Crystal Collimation with proton at flat top energy


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Summary

During this MD, performed on November 6th, 2015, bent silicon crystals were tested with proton beams for a possible usage of crystal-assisted collimation. Tests were performed at both injection and flat top energy using horizontal crystal. Proton channeling was observed for the first time at 6.5 TeV.

1 Introduction

Crystal Channeling phenomena could be used to steer halo beam particles at large angles, up to tens of $\mu$rad. Using crystals as primaries could send halo particles in a single absorber, unlike standard collimation, which scatters particles by means of amorphous collimators at few $\mu$rad, hence needs more stages to absorb them. A setup has been studied using only existing secondary collimators as absorbers for the channeled beam [1]. The scope of LHC tests is to demonstrate that channeling can be achieved and that a good collimation cleaning can be produced with a reduced set - ideally with one - secondary collimator. During MD3, the horizontal crystal was tested at flat top energy and channeling was observed for the first time at 6.5 TeV in the LHC. The involved hardware was checked showing a good reproducibility [2].

In this note, the beam setup and machine configuration for the tests is presented. The list of measurements performed is shown, covering results from crystal angular scans and transverse scans of channeled halo. Some initial conclusions are then drawn.

2 Beam Setup

In Fig. 1, the beam current is shown as a function of time for both injection and flat top fills of the crystal MD, which was performed using several pilot bunches at flat top energy with standard optics. Individual bunches were excited with the transverse dumped (ADT),
exciting the beam with white noise as in standard loss maps, to achieve controlled primary
beam losses on crystals and/or collimators. Having several pilots allowed for multiple bunch excitation.

The overall LHC availability during those studies was poor. Measurements were inter-
rupted for several hours after a cryogenics problem just after the end of the first energy ramp. For this reason, we concentrate the flat top measurements on the horizontal crystal.

As for the first MD of August, the measurements involved the following main activities:

1) beam-based alignment of the crystal with respect to the beam orbit and transverse
positioning as primary collimator;

2) angular scan for the determination of the channeling condition;

3) transverse scan of the channeled beam with a secondary collimator;

4) cleaning measurements through loss maps of a reduced collimation system based on a
crystal in channeling position and a reduce set of secondary collimators.

The first step is performed in a similar way as a standard collimator jaw alignment and
is not presented in detail. In the following section, the results of measurements (2), (3) are
presented for both energies. Cleaning measurements (4) were not performed due to the lack
of time. The crystal was typically set at a transverse positions 500 µm and 50 µm closer to
the beam orbit than the primary collimators for injection and flat top, respectively.

3 Measurements

3.1 Preliminary Checks at Injection Energy

The first operation of the MD was to repeat a minimal set of measurements for the horizontal
crystal at injection energy. The reasons for this procedure were to re-establish channeling
positions and to check the angular reproducibility of the goniometer after two months from
the first test in August, an angular scan is shown in Fig. 2. The best channeling orientation
(highest losses reduction at crystal position) was found at 3149 µrad and 3152 µrad in August
and November tests, respectively.
3.2 Crystal Angular Scan

Angular scans are performed by changing the crystal angle while monitoring beam losses immediately downstream of the crystals. The onset of channeling is measurable as a reduction of the local beam losses, as in channeling the nuclear interactions with the crystals are suppressed compared to the losses through an amorphous material [3]. Once the optimum location is identified with a faster scan in the range identified during previous injection energy tests, slower scans are performed to measure in detail the whole range where coherent interactions (channeling, volume reflection [4]) occur. The results of the “slow” angular scan of the horizontal crystal are shown in Fig. 4.

Figure 2: Horizontal crystal angular scan at injection energy. Losses normalized to the beam flux as a function of the goniometer angle.

Figure 3: Horizontal crystal losses during angular scan at flat top. Losses at crystal position are shown as a function of time.
These measurements were recorded with the collimator settings listed in Table 1. Three different pilots were used to complete the angular scan. The procedure to use different pilot bunches was required because the ADT settings that gave good loss rates killed the bunch faster than the goniometer angular speed (0.2 µrad/s). Losses recorded at 1 Hz, normalized to the bunch by bunch flux, and to the steady losses measurement with crystals in amorphous orientation, are used to produce this plot. The beam flux is calculated fitting with a 3rd order polynomial function the slope in the beam current. Raw data before normalization are shown in Fig. 3.

![Horizontal Crystal Angular Scan @ 6.5 TeV](image)

Figure 4: Horizontal crystal angular scan at top energy. Losses normalized to the beam flux as a function of the goniometer angle.

The results presented represent the first convincing evidence of crystal channeling of LHC flat top energy beams. It is found that in channeling, losses are reduced by factors 24 for horizontal crystal.

### 3.3 Absorber Linear Scan

In order to characterize the properties of the channeled beam, one can make a transverse scan with secondary collimators located downstream of the crystal when it is oriented at its optimum angle for channeling. This was done with the secondary collimators TCSG.B4L7.B1. During these measurements, all the collimators located upstream of the secondary collimator used for the scan were opened to 8.0 σ. Inward and/or outward scans are performed by spanning the range in transverse amplitude between the primary beam halo (closest position) and apertures where the collimator jaw does not intercept the channeled beam anymore. The measurement is given in Fig. 5, where the losses recorded downstream of the secondary collimator used for the scan are given as a function of the collimator jaw position. Measurement results are in agreement with results from the previous MD [2].
Collimator Standard Horizontal scan

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Table 1: IR7 Collimators positions (in σ units) during flat top standard operation and horizontal crystal scan operation.

Figure 5: Horizontal crystal channeled beam scraping. Losses normalized to the beam intensity as a function of the absorber linear position.
4 Conclusions

The setup for crystal collimation in IR7 has successfully tested again for the first time at 6.5 TeV demonstrating first channeling of proton beams at this energy. Evidence of channeling comes from the monitoring of local losses downstream of the crystals, which are suppressed in channeling compared to amorphous orientations, and from scans of secondary collimators further downstream, which indicate the presence of a well-defined channeled halo separated from the beam core. Reproducibility of injection energy results obtained in the previous MD demonstrates the reliability of the equipment. Unfortunately, because of a lack of time, we could not complete the planned program at top energy. In particular, it was not possible to measure collimation cleaning of the crystal-based system nor characterize the vertical QM crystal.

5 Acknowledgements

We would like to thank the OP crew for their assistance during the MD and the LHC Machine Developments Coordinators.

References