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ALTERNATIVE HIGH LUMINOSITY LHC MATCHING SECTION LAYOUT*

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Abstract

In the framework of the HL-LHC Upgrade project possible variants for the layout of the LHC matching section located in the high luminosity insertions are investigated. This layout is optimized to reduce the demand on the voltage of the crab cavities, it also improves the optics squeeze-ability, both in ATS [1] and non-ATS mode. Moreover the injection and transitions to collision optics are also discussed.

INTRODUCTION

We present an alternative variant for the layout of the LHC matching section located in the high luminosity insertions. This layout is optimized to reduce the demand on the voltage of the crab cavities, to leave some margin with respect to the baseline [2]. At the same time it substantially improves the optics squeeze-ability, both in ATS [1] and non-ATS mode, as already shown in [3]. In fact the alternative layout we discuss here is a further optimization of the one presented in [3]. Starting from the layout presented in [3] and using the same constraints described in the paper we have optimized the layout, this time at injection, in order to solve the problem of the apertures in Q6 at injection. First we present the new layout features for collision and the injection optics and then we discuss the transition from injection to collision.

ALTERNATIVE LAYOUT

he new matching section layout is shown in Fig. 1. TQ5 is displaced towards Q4 with respect to the layout presented in Ref. [3] and the single MQYL type is replaced by 2 MQYY, same type foreseen for Q4. Q6 is displaced towards Q7+,

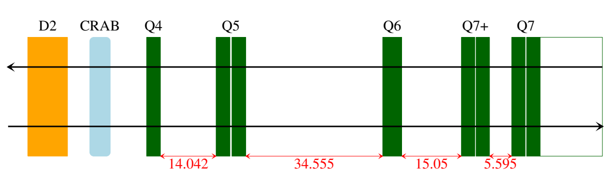

Figure 1: Alternative matching section layout.

which is the additional quadrupole introduced with the previous layout. This configuration reduces the β function in Q6 at injection, which was the limit of the previous triplet configuration of Q4, Q5 and Q6 [3].

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COLLISION AND INJECTION OPTICS

We show in this section the collision and injection optics, and apertures of the alternative layout as they compare to the baseline (Fig. 2). The crab cavity voltage gain and the chromatic properties are presented as well. Round optics are presented only. The same presqueeze could in principle be used for flat optics but a different optimization, taking into account the different beam sizes, may be required for flat beams.

The increase of the β function in both planes with respect to the baseline is clearly visible in the region between D2 and Q4 (around s = 400 m and s = 700 m), where the crab cavities are installed. The additional quadrupole gives more flexibility in collision and as already found for the old configuration [3], this layout offers the possibility to squeeze to a β^* of 15 cm without using the ATS scheme (Fig. 2 right), which is not possible with the present baseline layout. Figure 3 shows the injection optics with a β^* of 5 m for the alternative layout of Fig. 1.

Crab Cavity Voltage

The crab cavity voltage has been evaluated as the total equivalent kick given by the crab cavities: the values corresponding to the two alternative optics and the baseline are reported in Table 1. The alternative layout reduces the required crab cavity voltage by a factor 20-30% with respect to the present baseline requirement. Moreover it has the advantage to balance the required voltage between the left and the right side of the IP, as it was already found with the layout presented in [3].

Table 1: Equivalent Kick Required by the Crab Cavities for the Baseline Optics and the Alternative Layout

side, IR and beam	baseline [MV]	alternative [MV]	alternative non ATS [MV]
L/R 5 beam1	10.8/12.0	8.7/8.8	9.5/9.2
L/R 5 beam2	12.0/10.8	8.8/8.7	9.2/9.5
L/R 1 beam1	11.8/10.8	8.7/8.8	9.0/9.6
L/R 1 beam2	10.8/11.8	8.8/8.7	9.6/9.0

Chromatic Properties

In the non ATS optics we have corrected the linear chromaticity only, using the LHC sextupoles all together and taking care that their strengths do not exceed the maximum allowed value. Non corrected second order chromaticity is present with respect to the ATS optics. The chromatic variation of the β function for the squeeze optics are shown in Fig. 4. In both ATS optics the Montague functions $W_{x,y}$

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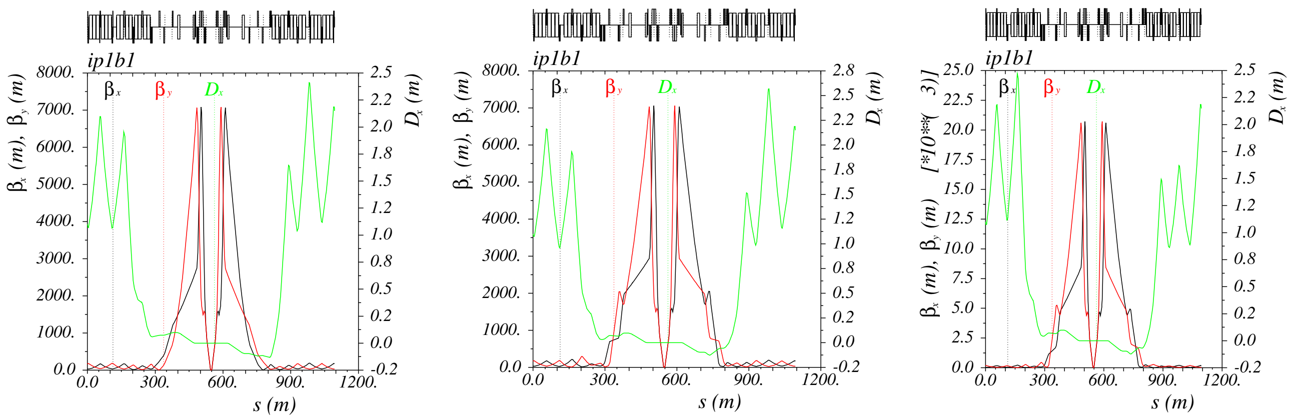

Figure 2: IR1 ATS presqueeze optics with the baseline layout (left), ATS presqueeze (center) with the alternative layout,β^*=44 cm. On the right the non ATS (right) optics with the alternative layout and β^*=15 cm is shown.

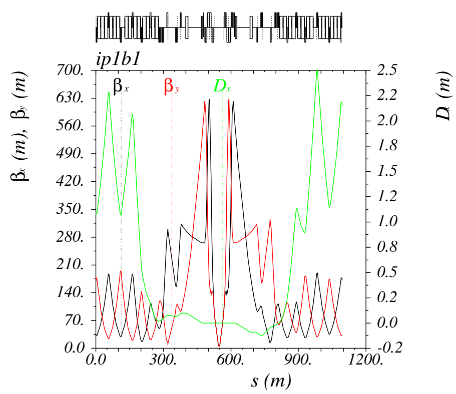

Figure 3: IR1 injection optics with β^*=5 m for the alternative layout shown in Fig. 1.

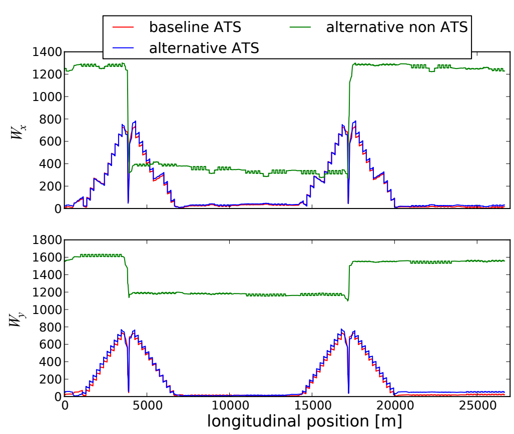

Figure 4: Horizontal (top) and Vertical (bottom) Montague Function for the Baseline ATS Optics, the Alternative ATS Optics and the Alternative non ATS Optics for beam 1

reach their maximum in the inner triplet of IP1 and IP5 and they are vanishing after the arcs adjacent to the two IPs, in particular in the collimation insertions of IR3 and IR7. In the non ATS case the Montague functions are almost constant assuming a different value in the two halves of the ring.

Apertures and Magnet Types

In Table 2 the magnet type and the minimum value of apertures between the two beams, the two sides and the two high luminosity interaction regions are reported, for each of the magnet in collision ($\beta^* = 15$ cm) and at injection ($\beta^* = 5$ m). The corresponding values for the baseline collision optics are also shown. They have been computed

Table 2: Apertures at Collision, the Baseline ATS Optics is Compared with the Alternative ATS Optics

baseline (type)	collision [σ]	alternative (type)	collision [σ]	injection [σ]
TAS	14.63		14.65	12.58
Triplet	10.96		10.96	12.21
CRAB	24.56		20.55	16.40
TAN	14.52		12.16	11.79
D2	16.80		13.61	12.98
Q4(MQYY)	22.66	(MQYY)	16.26	13.16
Q5(MQYL)	27.73	(2 MQYY)	17.06	15.92
Q6(MQML)	28.09	(MQML)	24.56	7.15
Q7+(-)	(-)	(2 MQM)	30.34	8.07

assuming nominal LHC normalized emittance ($\gamma\epsilon$=3.75 µm) at injection and ($\gamma\epsilon$=3.5 µm) in collision, a total crossing angle of 590 µrad, the latest aperture model for the new HL-LHC magnets described in [2], and same beam tolerance budget (closed orbit, beta-beating, spurious dispersion) and beam halo geometry as the one described in [4] at injection and the corresponding recently updated values [5] in collision. Taking advantage of the operational experience of the LHC run I, the parameters entering in the definition of the apertures for the LHC have been updated [5]. In particular the halo cross-section, the emittance and the parasitic dispersion used for the LHC design bring the aperture values in the inner triplet at collision from ~7 to ~11. In both cases we have considered the same geometrical model and tolerances as the nominal Q7 for Q7+, being the same type of magnets and very close in space. For the 2 MQYY of Q5 we have used the same model of Q4.

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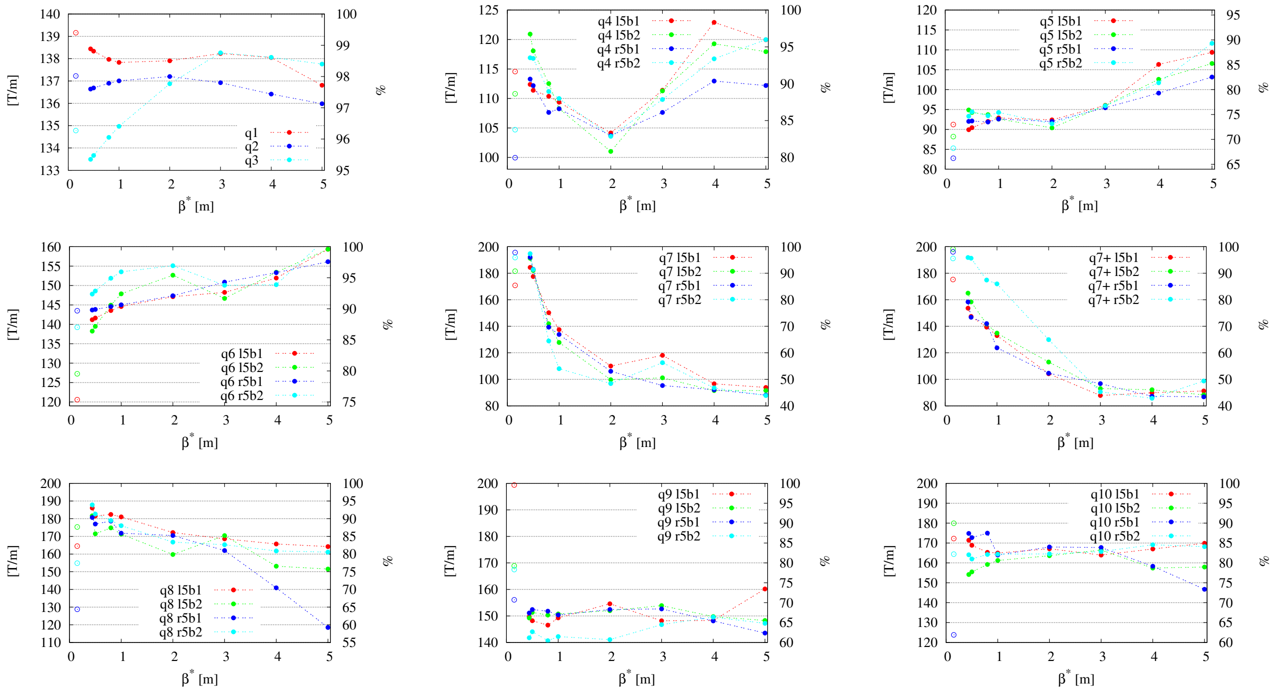

Figure 5: Transition strengths of the two High Luminosity interaction regions quadrupoles after one iteration of smoothing. The empty circles at β^* of 15 cm are the strengths of the non ATS optics.

TRANSITION TO INJECTION OPTICS

The quadrupole strengths for the transition optics are shown in Fig. 5 for the layout under study. The maximum β^* reached with the ATS Left and Right phases is 3 meters. For transition optics between 3 and 5 meters the constraint on the total phase of the two interaction regions only is considered in the matching. The maximum β^* at injection is limited by the maximum strength of Q6 and the minimum strength of Q7 and Q7+. We have used the same fitting function for all the quadrupoles:

$$f(x) = (a + bx + cx^2 + dx^3)e^{(hx)} \qquad (1)$$

where, a, b, c, d, h are free parameters for each of the quadrupole. Re-matching all the optics variants with the functions resulting from the fit we obtain the transitions showed in Fig. 5. Except for the two Q7 that vary in their full allowed range, the other magnet strengths have an excursion of 10-20%. The triplet quadrupoles vary within 5% of their strength, which is well inside the maximum strength variation of 11% provided by the Inner Triplet Trim [6].

CONCLUSION

The alternative variant for the layout of the two HL-LHC matching sections insertions, optimized to reduce the demand on the voltage of the crab cavities, is becoming more and more robust in terms of apertures and transition strengths. The major modifications with respect to the baseline are: the additional Q7 quadrupole (Q7+), the substitution for Q5 of the MQYL with 2 MQYY, same type as Q4, the displacement of Q5 and Q6 in doublet configuration with Q4 and Q7+. This alternative layout permits to reduce the crab cavity voltage of about 20% and to squeeze to very low β^* without using the ATS scheme. The drawback of this configuration is the additional cost required by the new hardware.

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