UPGRADE STUDIES FOR THE LHC COLLIMATORS

A. Rossi*, D. Wollmann, R. Assmann, Geneva, Switzerland

Abstract

The Phase-I LHC Collimation System has to be upgraded to work at high intensity and energy. Theoretical and engineering studies are focusing on different regions of the machine. The IR3 combined momentum and betatron cleaning, initially approved for installation, has presently been kept as fallback solution in case radiation to equipment limits LHC performance. The installation of collimators in the dispersion suppressor section DS3 has been delayed. In this paper we present predictions with matched optics and the effect of machine imperfections on the collimation performance with IR3 combined cleaning, with and without DS3 collimators.

INTRODUCTION

Combined momentum and betatron cleaning in the LHC insertion region 3 (IR3) was proposed [1] as an alternative to the present collimation system if the mitigation measures put in place to reduce collimation correlated radiation to electronics in IR7 are not sufficient at nominal beam intensity (1.15×10^{11} protons per bunch and 2808 bunches) and energy (7TeV), therefore limiting LHC performance. Furthermore, according to quench levels estimated in [2] (7.6×10^{6} protons/s/m), the present LHC collimation system [3] would need upgrading to screen cold dispersion suppressor (DS) magnets from losses that would otherwise lead to a quench. On the other hand, in view of recent results at 3.5TeV [4], which seem to indicate that the quench level and/or the distribution of the losses along the DS magnets are larger, and of the fact that LHC beam lifetime has been at worst 1h [5] (against 0.2h assumed so far), the installation of DS collimators has been postponed. This will give time to verify if it is really necessary and to find a better solution (not displacing about 20 magnets and 2 distribution feed boxes for arc DFBA).

Studies of combined cleaning were presented in [6]. In this paper the impact of machine alignment imperfections is analysed and discussed.

SYSTEM LAYOUT

IR3 Insertion Region

A schematic of the layout of IR3 combined cleaning for beam 1 (symmetric for beam 2 line) is shown in Figure 1.

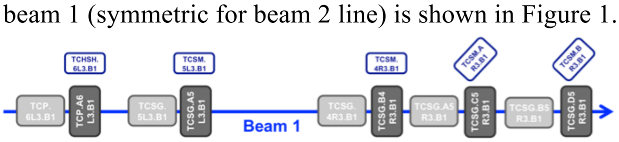

Figure 1: Layout of primary and secondary collimators for IR3 combined cleaning.

* adriana.rossi@cern.ch

The additional (dark grey in the picture) vertical primary (TCP) and secondary (TCS) collimators necessary to make IR3 collimation suitable for both betatron and momentum cleaning (see also Table 1 and 2), will be positioned in place of Phase-II collimators [7] place holders (blue in the picture), already foreseen and equipped in the LHC layout. The tungsten collimator absorbers (TCLA) will be kept as they are.

DS3 Dispersion Suppressor Region

Tungsten collimators could be installed in the dispersion suppressor region (see Figure 2), to intercept off momentum particles generated by Single Diffractive (SD) scattering at collimators. Since these collimators would be installed in a section at cryogenic temperature (displacing some magnets and filling the space of a "missing dipole" cryostat), they have been called TCRYO. The actual operating temperature of the collimators may be room temperature (presently under study [8]) or cryogenic temperature.

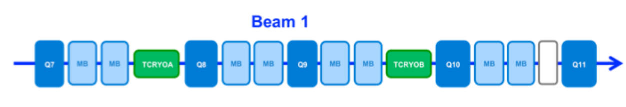

Figure 2: Layout of DS3 region with collimators.

Table 1: List of collimators in IR3, Beam 1 and Beam 2. The angle is specified with respect to the ring plane.

Equipment IR3 beam 1	Equipment IR3 beam 2	Angle and Material
TCP.6L3.B1	TCP.6R3.B2	hor, CFC
TCP.A6L3.B1	TCP.A6R3.B2	ver, Carbon
TCSG.5L3.B1	TCSG.5R3.B2	hor, CFC
TCSG.A5L3.B1	TCSG.A5R3.B2	ver, Carbon
TCSG.4R3.B1	TCSG.4L3.B2	hor, CFC
TCSG.B4R3.B1	TCSG.B4L3.B2	ver, Carbon
TCSG.A5R3.B1	TCSG.A5L3.B2	170°, CFC
TCSG.C5R3.B1	TCSG.C5L3.B2	ver, Carbon
TCSG.B5R3.B1	TCSG.B5L3.B2	113° and 11°, CFC
TCSG.D5R3.B1	TCSG.D5L3.B2	ver, Carbon
TCLA.A5R3.B1	TCLA.A5L3.B2	ver, W
TCLA.B5R3.B1	TCLA.B5L3.B2	hor, W
TCLA.6R3.B1	TCLA.6L3.B2	hor, W
TCLA.7R3.B1	TCLA.7L3.B2	hor, W
TCRYO.AR3.B1	TCRYO.AL3.B2	hor, W
TCRYO.BR3.B1	TCRYO.BL3.B2	hor, W

SIMULATION PARAMETERS

The IR3 combined cleaning has been studied at 7TeV, with a "sheet beam halo", i.e. protons directly impacting either on the horizontal or on the vertical primary collimator in IR3, at a fixed transverse offset (0.7 um) from the jaw edge and having Gaussian distribution in the other direction, with RMS determined by the beam size at the jaw location. The collimator settings are listed in Table 2.

Table 2: Collimator Settings (in nominal beam sigma) for Combined Cleaning

LHC sector	Collimator type	Half gap (nominal beam sigma)
IR3 (momentum and betatron cleaning)	TCP	6
	TCSG	7
	TCLA	10
IR7	TCP	Open
	TCSG	Open
	TCLA	Open
IR6 (dump)	TCDQ	8
	TCSG	7.5
IR1, 2, 5, 8 (experimental insertion regions)	TCT (1, 2, 5, 8)	8.3
	TCL (1, 5)	10
DS3	TCRYO	Open or 15

RESULTS

Perfect Machine

Results of IR3 combined cleaning without TCRYO collimators, for a perfect machine, are shown in Figure 4 and 5 for the vertical beam halo. The results for the horizontal beam halo (not shown here) are better, as to be expected, both for the losses in the DS3 region and onto the tertiary (TCT) collimators in the experimental regions. The red line indicates the quench limit, equivalent in terms of local inefficiency, corresponding to 7.6x10^6 protons/s/m, if losses are produced by a nominal proton beam of 0.2h lifetime. The blue line corresponds to the beam dump threshold provided by beam loss monitors (BLMs).

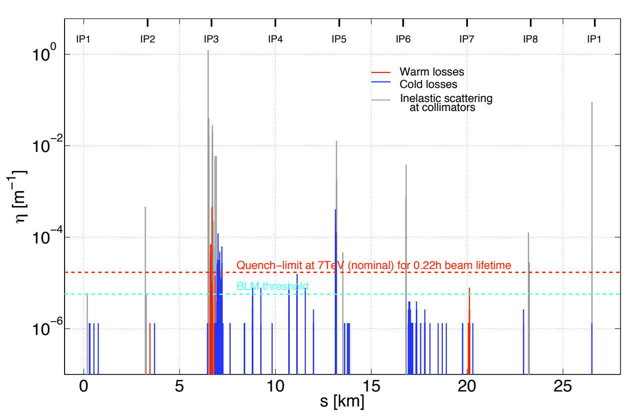

Figure 4: Collimation inefficiency in the vertical plane with IR3 combined cleaning, without DS collimators, with 7TeV proton beam, and a perfect machine.

The cleaning inefficiency is about a factor of 5 to 10 worse than with betatron cleaning in IR7 [9]. In particular we have higher contribution into the DS3 region from SD scattering and higher leakage into the experimental regions.

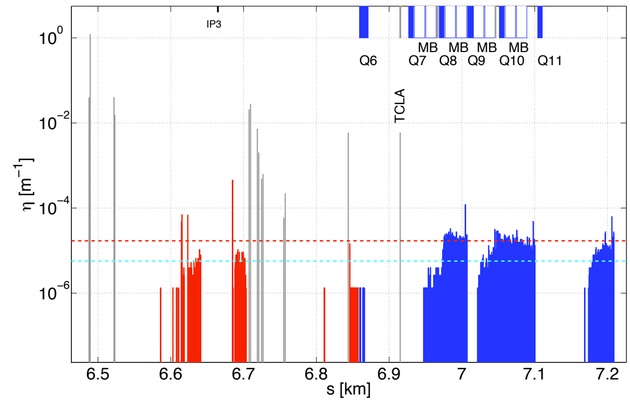

Figure 5: Zoom in the IR3 and DS3 regions. Q6 to Q10 are quadropole magnets, MB are bending magnets.

If we now introduce tungsten DS collimators set at 15 nominal beam sigma (half gap opening), we can suppress losses onto the DS magnets and reduce losses all around the ring, as shown in Figure 6 and 7, again for the perfect LHC machine, with vertical halo simulations.

Leakage to the TCT in the experimental regions, not related to SD scattering at collimators, remains higher than in the standard cleaning configuration.

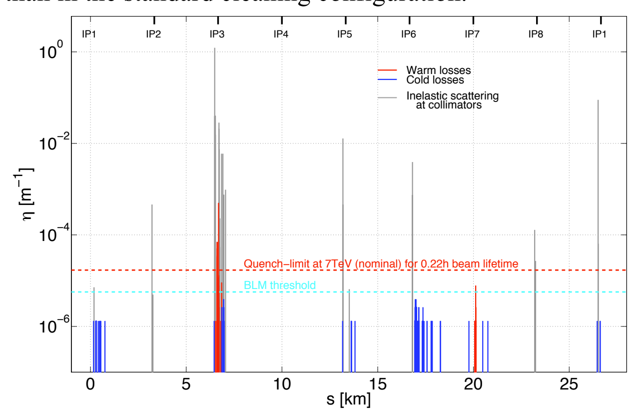

Figure 6: Results of collimation inefficiency in the vertical plane with IR3 combined cleaning, with DS collimators, at 7TeV.

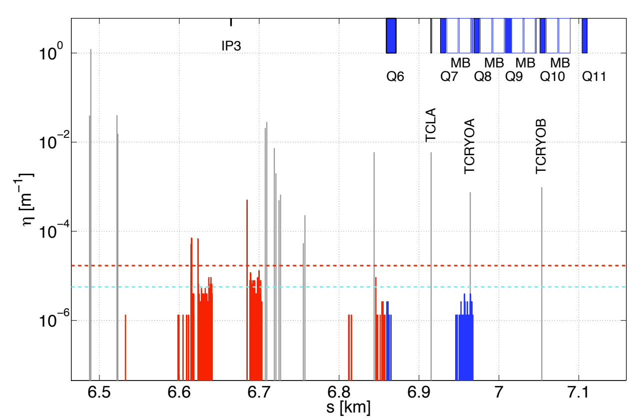

Figure 7: Collimation inefficiency in the vertical plane with DS collimators, at 7TeV. Zoom in the IR3 and DS3 regions.

Machine with Alignment Imperfections

The impact of machine imperfections, such as jaw flatness errors, collimator setup errors, machine alignment errors and orbit errors, was studied in [10]. Machine alignment errors, simulated as aperture errors at specific equipment, assigned with random distributions within the value measured around the machine [11] (see Table 3), worsen the performance by a factor of about 10, and have by far the highest impact.

Table 3: Alignment Errors Applied Randomly (with 1.5 sigma cut), as Extracted from Measurements [10,11]

Element type	Description	RMSx (mm)	RMSy (mm)
MB.	Arc dipole magnets.	2.4	1.56
MQ.	Arc quadrupole magnets	2.0	1.2
MQX	Inner triplets quadrupole magnets	1.0	1.0
MQWA	Twin aperture warm quadrupole magnets	2.0	1.2
MQWB	Twin aperture warm quadrupole magnets	2.0	1.2
MBW.	Twin aperture warm dipole magnets	1.5	1.5
BPM	Beam Position Monitors	0.5	0.5

The same study was reproduced here for the IR3 combined cleaning scheme, with and without DS collimators. Figures 8 and 9 show some typical results of cleaning inefficiency with and without DS collimators respectively. The cases shown relate to the vertical halo. As it can be seen, the presence of DS collimators reduces dramatically the impact of machine alignment imperfections by making the system more robust to errors.

CONCLUSIONS

The IR3 combined cleaning has been studied at 7TeV, with and without collimators in the Dispersion Suppressor region just downstream, for the perfect machine and with alignment imperfections.

This collimation scheme, without DS collimators, could in principle be used as fallback solution in case collimator induced radiation to electronics, at high intensity, limits LHC performance, and as long as the quench level for the magnets along the ring or the loss distribution along the magnets are at least a factor of 10 higher than what was forecasted in [2]. This assumption seems to be supported by recent experimental data [4], but is yet to be confirmed.

Introducing DS collimators makes the system much more robust, suppressing losses in the DS regions and limiting the effect of machine alignment imperfections.

The consequences of higher losses in the experimental regions have yet to be evaluated.

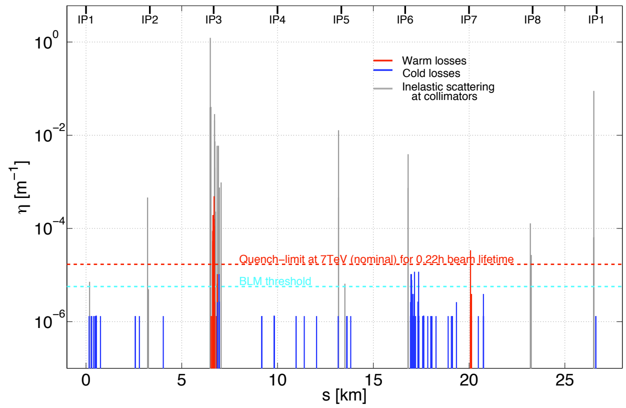

Figure 8: Impact of machine alignment imperfections with DS collimators.

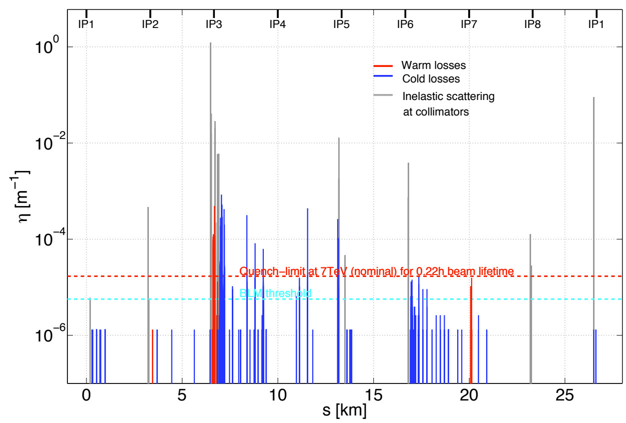

Figure 9: Impact of machine alignment imperfections without DS collimators.

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