RESULTS FROM EXPERIMENTS OF CRYSTAL EXTRACTION OF 900 GEV PROTON BEAMS FROM THE TEVATRON COLLIDER[1]

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ABSTRACT

The extraction of a small flux of primary protons from a collider in a parasitic manner is very attractive for a number of fixed target applications. The key requirements of the extracted beam are small average currents with relatively small temporal variations. At this time a bent crystal is installed in the Tevatron Collider which is designed to channel protons down an instrumented beam abort transfer line. In this paper the results of experiments with this crystal are presented. The impact on the high energy physics collider detectors of the crystal as a collimator and the transverse mechanism necessary to deposit the protons into the crystal for alignment purposes are described

I. OVERVIEW

The E853 experiment at Fermilab [3] is dedicated to studying the feasibility of extracting halo particles from a collider without inducing detrimental losses [4] in the dedicated high energy physics experiments. Since the installation of a bent crystal, studies have been aimed at aligning the crystal with respect to the beam. Extracted particles must negotiate a relatively narrow aperture to enter the C0 abort line in which scintillators, silicon, and fluorescence detectors are placed. In addition, a set of scintillators exist just downstream of the crystal itself.

II. Kick Mode Crystal Alignment

In order to determine the correct angle and position of the crystal with respect to the beam and the narrow extraction channel, beam was sent into the crystal via horizontal kicks from the E17 proton injection kicker. This form of crystal studies is referred to as kick mode [5]. The geometry of the kick mode experiments is sketched in figure 1.

It turns out that the polarity of the kicker is such that the sign of the beam position on the first beam pass of the crystal is radially inward, away from the crystal. Given the horizontal tune of the Tevatron (displayed in figure 2), the beam should impact the crystal on the second turn after the kick. Figure 3 contains the results of a calculation of the phase space position of the kicked bunch at the crystal on successive turns. As a result, observing a loss monitor such as one of the scintillators just downstream of the crystal, nuclear interactions with the crystal should produce a modulated turn-by-turn loss pattern reflecting the position of the crystal at each turn and the scattering of particles on previous turns. Figure 4 contains a plot of the calculated loss pattern generated by a multiparticle computer simulation program.

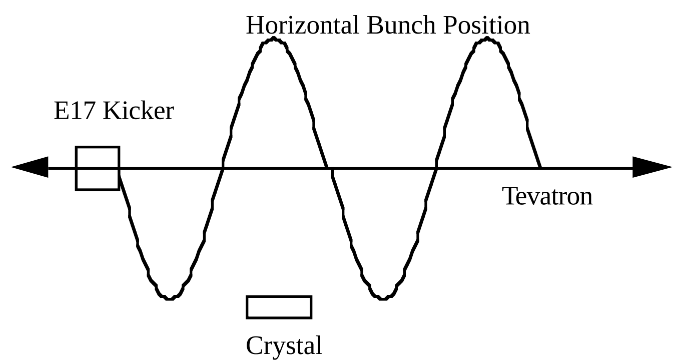

Figure 1: Sketch of the kick mode geometry for crystal extraction tests.

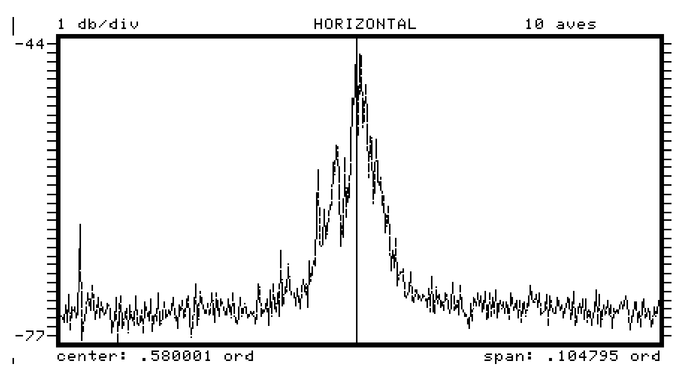

Figure 2: Horizontal betatron tune signal in the Tevatron during kick mode studies. The cursor is sitting at the tune 20.5795 and the full span of the plot is 0.1 units of tune. The vertical scale is 1 dB/div.

Figure 5 contains a close-up of the first few turns of the prediction plotted in figure 4. As expected, on the first turn there is no signal and on the second turn the maximum signal is expected. This prediction should be compared with the measured data presented in figure 6, in which the beam was kicked by approximately 0.5 mm at 900 GeV. Note that the agreement is only qualitative.

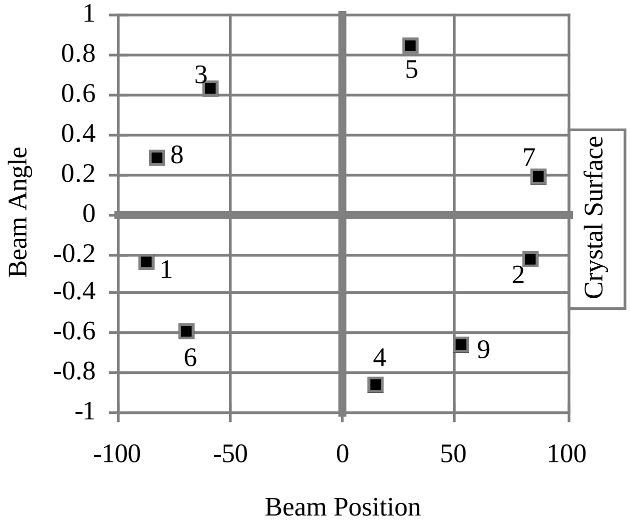

Figure 3: Calculation of the phase space position and angle (arbitrary units) of the beam at the crystal after being horizontally kicked by the E17 kicker magnet.

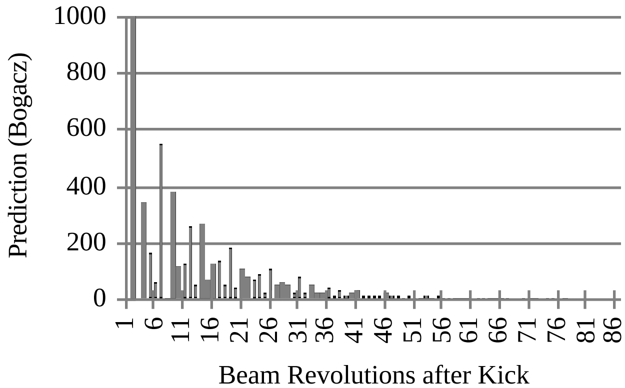

Figure 4: Predicted turn-by-turn losses in a proportional detector just downstream of the crystal.

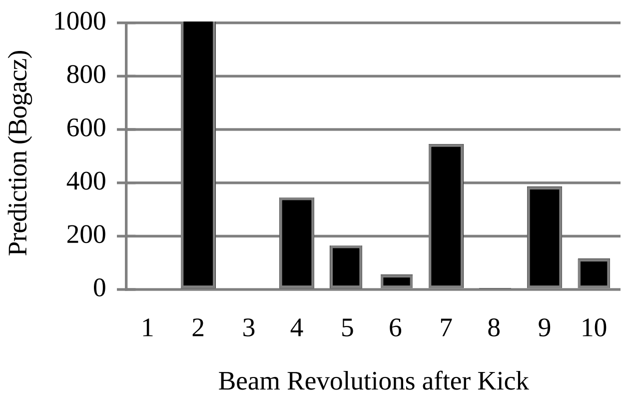

Figure 5: Close-up of the prediction presented in figure 4.

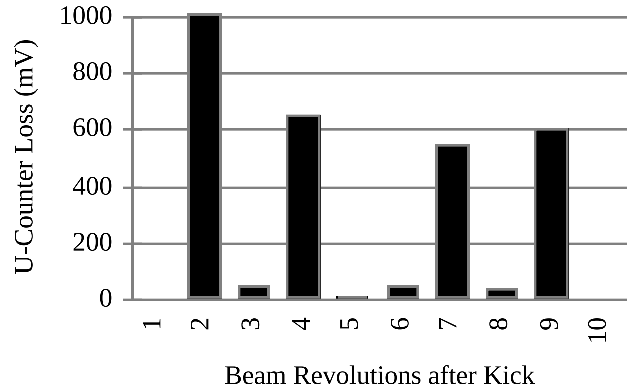

Figure 6: Particle shower amplitude in a scintillator just downstream of the crystal on the first 10 turns of the beam past the crystal after the beam kicker fired.

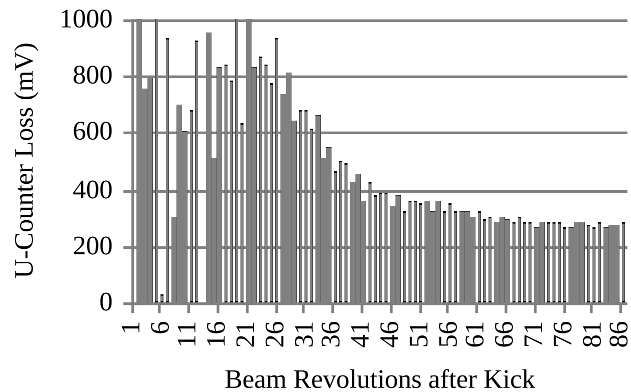

Figure 7: Expanded view of the observed data displayed in figure 6.

Another disagreement between calculation and observation can be seen by comparing figures 4 and 7. The long term evolution of the losses can sometime be completely different, with Tevatron losses just downstream of the crystal persisting for up to a minute. At other times there are no long term losses observed and the measured data trails off in a manner very similar to that calculated.

Attempts to observe channeled particles in the C0 extraction line have not been definitive to date. After a few short Tevatron study periods, in which kick mode scans of vertical crystal angle and position were executed, no clearly identifiable signal enhancement has been observed. On the other hand, a great number of strange and unexpected turn-by-turn loss profiles have been recorded.

For example, in a situation in which the output of a scintillator in the extraction line looks similar to the pattern displayed in figure 4, after about 50-70 turns the loss signal begins to grow again to approximately one third or one quarter of its original amplitude. This may be the effect of channeling particles which have been sufficiently scattered that their angles are sometimes big enough with respect to the closed orbit to correctly enter a misaligned crystal and be channeled out of the Tevatron.

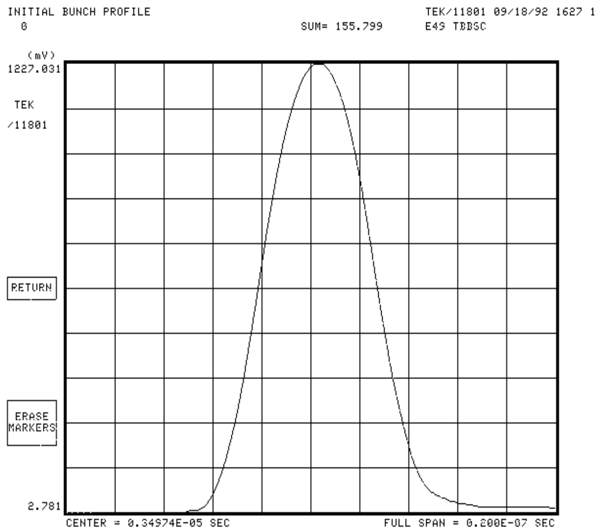

Figure 8: Longitudinal beam distribution as measured by a broadband resistive wall monitor and oscilloscope. The scale of the time axis is 2 nsec/div.

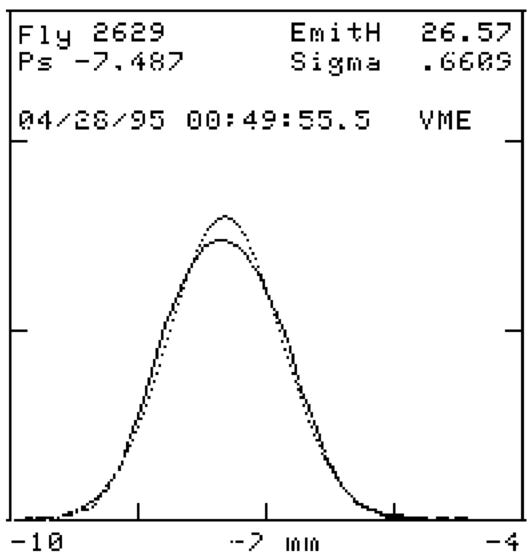

Figure 9: Original horizontal beam size at the E11 flying wire (0.66 mm) and emittance (26.57 π mmmr 95% normalized) before the bunch has been kicked. At this time the vertical beam size at the E11 flying wire is 0.66 mm with an emittance of 32.5 π mmmr.

Repeated attempts to measure any sign of channeled particles have proven fruitless. The present suspicion is that there is an aperture restriction somewhere in the extraction channel. At the same time, considerable effort is being directed toward better simulations. Some future improvements may include more accelerator effects such as Main Ring ramp induced Tevatron beam motion and horizontal-vertical coupling. To verify that the kicker is performing correctly, turn-by-turn beam position data and flying wire profiles of the beam were measured.

Figure 8 shows the longitudinal length of the bunch. Figures 9 and 10 document the amount of emittance growth that is suffered by the beam (vertical size is also measured by not shown) after a large number of kicks.

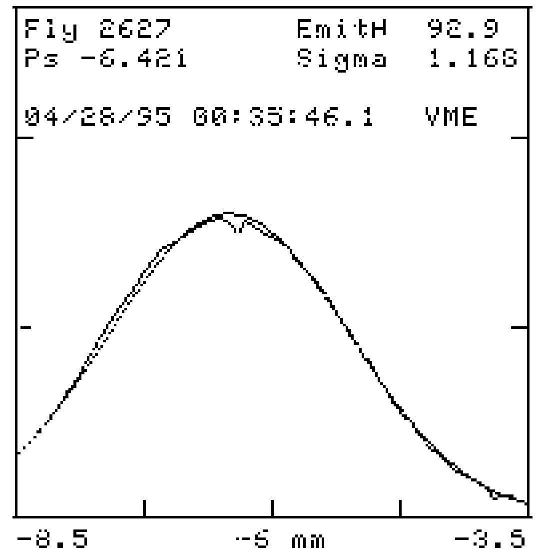

Figure 10: Horizontal beam size at the E11 flying wire (1.17 mm) and emittance (92.9 π mmmr 95% normalized) after many kicks. At this time the vertical beam size at the E11 flying wire is 1.2 mm with an emittance of 109 π mmmr.

III. Future Work

One of the leading problems with the present experimental configuration is the absence of a gated CCD array or camera monitoring the spatial distribution going down the extraction line. It is imperative that instrumentation suitable to accelerator physicists is given priority. In addition, a simulation which explains some of the mysterious patterns in the turn-by-turn data is needed.

IV. REFERENCES

[1] Presented for the E853 Collaboration (Fermilab, U. Virginia, UCLA, Argonne, U. Texas at Austin, U. New Mexico, U. Wisconsin, CEBAF, SUNY at Albany, JINR at Dubna, IHEP at Serpukhov, and PNPI at Gatchina).

[2] Operated by Universities Research Association Inc., under contract with the U.S. Department of Energy.

[3] G. Jackson, "Extraction from the Fermilab Tevatron using Channeling with a Bent Crystal", Proc. 1993 Part. Acc. Conf. (Washington D.C.) 1366.

[4] G. Jackson, "Results from Beam Diffusion and Collimation Measurements in Preparation for Fermilab Tevatron Crystal Extraction", Proc. 1993 Part. Acc. Conf. (Washington D.C.) 402.

[5] S. Weisz and the RD22 Collaboration, "Proton Extraction from the CERN-SPS by a Bent Crystal", Proc. 1993 Part. Acc. Conf. (Washington D.C.) 26.