate number of betatron oscillations. Protons channeled by the crystal are then bent up by an angle of 0.64 mrads into the field-free hole of the Lamberson magnets, shown in Fig. 3.

In the extracted particle line (see Fig. 1), there are two air gaps separated by 40 m in which there will be four scintillators and four silicon strip planes to count the extracted beam and measure its trajectory precisely (in order to prove that it is channeled beam, not just scattered background). These detectors are removed from the beamline remotely when they are not in use.

We will use the (110) planes of a silicon monocrystal of dimensions 30mm x 3mm x 10mm. There are some interesting challenges in this application. The critical angle of this plane, which is the vertical angle of a beam particle beyond which channeling does not occur, is 5.2 microrads at 900 GeV. However, the rms of the beam vertical divergence is 11.5 microradians, so we already know that the efficiency for single-turn extraction will not be very high. (At the SSC, the lattice is more favorable, and the critical angle is bigger than the beam divergence.) It will be important to simulate and understand multi-turn extraction, for a particle first incident on the crystal with an angle greater than the critical angle will be multiple scattered by the crystal to a different point in phase space and often will reenter the crystal on a later betatron oscillation with a smaller angle.

Another issue is how to control the bend angle of the crystal to the required

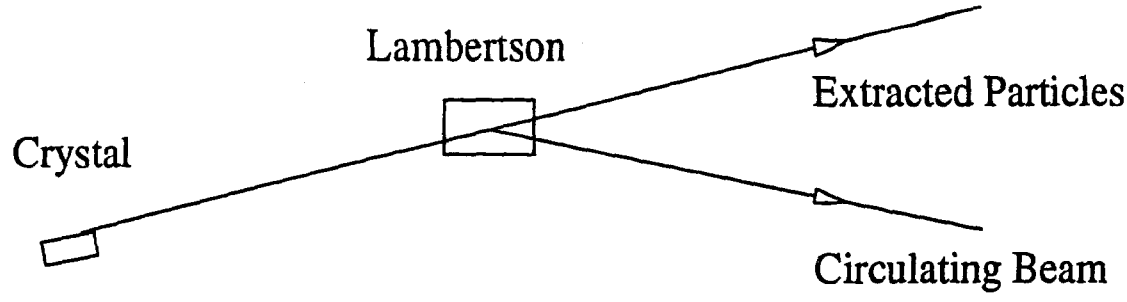

Figure 1. A schematic of the beam line around the Tevatron C0 region; the crystal bends up out of the page. Accompanying magnetic elements besides the crystal and the Lambertson magnet are not shown.

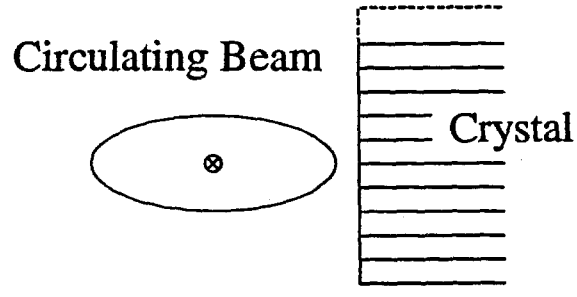

Figure 2. Rear view of the bunch at the bent crystal septum. The crystal is bent upward. The parallel lines on the crystal face indicate the channeling planes. For extraction, the beam or the crystal is moved so they overlap a small amount.

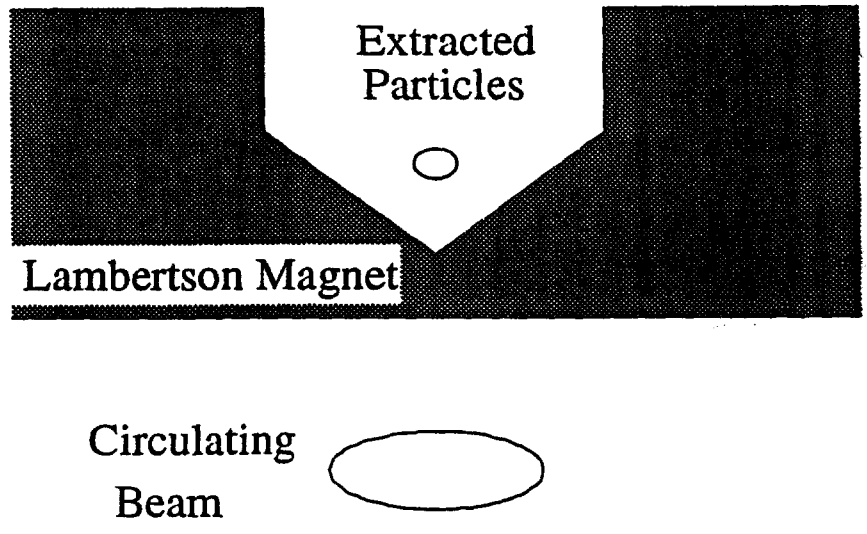

Figure 3. View at the Lambertson where the extracted beam is in the field free region of the magnet, and the main bunch is in the region with magnetic field.

precision of 0.12 mrad, half the acceptance angle of the extraction channel. The sagitta of the 20mm bent part of the 30mm crystal is only 1.6 microns - measurable only by high-precision interferometric methods.

The horizontal edge of the crystal which faces the circulating beam (the "septum") must be aligned very well to the beam angle, but more importantly, must be very flat, in order to minimize the thickness of the region for which an incident proton would go in and out of the crystal and be only partially bent. It is certainly possible to achieve a flatness of 0.5 microns (the wavelength of light), but we would like to do much better, as the average "step size" of the beam will probably be only a couple of microns.

Heating and radiation effects have been investigated and are negligible at the Tevatron.

However, the biggest challenge of this technique is that there is inadequate halo, at either the Tevatron or the SSC, to obtain extracted intensities high enough to be interesting for experiments. Therefore, halo must be generated by perturbations of either the transverse or longitudinal phase space, and in a manner which does not appreciably decrease the luminosity for the collider experiments. Therefore, the usual method of "resonant" extraction in the horizontal plane is not permitted. For that reason, we have been concentrating on techniques to create off-momentum halo in longitudinal phase space, and placing the crystal at a point of high dispersion so that the off-momentum particles are at large x at the crystal. The particular idea is to find ways to excite particles which are already in the tail of the momentum distribution to move quickly to much larger momenta so as to achieve large step sizes, without affecting very much the core of the momentum distribution. The topic is discussed in more detail in the next paper.

4. Preliminary Results

During the current collider run Ia, an unbent crystal with only one degree of freedom (x, controlled a simple in/out drive) has been placed at the location shown in Fig. 1. The purpose is to study whether halo beam scattered by this crystal creates intolerable backgrounds at either of the two collider experiments. Although beam has yet to be incident on the crystal, there is one interesting result from deliberately exciting the momentum spectrum with modulations of the RF voltage. Enough noise in a low-frequency band width (centered on the synchrotron frequency) was added to the RF voltage such that 20 per cent of the beam left the RF bucket within about 5 hours. This beam was eventually scraped by a collimator at A0, at which point CDF detected background at the limit of their tolerance. However, this rate of exciting the momentum spectrum is an order of magnitude larger than that intended in the actual experiment.

5. Results from an SPS Experiment

A group at CERN is currently executing a very similar experiment in the SPS, operating at 120 GeV. This effort is directed towards implementing the idea for a fixed target B-physics experiment in the LHC. Their method of diffusion is

to introduce white noise on a horizontal damper. To date, they report[8] extracting beam with an efficiency of about 0.03 and a beam lifetime of 34 hrs. Further work continues.

6. Acknowledgements

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