LAYOUTS FOR CRYSTAL COLLIMATION TESTS AT THE LHC*

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Abstract

Various studies have been carried out in the past years regarding crystal collimation for the LHC. A new extensive campaign of simulations was performed to determine optimum layouts for beam tests at the LHC. The layouts are determined based on semi-analytical models for the dynamics of channeled particles. Detailed SixTrack tracking with all collimators of the ring are then used to validate the different options. An overview of the ongoing studies is given. Comparative studies between the present collimation system, the crystal collimation system, and different crystal collimation layout are presented.

INTRODUCTION

The possibility to install crystals in the LHC during the long shutdown (LS1) for crystal collimation studies is being considered. The crystal experiment would be installed in the betatronic cleaning insertion (IR7), with minimum changes of the present optics and collimation layout, that are not optimized for this type of experiment. It is therefore crucial to determine optimum locations that allow one to achieve the main goal of the experiment in the various configurations (injection, ramp, squeeze, etc): demonstrate an efficient crystal collimation based on a bent crystal as primary restriction of aperture and a minimum number of "absorbers" to intercept the channeled beam (ideally one only). The layout optimization must take into account other important constraints like space and infrastructure (control cabling, supports, etc.) availability.

Different scenarios have been investigated: crystals in the horizontal and vertical planes, 7 TeV beam with nominal collision optics (β*=55 cm), either full collimation chain downstream the crystal in place or only one secondary collimator inserted to absorb the channeled and extracted beam.

This paper summarizes the layout studies and describes detailed loss maps performed for candidate locations.

SEMI-ANALYTICAL MODELS

Using particle accelerator physics theory it is easy to demonstrate that, ideally, the best basic layout could consist of a crystal at a location with zero dispersion and divergence, and with an absorber placed at $\frac{\pi}{2}$ phase advance. More details and experimetal evidence are reported in [1].

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This condition is not met by the present IR7 layout [2]. Changes of optics are in principle possible, but the overhead for beam tests will become too important if new optics were to be commissioned. The baseline is therefore to conceive optimum layouts for the nominal IR7 optics. Other main constraints to be taken into account are: to maximize the number of secondary collimators available downstream the crystal to ensure a sufficient number of devices that can intercept the channeled beam with the present layout, and the absorption of channeled and extracted halo sufficiently upstream of cold magnets. Secondary stage collimators (TCSG) made of Carbon are considered as condidate absorbers for low intensity studies.

A first definition of optimum layouts that fulfil the above requirements is done by considering the trajectory of channeled particles (x_s) for ideal crystals. It can be done using the matrix transportation formalism:

$$x_s = \sqrt{\frac{\beta_s}{\beta_{Cr}}}\cos(\Delta\phi)x_{Cr} + \Theta\sqrt{\beta_s\beta_{Cr}}\sin(\Delta\phi) \qquad (1)$$

where the subscripts s and Cr indicate the optics parameters (β) and the particle displacement (x) at any s of the ring and at the crystal location, respectively. $\Delta\phi$ is the phase advance between those two points of the ring, and Θ is the kick experienced at the crystal by the particle.

In order to perform efficient systematic studies, a dedicated script has been written, and detailed parametric studies have been done. They consist of the calculation of the trajectory made by the extracted halo for every available

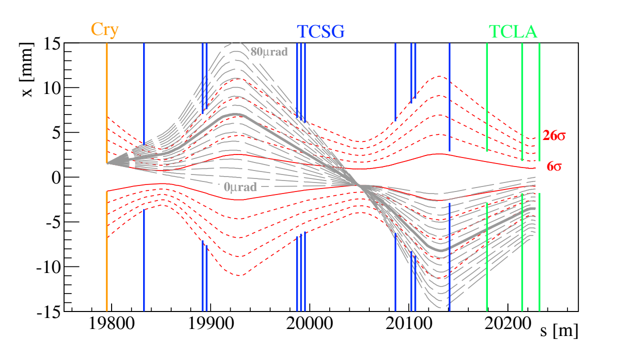

Figure 1: From 6σ to 26σ beam envelope with steps of 5σ (red lines), trajectory of particle experienced a kick from 0μrad to 80μrad with steps of 5μrad (gray lines), versus longitudinal position in IR7. Orange line: crystal aperture, blue lines: projection on the plane of interest of the secondary aperture, green lines: projection on the plane of interest of the absorbers aperture.

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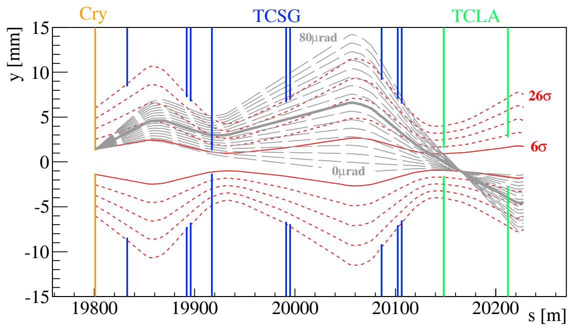

Figure 2: Same notation as in Fig. 1, but for the vertical plane.

Table 1: IR7 collimation chain settings for cases of crystal in the horizontal and vertical planes. Reported also the s-position for the proposed crystals locations.

Coll. Name	**s [m]**	**Orient.**	**Setting [σ] Hor. plane**	**Setting [σ] Ver. plane**
CRY.TCP.H	19795.18	Hor.	6	99
CRY.TCP.V	19800.78	Ver.	99	6
CRY.TCSG.H	19919.24	Hor.	6	99
CRY.TCSG.V	19845.30	Ver.	99	6
TCP.*	-	H/V/S	99	99
TCSG.*	-	Skew	25	25
TCSG.D4L7	-	Ver.	25	7
TCSG.6R7	-	Hor.	7	25
TCLA.*	-	H/V	10	10

layout for crystals installation, and then it is checked which one best fits all the considerations mentioned above (taking into account also the trajectory of the scattered particles). Two suitable positions have been found for both horizontal and vertical planes, which are either where are presently placed the primary stage collimators (TCP), or in the middle of the TCSG.

Examples of the output of these studies are shown in Fig. 1 and 2, for the horizontal and vertical plane respectively, and crystals placed at the TCP location.

The proposed layouts allow to achieve a crystal-based collimation with insertion of one TCSG only.

The settings considered are given in Table 1 (including the absorbers TCLA). These settings are the same used in the SixTrack simulations reported later, regarding the case of secondary collimators chain in the IR7 open. The IR7 settings used for simulations of standard collimation are: 6σ for the TCP, 7σ for the TCSG, 10σ for the TCLA [5].

HALO TRACKING WITH CRYSTALS

Simulations Setup

The semi-analytical models of previous section provide an efficient way to determine optimized layouts, but cannot provide exhaustive conclusions of collimation cleaning. This requires detailed simulations of loss maps around the ring to identify critical loss locations taking into account the interaction of the proton beam with crystals and other collimators. These simulations have been performed using the SixTrack code, in which a routine has been implemented to model the different interactions type in a bent crystal [3]. For this study, the simulations have been done for a perfect machine, i.e. without optics and orbit errors, collimator setup errors, etc. Results achieved in the past have been reproduced, and further checks on the implementation of the physics processes in the crystal routine are ongoing.

Particular attention has been paid to the generation of the tracked halo, which determines the impact parameter and the angular spread of the particles at the first hit on the crystal and hence the value of the single-pass channeling efficiency. Parametric studies have been performed, changing the amplitude and spread of the generated halo. It is then taken as halo generation the one which leads to reasonable computing time needed to run the simulations, and at the same time gives a single-pass channeling efficiency comparable with the experimental data provided by the beam tests performed on the SPS extraction line [4]. The average impact parameter of the simulated impacting halo is $\sim 5\mu$m.

Loss Maps

The final goal of these studies is the estimation of the losses generated along the whole LHC ring by each layout. Comparative studies have been performed between the standard Collimation system and each suitable configuration for the crystal-assisted collimation, in the horizontal and vertical planes separately. Simulations are made with a statistics of $\sim 10^7$ protons intercepted by the collimation system, which allow sufficient statistics for loss estimation of $\sim < 10^{-5}$. Particular attention has been paid to the far losses, and to the losses in the IR7 Dispersion Suppressor (DS), for the reasons reported and explained in [1].

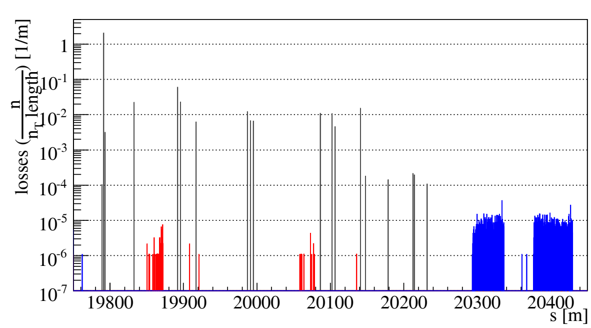

Figure 3: Local cleaning inefficiency in the IR7, in case of standard collimation. Losses on: collimators (grey bars), warm magnets (red bars), superconducting magnets in the DS (blue bars).

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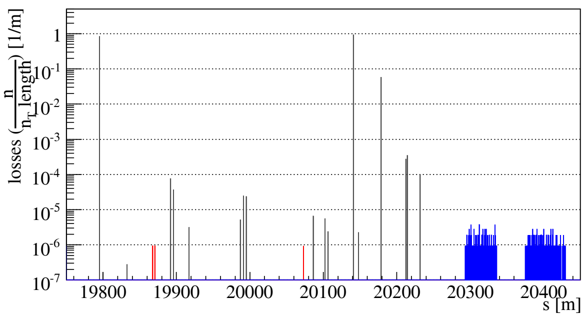

Figure 4: Local cleaning inefficiency in the IR7, in case of crystal at the TCP in channeling orientation. And same notation as in Fig. 3.

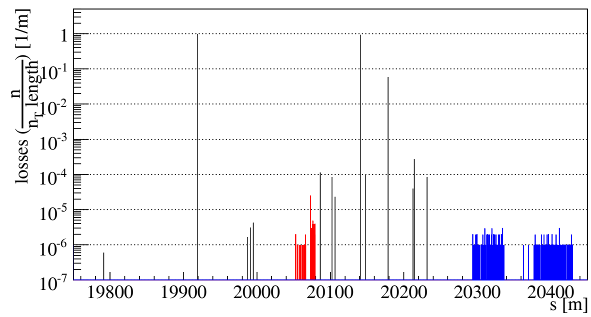

Figure 6: Local cleaning inefficiency in the IR7, in case of crystal at the TCSG in channeling orientation. And same notation as in Fig. 3.

Parametric studies on the aperture of the secondary chain are ongoing for the layouts with crystals.

The reference loss map for standard collimation with nominal settings is given in Fig. 3. It is shown only the IR7 region since the DS is the limiting location of the whole LHC, as reported in [6]. The losses generated by two different layouts for the horizontal plane are shown in Figs. 4, 5, and 6; in case of a crystal at the TCP in channeling, crystal at the TCP in amorphous, and crystal at the TCSG in channeling orientation, respectively. Also for these cases it is reported only the IR7, since no dangerous spikes are observed in the rest of the ring loss.

Similar results have been found for the four suited positions of the crystals, in the two planes. Moreover, at the restart after LS1 relaxed settings will be used for the standard collimation [5], which means that the possible gain from crystal cleaning would be more apparent.

CONCLUSIONS

Possible layouts for a crystal collimation experiment at the LHC were presented. The results are based on a semi-analytical approach to identify interesting layout options.

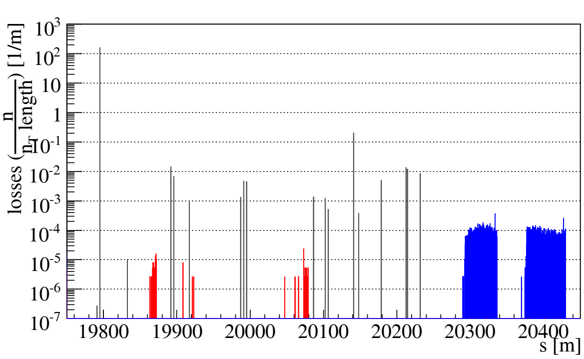

Figure 5: Local cleaning inefficiency in the IR7, in case of crystal at the TCP in amorphous orientation. And same notation as in Fig. 3.

Then, detailed tracking simulations of collimation cleaning have been performed. Taking into account the current status of the crystal routines used, the comparative studies reported showed that the level of losses in the DS are reduced using a crystal-assisted collimation with respect to a standard collimation system. This opens the possibility to test with low intensities the principle of crystal-based collimation at the LHC. The deployment of this scheme for unsafe beam intensities is not yet discussed, but will not be in the scope of the first beam tests. The results presented here are being used for a detailed definition of IR7 layouts that are foreseen for implementation in the LHC long shutdown 1 (LS1). The final decision will take into account other layout constraints, such as the doses to personnel for the different options, that are under investigation.

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