

STUDY OF THE IR2 AND IR8 SQUEEZEABILITY FOR HL-LHC UPGRADE PROJECT*

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Abstract

The paper presents the results of the study of different optics configurations of the long straight sections (IR2 and IR8) which allow to reach smaller beta functions at the IP2 and IP8 in the framework of the HL-LHC project [1]. The variants at collision energies must be compatible with the Achromatic Telescopic Squeezing (ATS) [2] scheme which provides small beta functions at the IP1 and IP5 or provide low beta functions for Alice and LHCb during ion operations. The ones at injection must satisfy injection transfer lines and aperture constraints. The final goal is to find the overlap between the phase advances of all the configurations for IR2 and IR8 respectively, in order to maintain the LHC working point without rematching the remaining insertions or the arcs.

INTRODUCTION

This study is based on the SLHCv3.1b [3] layout optics for the HL-LHC upgrade project [1], which implements the ATS scheme [2] to achieve very small values of the β -functions (β^*) at the high luminosity interaction points (IP). The beam optics of IR8 and IR2, neighbor of IR1 are modified to support the ATS scheme such that the beta beating wave, essential to reduce the beta function in IP1, is created in the matching sections of IR2 and IR8. In those insertions, where LHCb and ALICE experiments are located, the low-beta insertions have to be kept flexible enough to guarantee successful data taking of these experiments. Five different scenarios of LHC operation have been identified [5] with the corresponding main optics configuration parameters listed in Table 1. Values at IP1 are given for reference but only the ratio between the pre-squeeze and final β^* values in IP1 is relevant for the Twiss parameters on the right of IR8 and left of IR2.

PHASE ADVANCE SCAN

In order to realize the desired optics variants, the following elements could be varied with some exceptions: final focus triplets of IP2 and IP8 (without using the trims [4]) and the 20 matching quadrupoles between the triplets and the arcs (Q4-13) in the left and right of the IR. Special requirements are also needed. The phase advance for Beam

Table 1: General β^* Parameters at the IP for the IR2 and IR8 Optics Configurations Proposed for the HL-LHC (in parenthesis the ATS de-magnification factor)

Scenario	IP1 β_x^*	IP1 β_y^*	IP2 $\beta_{x,y}^*$	IP8 $\beta_{x,y}^*$
1. ATS (4x)	10 cm	10 cm	3 m	10 m
2. ATS (2x,8x)	5 cm	20 cm	3 m	10 m
3. ATS (8x,2x)	20 cm	5 cm	3 m	10 m
4. low-beta no ATS	40 cm	40 cm	50 cm	50 cm
5. injection	6 m	6 m	10 m	10 m

1 and Beam 2 over IR2 and IR8 should be the same. The ratio of the corresponding quadrupole strengths of Beam 1 and Beam 2 should stay between 0.5 and 2 due to the three-lead powering scheme of the IR quadrupoles [6]. At injection the strengths of the triplets and few other quadrupoles cannot be changed to avoid a mismatch of the injection transfer line optics. The phase advances between the injection element and the protection devices should not be degraded. Finally, to provide the largest aperture margins, tight constraints on the peak β and dispersion functions are estimated and imposed during the matching process, but a refinement using the aperture model is needed for a proper assessment of the aperture margins.

The matching routines were made to scan the area of phase advances in both planes and if satisfactory optics was found it was saved. The procedure was automatized to reduce the time needed to explore the parameter space. However, the optimization algorithm can miss solutions that could otherwise be found by manually steering the matching routine (e.g. change optimizer settings, momentarily excluding or reducing variables close to the limit, correct the loss of vertical horizontal alternating beta functions), due to the high dimensionality and large non-linearity of the problem. For this reason, after that a common phase advance was chosen, each scenario was manually adjusted to satisfy finer constraints paying attention not to exceed the maximum current in the triplets, keep the ratio of the corresponding quadrupoles of Beam 1 and Beam 2 within limits, and reduce the peak beta functions where possible.

The results of the phase scan for IR8 and IR2 are shown in Fig. 1 where different color dots are representing various optics solutions for the five scenarios. The area surrounded by the black line indicates the values where a common phase advance is achievable for all the optics requirements. In general the smaller region of compatible phase advances corresponds to injection optics for which comparably large phase advances are preferred. Low beta optics

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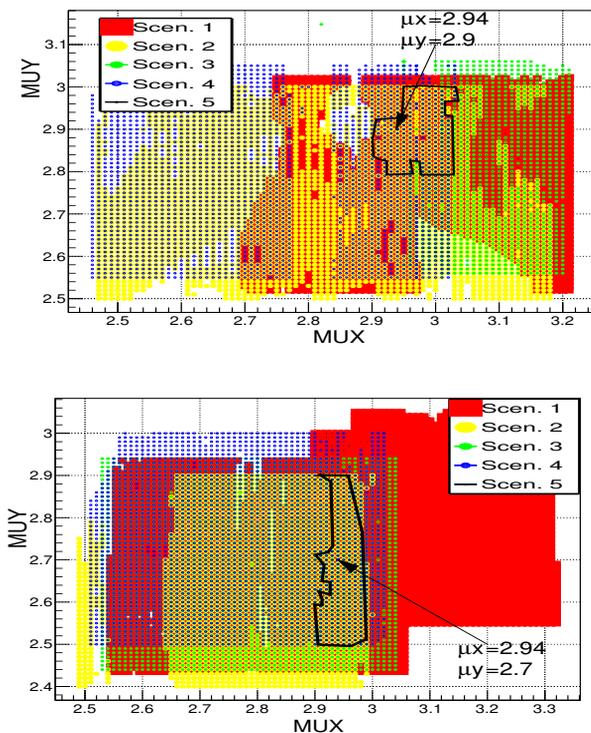


Figure 1: Phase advance where optics solutions for the five operational scenarios of operation for IR8 (top) and IR2 (bottom) have been found. The black curve represents the area of optics solutions with the same phase advance.

have a large tunable range which favours lower horizontal phase advances. The ATS round squeeze has the largest tunable range, while the flat optics versions are less flexible probably due to the larger difference in the boundary conditions on a given plane.

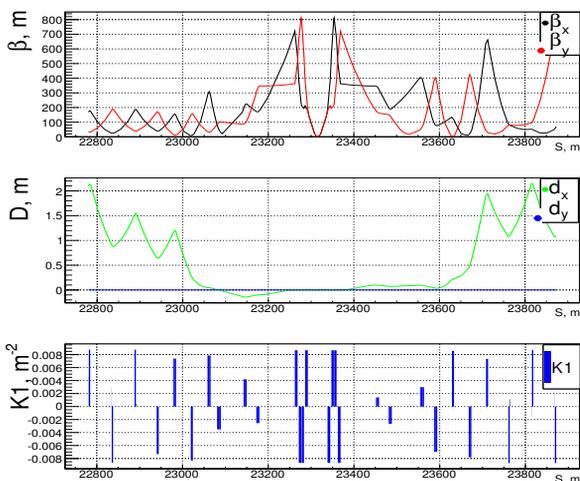


Figure 2: Example of IR8, Beam 1 optics for Scenario 1 with $\mu_x = 2.94$, $\mu_y = 2.9$, $\beta_{x,y}^* = 3$ m. The boundary conditions on the right reduce β^* in IP1 by a factor of 4.

IR8

Examples of IR8 optics for Scenario 1, 4 and 5 with phase advances $\mu_x = 2.94$, $\mu_y = 2.9$ are shown in Figs. 2, 3 and 4 respectively. For the injection optics it is difficult to reduce the beta function in MQM.6R8.B1 and MQM.6L8.B2 due to the frozen part of the optics. A small degradation of the phase between the TDI and the MKI was needed. For the low-beta optics, it is necessary to dis-symmetrize the strengths of Q4-Q7 to obtain relatively well balanced optics. A squeeze exercise to find smooth transition with injection, should be performed to validate the final strengths.

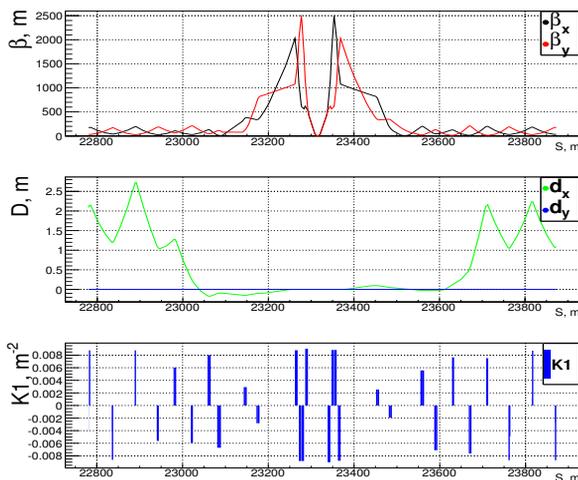


Figure 3: Example of IR8, Beam 1 optics for Scenario 4 with $\mu_x = 2.94$, $\mu_y = 2.9$, $\beta_{x,y}^* = 0.5$ m.

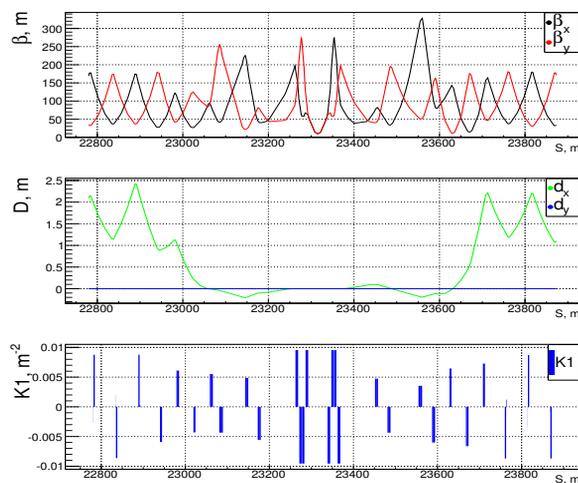


Figure 4: Example of IR8, Beam 1 optics for Scenario 5 with $\mu_x = 2.94$, $\mu_y = 2.9$, $\beta_{x,y}^* = 10$ m with injection constraints.

IR2

Examples of new optics for IR2 for scenarios 2, 4 and 5 with phase advances $\mu_x = 2.94$, $\mu_y = 2.7$ are shown in Figs. 5, 6 and 7 respectively. As for IR8, the injection is the most difficult to fulfil once the aperture model is used to compute the aperture margins. In addition the strength of Q8 left Beam 1 tends to be slight below the minimum recommended value. For low-beta optics the strength of Q7 left Beam 1 and Right Beam 2 are the most difficult to reduce. For flat optics, the strength ratio of the left Q8 is difficult to optimize.

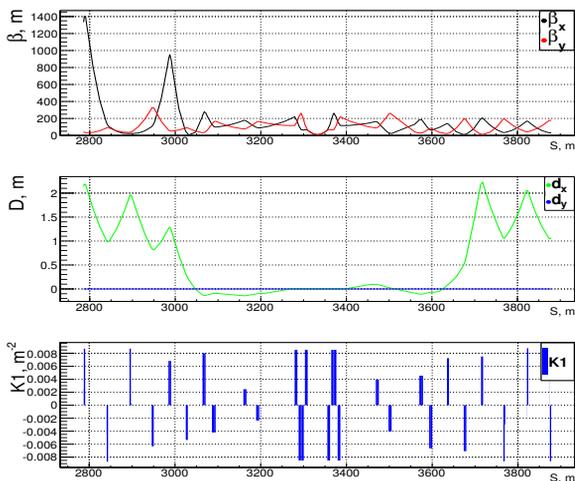


Figure 5: Example of IR2, Beam 1 optics for Scenario 1 with $\mu_x = 2.94$, $\mu_y = 2.7$, $\beta_{x,y}^* = 10$ m. The boundary conditions on the left reduce β_x^* and β_y^* in IP1 by a factor 8 and 2 respectively.

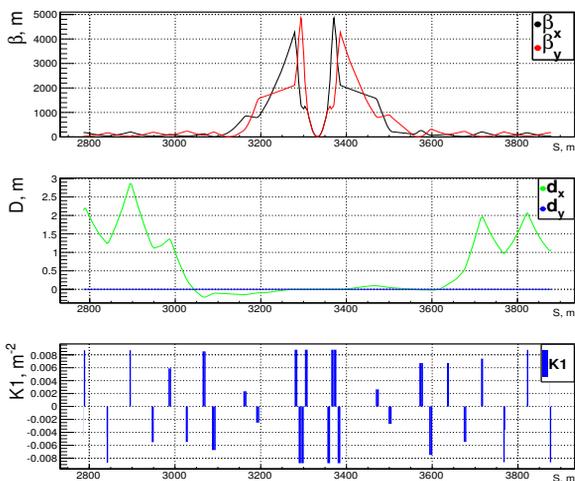


Figure 6: Example of IR2, Beam 1 optics for Scenario 4 with $\mu_x = 2.94$, $\mu_y = 2.7$, $\beta_{x,y}^* = 0.5$ m.

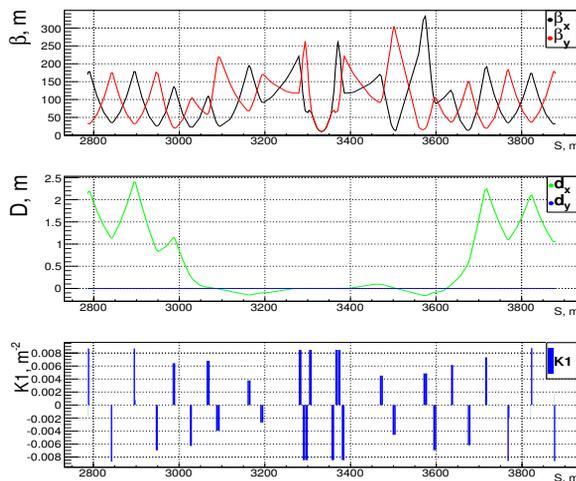


Figure 7: Example of IR2, Beam 1 optics for Scenario 5 with $\mu_x = 2.94$, $\mu_y = 2.7$, $\beta_{x,y}^* = 10$ m with injection constraints.

CONCLUSION

Optics configurations satisfying given requirements for IR2 and IR8 have been partially studied with an automatic procedure in a compatible range of phase advances. In the overlap between different requirements, a phase advance choice has been further optimized. The resulting optics have been used as a starting point in the integration of new phase advances in the HL-LHCv1.0 optics on which additional optimizations have been performed leading to the final choices of (3.02, 2.8) and (2.95, 2.7) for IR8 and IR2, respectively. A further analysis of the optics transitions between all the optics configurations is needed to fully qualify the feasibility of the optics scenarios.

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