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ON POSSIBLE USE OF BENT CRYSTAL TO IMPROVE TEVATRON BEAM SCRAPING [*]

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Abstract

A possibility to improve the Tevatron beam halo scraping using a bent channeling crystal instead of a thin scattering primary collimator is studied. To evaluate the efficiency of the system, realistic simulations have been performed using the CATCH and STRUCT Monte Carlo codes. It is shown that the scraping efficiency can be increased and the accelerator-related backgrounds in the CDF and DØ collider detectors can be reduced by about one order of magnitude. Results on scraping efficiency versus thickness of amorphous layer of the crystal, crystal alignment and its length are presented.

1 INTRODUCTION

Bent-crystal technique is well established for extracting high energy beams from accelerators. It was successfully applied at up to 900 GeV[1], and simulations were able to predict the results correctly. Recent experiments at IHEP Protvino[2] have demonstrated that 50-70% of the beam can be extracted using a thin (3-5 mm) Si channeling crystal with bending of 0.5-1.5 mrad. It would be promising to apply this technique for a beam halo scraping at high energy colliders[3, 4]. A bent crystal, serving as a primary element, should bend halo particles onto a secondary collimator. A demonstration experiment of this kind was recently performed at IHEP[2] where a factor of 2 reduction in the accelerator background was obtained with a bent crystal.

2 BEAM LOSS AND BACKGROUNDS

The current approach to the Tevatron Run II collimation system is described in detail in[5]. Below we show how a silicon bent crystal can improve the Tevatron collimation system efficiency. Two cases are compared for a 900 GeV proton beam:

- the Run II collimation system with only one of three primary collimators—(D17h) horizontal—used. It intercepts large-amplitude protons and protons with positive Δp;
- the same collimation scheme, but a silicon bent crystal is used instead of D17h.

In reality, two additional primary collimators (bent crystals) should be used at D17v and D49h locations for vertical amplitude and off-momentum scraping. Therefore, results presented here represent about 30% of total losses in the machine.

The studies[6] have shown that the accelerator related background in the DØ and CDF collider detectors is originated from beam halo loss in the inner triplet region. In addition to the optically small aperture at β_{max} location, the aperture restrictions in this area are the DØ forward detector's Roman pots placed at 8σ and the BØ Roman pots placed at 10σ at the entrance and exit of the beam separators. Beam losses in BØ and DØ depend strongly on the secondary collimator offset with respect to the primary collimators. Each of the Roman pot detectors at DØ consists of four $2{\times}2$ cm^2 plates (two horizontal and two vertical placed on the both sides of the beam). Each of the CDF Roman pots consists of twelve units: three DØ type sets with 12 cm between them, which results in higher total hit rates at CDF[7]. The CDF detectors are made of a silicon wafer, about 400 μm thick, on which a thin 50 μm layer of diamond is deposited. Each DØ detector is a box that includes a scintillation fiber detector with a total length of 37.7 mm along the beam. The vacuum windows are composed of a 50μm stainless steel foil in order to reduce multiple Coulomb scattering.

3 USING BENT CRYSTAL

A silicon (110) crystal bent at an angle of 0.1-0.3 mrad is placed upstream of the D17 secondary collimator instead of the original thin scattering tungsten target[5, 7] in the same position. Crystal channeling is simulated as described in[8]. Particle tracking in the lattice is done with the STRUCT code[9] with updated MARS physics[10]. A non-channeling amorphous layer on the crystal surface due to its irregularity at a micron level is taken into account as a silicon target upstream of the crystal as shown in Fig. 1.

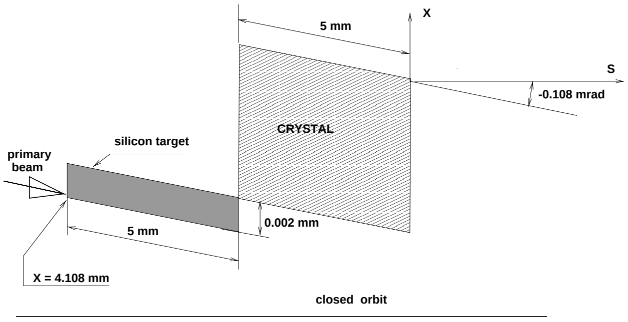

Figure 1: Amorphous layer and crystal layout at D17 used in simulations.

A number of protons passed through the Roman pots upstream of the DØ and CDF main detectors with a 5 mm

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thick tungsten target at D17 as a primary collimator and with a crystal instead is presented in Table 1. A crystal angle with respect to the beam is -0.108 mrad, and its length is 5 mm. In both cases, a nuclear interaction rate in the primary element itself is also shown as a measure of irradiation of the downstream superconducting components at D17. One can see that the use of the crystal can reduce background in the detectors by about one order of magnitude and decrease the machine irradiation by a factor of four.

Table 1: Halo hit rates at the DØ and CDF Roman pots and nuclear interaction rates N in target and crystal (in $10^4 p/s$)

	with target	with crystal		
		amorphous layer thickness		
		10 μm	5 μm	2 μm
DØ	11.5	1.35	1.60	1.15
CDF	43.6	5.40	3.20	3.43
N	270	82.4	70.6	50.3

Extracted and scattered beam densities at the entrance and exit of the crystal with a 5μm amorphous layer is presented in Fig. 2-3. Several groups of particles are clearly seen. They represent protons which come to the crystal on the 8-th, 13-th, 18-th, 20-th, 32-nd, 37-th and 51-st turn after interaction with the amorphous layer.

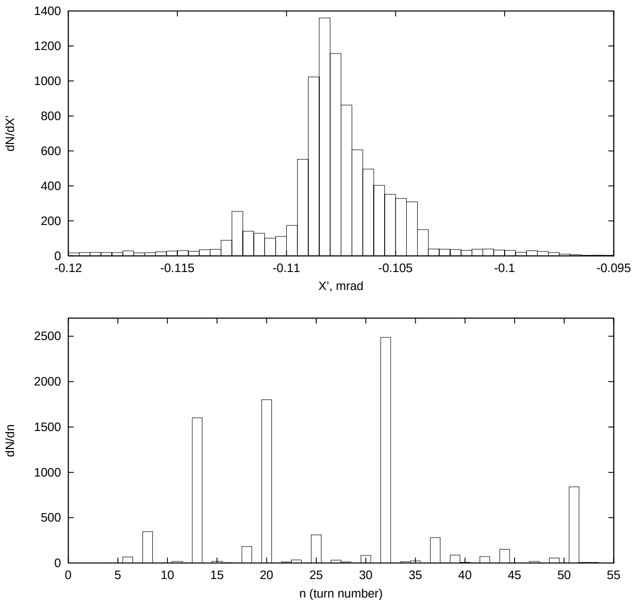

Figure 2: Proton angular distribution on the crystal (top) and distribution of the number of turns for protons to be captured after scattering in the amorphous layer (bottom).

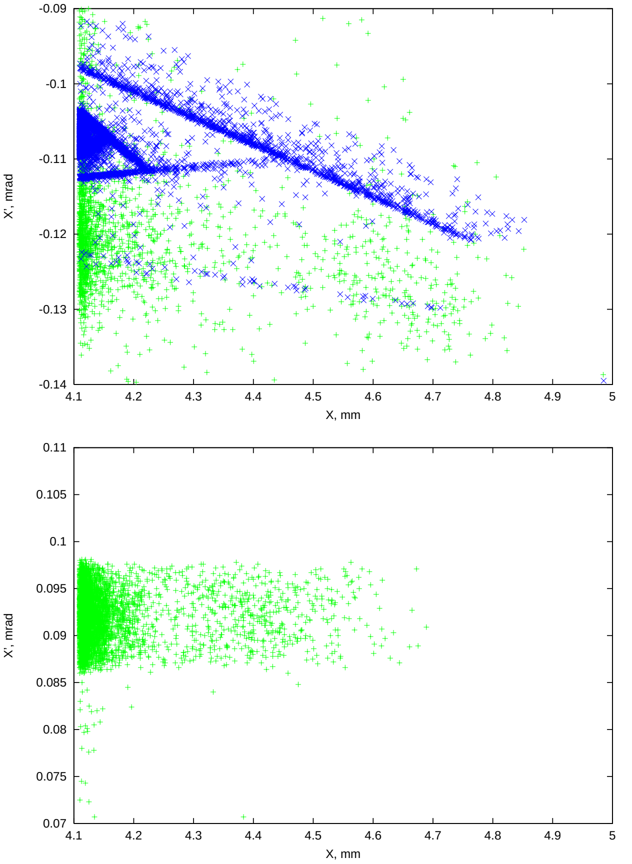

Figure 3: Horizontal phase space on the crystal entrance (top) and exit (bottom). The top plot also shows (gray) uncaptured protons at the crystal exit.

The crystal critical angle is ±5 μrad, therefore the efficiency depends strongly on the crystal alignment. With the alignment of -(104 - 111) μrad the large amplitude protons are captured by the crystal over the next 32 turns after the first scattering. For poorer alignment it takes longer time for the scattered protons to get into the critical region, which increases background in the detectors as shown in Fig. 4 for a 5 mm crystal with a 2μm amorphous layer. Angular distribution of protons after scattering on the amorphous layer depends on the crystal length. Shorter crystal would give smaller particle divergence, which should improve the system efficiency. In reality, a combined effect of scattering, channeling and tracking in the lattice could smear such a simple dependence as shown in Fig. 5 for a crystal with a 2μm amorphous layer. A shorter crystal indeed is better for the CDF Roman pots if its length <5 mm, but for longer

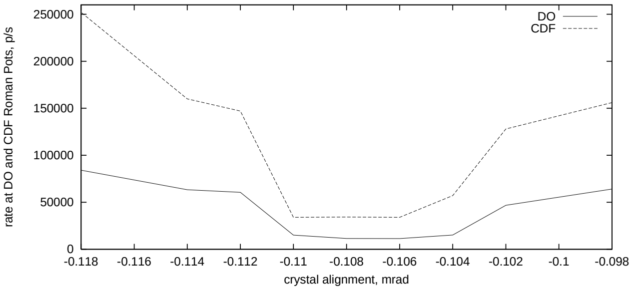

Figure 4: Hit rates on the DØ and CDF Roman pots *versus* crystal alignment.

crystals and for the DØ detectors the results obtained are almost independent of length.

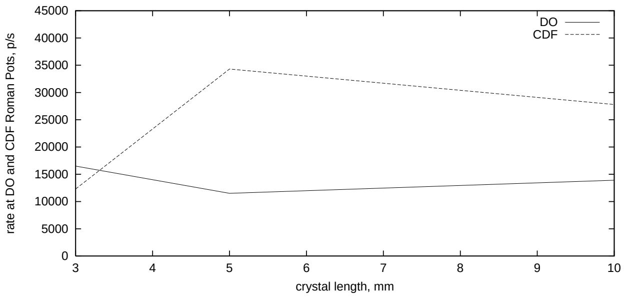

Figure 5: Hit rates on the DØ and CDF Roman pots *versus* crystal length.

Overall beam loss distribution along the Tevatron lattice is shown in Fig. 6 for the two studied cases with a 5 mm thick tungsten target and a 5 mm thick silicon bent crystal as the D17 primary scatterer at 5σ. The secondary collimators are installed at 6σ. Beam loss on the primary element itself is not shown. One sees that not only beam loss is lower at the collider detectors at BØ and DØ, but the entire machine becomes cleaner if the bent crystal is used.

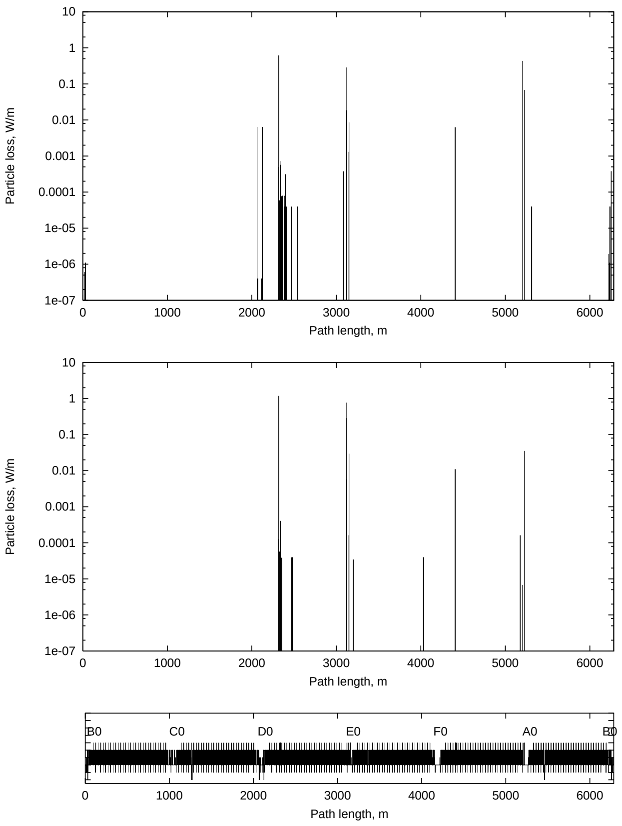

Figure 6: Beam loss distribution in the Tevatron with a 5 mm thick tungsten target (top) and a 5 mm thick silicon bent crystal (bottom) as a primary scatterer at D17.

4 CONCLUSIONS

The studies performed show that a replacement of the amorphous tungsten target as a primary collimator in the Tevatron beam collimation system with a 5 mm thick silicon bent crystal would reduce by about one order of magnitude the accelerator-related backgrounds in the CDF and DØ detectors and decrease beam losses in the supercondcting magnets of the D sector by a factor of four.

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