HIGH LUMINOSITY LHC MATCHING SECTION LAYOUT VS CRAB CAVITY VOLTAGE*

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Abstract

In the framework of the HiLumi-LHC project we present a new possible 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, while substantially improving the optics squeeze-ability, both in ATS [1] and non-ATS mode. This new layout will be described in details together with its performance figures in terms of mechanical acceptance, chromatic properties and optics flexibility.

INTRODUCTION

In the framework of the optics task Task2.2 [2] of the luminosity upgrade of the LHC (HiLumi-LHC), we present a promising direction for optimizing the layout of the matching section in the two high luminosity insertions, namely IR1 and IR5. The main goal of the optimization is the reduction of the required crab cavity voltage, in order to leave some margin with respect to the present baseline [3]. Three crab cavities providing a total equivalent kick of about 12.5 MV are indeed presently needed for each of the two beams in the region between D2 and Q4 on either side of the two high luminosity IRs [3]. It can be shown that the crab cavity voltage required to rotate the proton beam by half the crossing angle is given by the following equation:

$$V_{crab} = \frac{cE\theta_c/2}{\omega_{crab}\sqrt{\beta^*\beta_{crab}}} \qquad (1)$$

where θ_c is the full crossing angle, β_{crab} is the β function value at the crab cavity location. Therefore, the only method to reduce the required crab cavity voltage is to increase the β function at the crab location, being fixed the β^*, the beam energy (E), the position and the frequency (ω_{crab}) of the crab cavity [4]. The β function can be modified by changing the position and the strength of the magnets in the matching sections. As further constraints to our optimization we have considered:

- compatibility with the ATS optics scheme;
- possibility to design a low β^* optics in non ATS mode, i.e. using the strengths of the IR magnets;
- possibility to realize an injection optics with low β^*.

The optimization of the matching section is performed using the pre-squeeze optics (first stage of the ATS optics), since the ATS scheme reduces the number of possible configurations of the matching section, due to the stringent conditions imposed on the betatron phase advance between the left and right side and the Interaction Point (IP).

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PROPOSED LAYOUT

A past analysis of the ATS optics, discussed in [5], has shown that in the high luminosity matching section optics the Q7 strength is very close to its maximum, while very low gradients are imposed to Q5 and Q6. In order to cure the weakness of Q5 and Q6 we have chosen to put them in triplet configuration with Q4, without moving Q4. To overcome the Q7 limit, a new quadrupole of the same type and polarity of Q7 is added, just in front of the main cryostat of the LHC arc, as sketched in Fig. 1. Finally we have iterated the optimization of the new matching section layout several times, increasing the initial β_x, β_y conditions at the crab location.

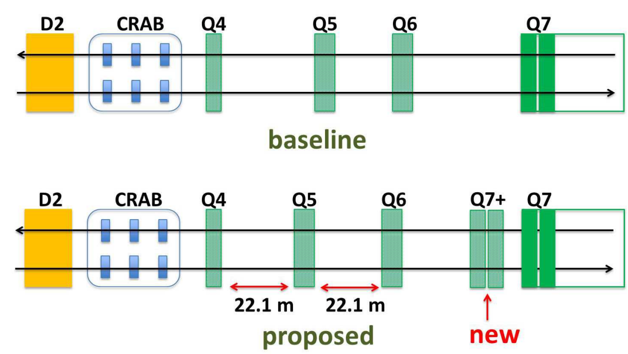

Figure 1: Proposed matching section layout.

In the following, the main performance figures of the final layout resulting from our optimization are described, in terms of mechanical acceptance (apertures), chromatic properties and optics flexibility. We start describing the effect of the proposed layout at collision and we discuss the injection case after.

COLLISION

We discuss the possibility to design collision optics with the proposed layout considering or not the ATS scheme, and we compare their main features to the HLLHCV1.0 baseline optics with β^*=15 cm and a crossing angle of 590 μrad.

ATS Optics

By comparing the optics obtained with the baseline and new layout (see Figs. 2(left) and 2(center), respectively), the increase of the β function in both planes 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 corresponding increment in the beam sizes is even more evident in Fig. 3, which shows the IR1 apertures correspond-

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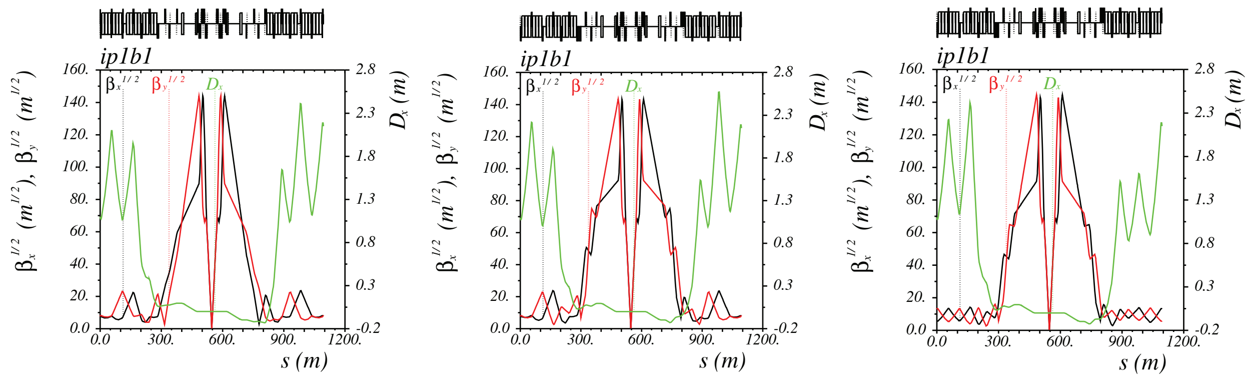

Figure 2: IR1 ATS squeeze optics with the baseline layout (left), ATS squeeze (center) and non ATS (right) optics with the proposed layout, β^*=15 cm.

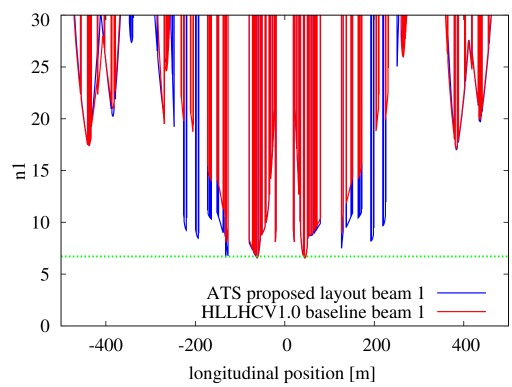

Figure 3: IR1 apertures (in n1 units [6]) corresponding to the baseline and the proposed matching section layouts.

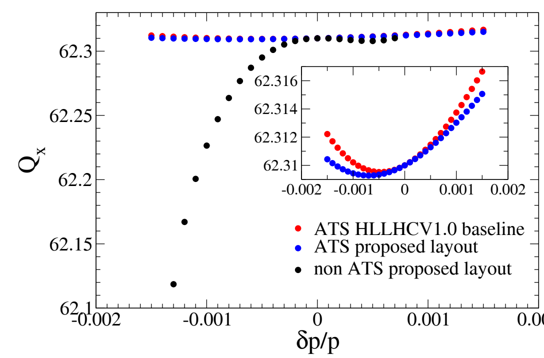

Figure 4: Horizontal tune variation as a function of δp/p for the baseline ATS optics, the proposed ATS optics and the proposed non ATS optics for beam 1.

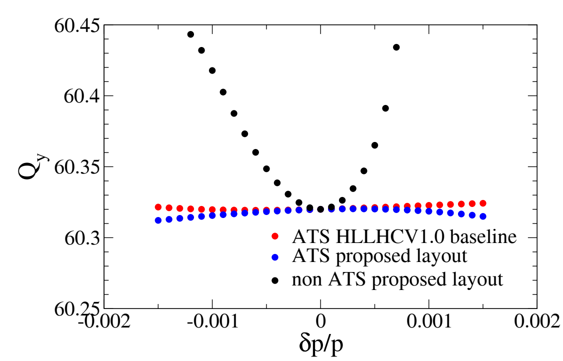

Figure 5: Vertical tune variation as a function of δp/p for the baseline ATS optics, the proposed ATS optics and the proposed non ATS optics for beam 1.

ing to the ATS squeeze optics with the baseline layout superimposed to the apertures from the proposed layout. The apertures are computed using the primary collimator value n1 [6], assuming nominal LHC normalized emittance ($\gamma\epsilon$=3.75 μm), a total crossing angle of 590 μrad, the latest aperture model for the new HL-LHC magnets described in [3], and same beam tolerance budget (closed orbit, beta-beating, spurious dispersion) and beam halo geometry as the one described in [6]. In the case of the proposed layout, the beam screen of Q5 has been re-oriented to have the larger aperture in the plane with the higher β function. For the additional Q7 we have considered the same model and tolerances as the nominal Q7, being the same type of magnets and very close in space. Despite the increase due to the optimization for crab cavity operation the aperture values are all above the reference value (n1=6.7 given by the green line in Fig. 3).

Non ATS Optics

With the additional Q7 quadrupole and the triplet given by the Q4/Q5/Q6 magnets in the proposed layout configuration, it is possible to realize a very low β^* optics in a more traditional way with respect to the ATS scheme, that is by using only the standalone quadrupoles equipping the low-luminosity IRs.

An example of optics realized with the proposed matching section layout in non ATS mode is shown in Fig. 2(right). The β functions in the inner and in the outer triplet region are pretty similar to the one shown in 2(center) , while the beta bumps in the adjacent arcs, characteristic of the ATS scheme, are missing. The IR1 apertures, computed in the same way as the ATS case, are all above the n1=6.7 reference value.

Chromatic Properties

The two ATS optics, corresponding to the baseline and the proposed layout for the matching section, present similar chromatic correction properties, as shown in Figs. 4

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and 5. In the non ATS optics case we have corrected the linear chromaticity using the LHC sextupoles all together and taking care that their strengths do not exceed the maximum allowed value but no method has been used to correct second and third order chromaticity. Therefore, the quality of the chromatic correction in this case is very poor.

Crab Cavity Voltage

The crab cavity voltage has been evaluated as the total equivalent kick given by the three crab cavities: the values corresponding to the two proposed optics and the baseline are reported in Table 1. The proposed layout reduces the required crab cavity voltage of 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.

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

side, IR and beam	baseline [MV]	proposed [MV]	proposed non ATS [MV]
L/R 5 beam1	10.8/12.0	8.7/8.8	9.2/9.4
L/R 5 beam2	12.0/10.8	8.8/8.7	9.4/9.2
L/R 1 beam1	11.8/10.8	8.7/8.7	9.3/9.3
L/R 1 beam2	10.8/11.8	8.7/8.7	9.3/9.3

INJECTION

The proposed layout and the larger apertures of the new inner triplet allow to design an injection optics with a β^* of 3 m, as shown in Fig. 6, and to easily switch to the ATS tunes and phases keeping the same β^* of 3 m. On the other hand the proposed layout, optimized using the pre-squeeze stage of the ATS scheme, gives less flexibility at injection, towards higher β^* values. In particular we observe a Q6 running close to its maximum and the additional Q7 with very low gradient (only 3% of its nominal current). The maximum β^* at injection is therefore limited (4.2 m is the maximum value reached so far).

Figure 7 shows the apertures in units of n1 [6] computed using the optics shown in Fig. 6, assuming the same model, and the same assumptions as the one described above for the collision optics. The values of n1 lying slightly below the green reference line (n1 = 6.7) correspond to the two Q6 magnets at the two sides of the IP. This would suggest either to replace the existing Q6 (56 mm aperture) with a new magnet type of larger aperture (e.g. 70 mm as the existing MQY type), keeping this configuration of the matching section layout, or to further optimize the latter to improve the aperture values at injection with the present type of Q6.

CONCLUSIONS

We propose a few changes in the high luminosity matching section layout, which consist in the addition of a quadrupole of the same type of Q7 and in the repositioning of Q5 and Q6 in triplet configuration with Q4. We have shown that the required crab cavity voltage is reduced by 20-30% with respect to the baseline layout. The same matching section layout gives more flexibility in collision towards lower β^* even without the ATS scheme, and allows to realize an optics with β^* of 3 meter at injection, even if some work is still needed to optimize it for apertures.

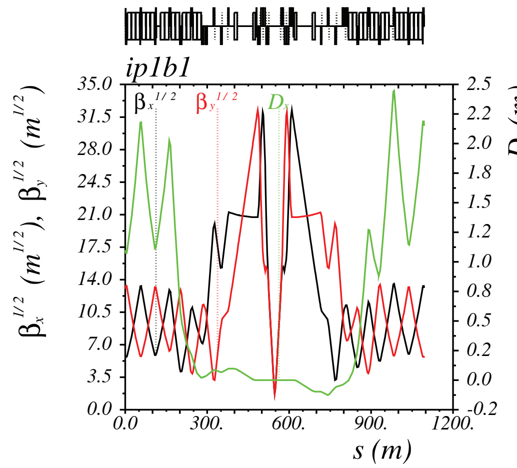

Figure 6: IR1 injection optics with the proposed matching section layout, $\beta^* = 3$ m.

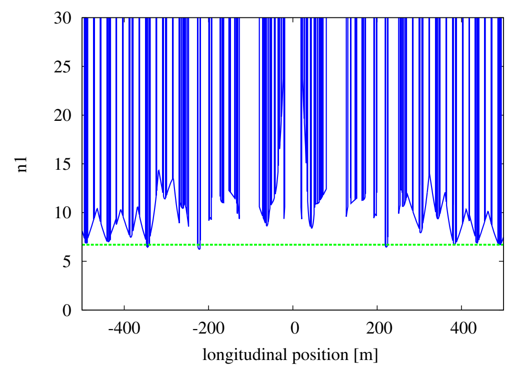

Figure 7: IR1 injection apertures (in units of n1 [6]) corresponding to the optics shown in Fig. 6.

ACKNOWLEDGMENT

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