THE FINAL COLLIMATION SYSTEM FOR THE LHC

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Abstract

The LHC collimation system has been re-designed over in order to address the unprecedented challenges that are faced with the 360 MJ beams at 7 TeV. The layout of the LHC has now been frozen and a final approach for collimation and cleaning has been adopted. In total 132 pure collimator locations have been reserved in the two LHC rings and can be installed in a phased approach. Up to 88 collimators of five different types will be available for initial beam operation. The system has been fully optimized for avoiding beam-induced quenches of super-conducting magnets and for sufficient survival of beam-line components against radioactive dose. The phased approach for LHC collimation is described, the various collimators and their functionalities are explained, and the expected system performance is summarized.

INTRODUCTION

Nominal luminosity of the LHC requires the storage and collision of 7 TeV beams with each 360 MJ of stored energy [1,2]. It is shown in Fig. 1 that this is about 200 times more than handled in present accelerators. The energy density at the LHC collimators reaches 1 GJ/mm^2.

The LHC must handle unavoidable beam intensity losses. Allowing for a peak loss of 1% of the beam within 10 s, a peak power load of 500 kW must be handled at 7 TeV [1]. At the same time no super-conducting (SC) magnet may be exposed to an energy deposition of more than 8.5 W/m, otherwise it would quench. The LHC collimation system is designed to intercept beam losses and to absorb them in the dedicated cleaning insertions in IR3 and IR7 [2]. Only a small fraction of lost protons (less than 10^{-3}) is allowed to escape the cleaning insertions. The cleaning performance is described more precisely by a local inefficiency η_c which is the ratio of number N_i of protons lost at any location of the ring in a given bin of length L_i over the total number N_{tot} of protons lost:

$$\eta_c = \frac{N_i}{N_{tot} \cdot L_i} \quad (1)$$

The required local cleaning inefficiency at 7 TeV is about 2×10^{-5} m^{-1} for nominal intensity of 3×10^{14} p per beam. This value allows an indicative comparison (the precise quench limit in the LHC depends on the magnet type and the geometry and time structure of losses).

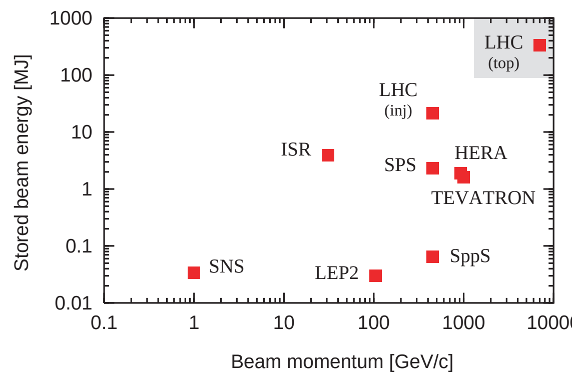

Figure 1: Stored beam energy versus beam momentum for various past, present and future high power accelerators.

COLLIMATION DESIGN

The LHC collimation system has been re-designed [2] with the following major goals:

1. **Robustness of collimators** [3, 4] against the specified regular beam losses (500 kW over 10 s) [1] and accident scenarios (2 MJ shock impact in 200 ns) [5].
2. **Excellent cleaning inefficiency** (2×10^{-5} m^{-1}) [2].
3. **Minimized impedance** with collimation gaps of down to 2.5 mm and a total installed collimator jaw length of about 48 m per beam [6, 7].
4. Adequate **tolerances** for mechanical parts (e.g. jaw flatness) and actuation (e.g. precise motors) for avoiding loss of efficiency due to imperfections [3].
5. **Integration** of the collimator with the existing machine infrastructure, including **radiation optimization** for fast handling of radioactive collimators [8].

The collimation layout is by now frozen for the LHC. It implements a phased approach. For the two beams there are in total 152 locations allocated to LHC collimators and absorbers. 14 of these locations are for transfer line collimators. The first phase of LHC collimation will include 88 ring collimators with a total beam intensity limited to less than 40% of the nominal intensity. A further 34 ring locations are equipped and ready for an upgrade with advanced collimators around the year 2010. Finally, 16 locations are reserved for ultimate efficiency, however, are not equipped with any infrastructure.

The collimation layout during the initial phase of LHC collimation is summarized in Fig. 2. Several families of collimators have been integrated for 3-4 stage cleaning and absorption.

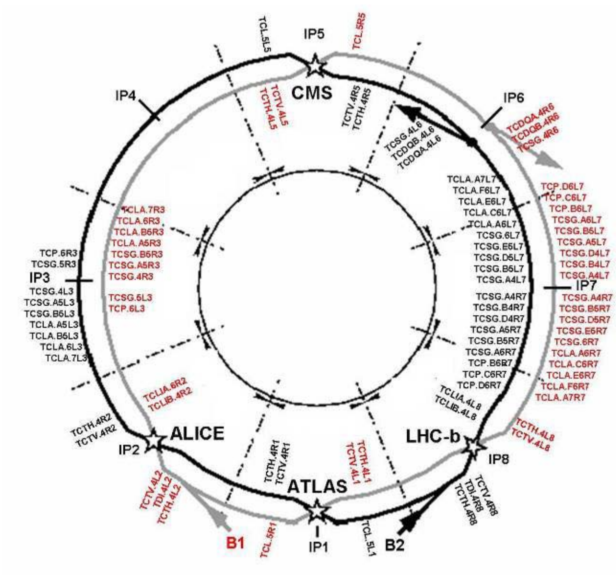

Figure 2: Layout for LHC collimation during phase 1. Red labels are beam 1 collimators; black labels beam 2).

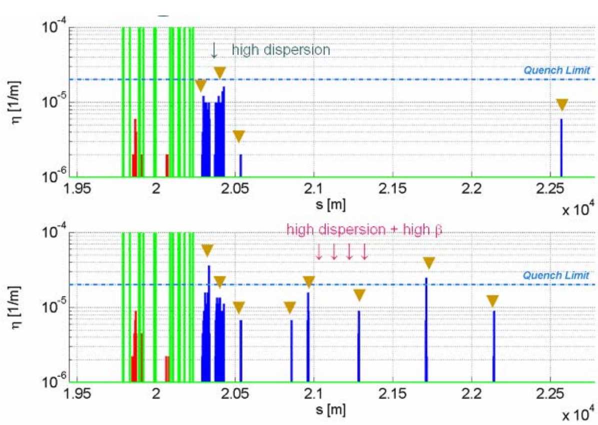

Figure 3: Proton loss pattern for 7 TeV beam 1 betatron collimation, for zero orbit (top) and a worst phase 4 mm static orbit (bottom). Blue bars indicate losses in SC elements, red in warm elements and green in collimators.

Here we shortly describe the major LHC collimators:

1. **Primary collimators** (TCP) with robust CFC jaws [3, 4] for interception of primary beam halo.
2. **Secondary collimators** (TCSG) with robust CFC jaws [3, 4] for interception of secondary beam halo.
3. Tungsten based **absorbers** (TCLA) at the end of the cleaning insertions for protecting the SC arcs.
4. Tungsten based **absorbers** (TCT) for protection and cleaning at the triplets in the experimental insertions.

Several other collimators play an important role for local protection against injection and dump problems [5]. Upgrade collimators are not included in Fig. 2.

PERFORMANCE

The required settings of collimators and absorbers were worked out in detail and the multi-turn performance of the collimation system was studied in detail [7].

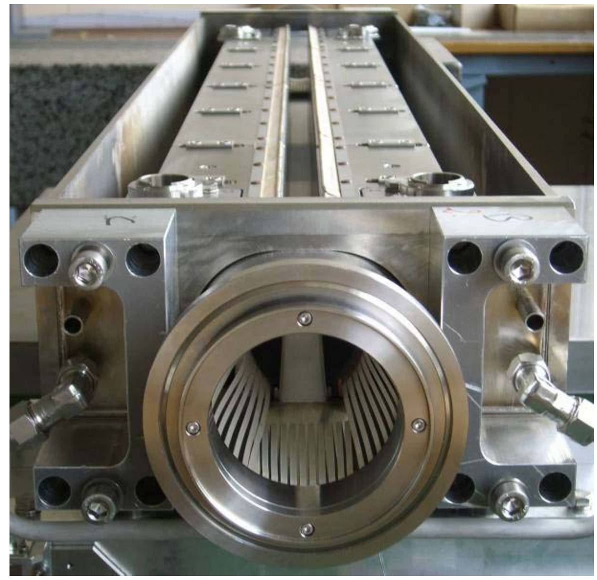

Figure 4: A view of a series TCS collimator during production. Both jaws and RF contacts have been mounted.

Simulations track 5 million halo protons for 200 turns with physical interactions in all collimators and absorbers, predicting losses in a detailed LHC aperture model [9, 10]. Studies were done for different energies, various collimation settings and for several imperfections [10, 11]. An example loss map is shown in Fig. 3 for zero and perturbed orbit. Independently collimator-induced impedance was studied [7]. It was found that the initial collimation system (phase 1) might be limited by several effects:

1. The total LHC impedance is strongly dominated by collimators [6, 7]. The **collimator-induced impedance** is expected to limit the total intensity to about 30-40% of its nominal value, if octupoles are fully powered.
2. The **collimation efficiency and energy deposition** [12] is compatible with about 40% of nominal intensity for protons. However, it is expected that imperfections will reduce the collimation efficiency by a factor 2-4 [11]. For ions it is expected that an intensity of about 50% of nominal can be reached [13].
3. The jaws will experience long term **damage** due to beam-loss induced radiation [14].

An upgrade of the system and the R&D on advanced collimators is therefore an integral part of the LHC collimation system. Ring locations have been already fully equipped for this mandatory upgrade.

DESIGN, PRODUCTION, INSTALLATION

The first phase of LHC collimation requires 8 different types of collimators and various masks. Major design work has been completed, prototyping and beam tests were successful [4] and series production has started. Fig. 4 shows the photograph of a secondary ring collimator during series production. The two CFC jaws are visible, as are the transverse and longitudinal RF fingers. Heavy cooling on the collimator jaws and the tank ensure full functionality for the peak beam loss rates.

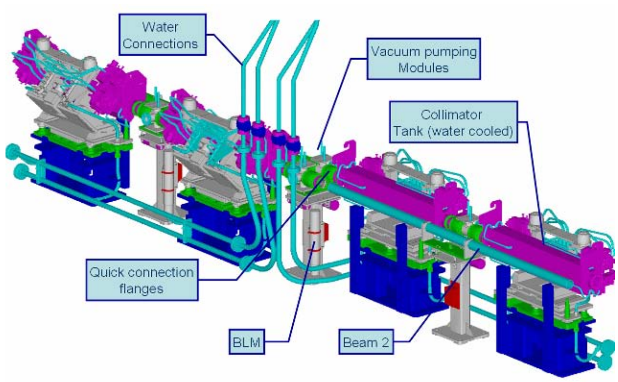

Figure 5: Integration study for ring collimators with all required infrastructure in the LHC tunnel.

Figure 6: Photograph of an installed ring collimator on its quick plug-in support in IR8 of the LHC.

The first collimators have been installed into the LHC tunnel. The collimator tanks have been integrated with radiation-optimized quick plug-in supports (water and controls passes through quick plugs), quick connection flanges, the second beam pipe, vacuum pumping stations, beam loss monitors and water connections. This is illustrated in Fig. 5 for a series of 4 collimators. A photograph of the first installed ring collimator in IR8 of the LHC is shown in Fig. 6. The first installation was completed in less than 10 minutes.

CONCLUSION

The collimation system has been re-designed over the last 3 years to address the challenges of the LHC. A powerful system has been implemented, including up to 152 collimators for the two rings. Initially up to 102 collimators will be used to extend the state-of-the-art in handling of stored energy in super-conducting rings from presently 2 MJ to 40-100 MJ. The important collimator designs for this initial system have been worked out, successfully tested, series production of 125 collimators has started and the first collimators have been installed into the LHC. Collimators and machine layout have been optimized for radiation impact and collimators were integrated with important beam instrumentation and infrastructure.

The LHC collimation system includes 34 fully equipped ring locations for an upgrade with advanced collimators around 2010. It is the goal that the upgraded system will allow nominal intensities in the LHC, bringing the state-of-the-art to 360 MJ and energy density at collimators to 1 GJ/mm^2. Final design choices and decisions for the upgrade will be based on the experience with the LHC beams and the initial collimation system. If required, an additional 16 collimators can be installed into non-equipped but reserved LHC locations.

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