High Luminosity LHC matching section layout vs crab cavity voltage

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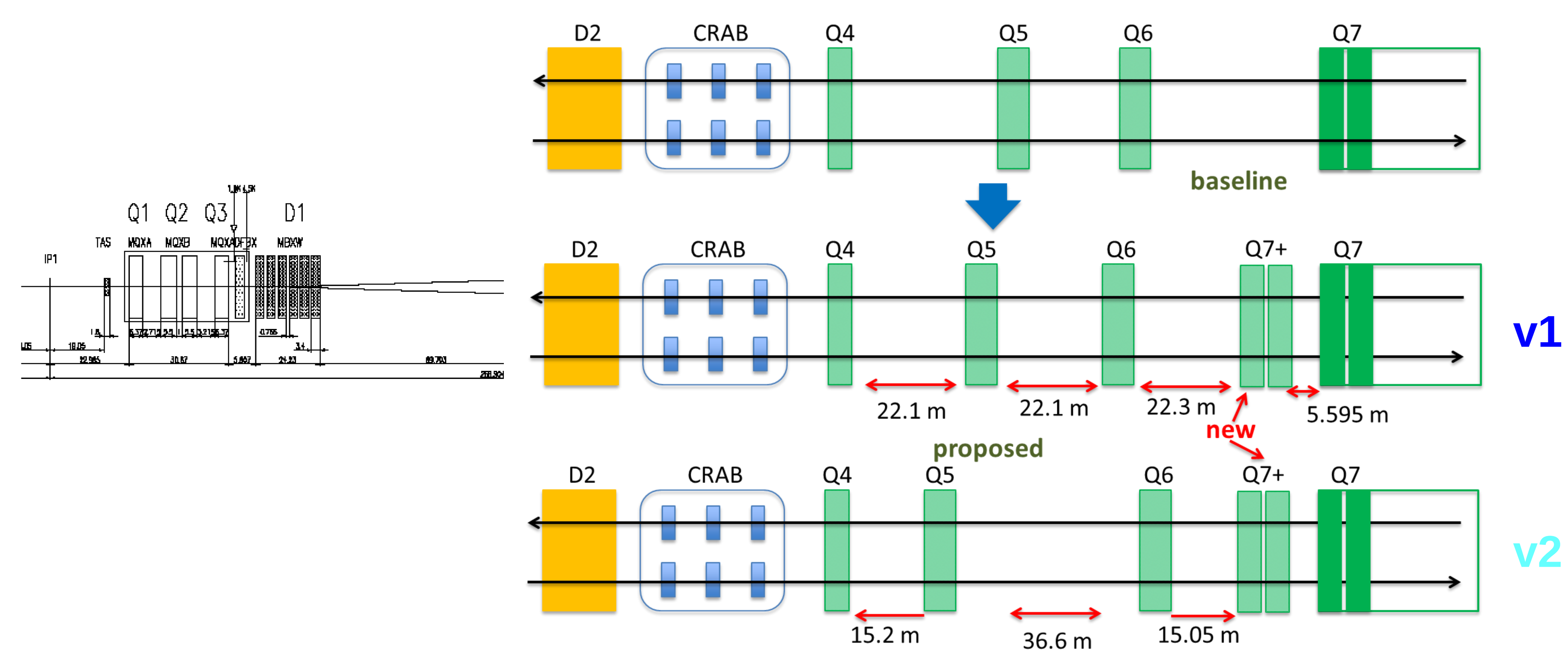
Introduction

In the framework of the optics task Task2.2 [1] 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 [2]. 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 beams in the region between D2 and Q4 on either side of the two high luminosity IRs [4]. It can be shown that the crab cavity voltage required to rotate the proton beam by half the crossing angle is:

$$V_{crab} = \frac{cE\,\theta_c/2}{\omega_{crab}\sqrt{\beta^*\beta_{crab}}}$$

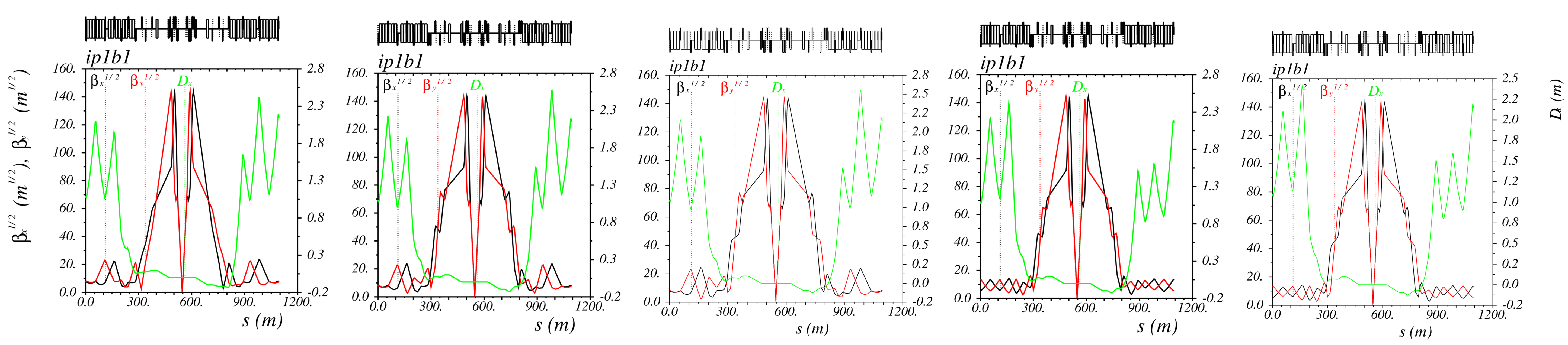
where θ_c is the full crossing angle, β_{crab} is the β function at the crab cavity location. Therefore, the only method to reduce the required crab cavity voltage is to increase the β function at the crab location, being fixed the β^*, the beam energy (E), the position and the frequency (ω_{crab}) of the crab cavity [5].
The optimization consists in improving the high luminosity matching sections optics with the Achromatic Telescopic Squeezing (ATS) scheme[6], in order to gain more lattice flexibility, and consequently to increase the β function at the crab location. Two configurations are compared here one with Q4, Q5 and Q6 quadrupoles arranged as triplet (**v1**) and one with Q4, Q5, Q6 and the additional Q7 settled as doublet (**v2**).

Proposed Layouts



Collision optics

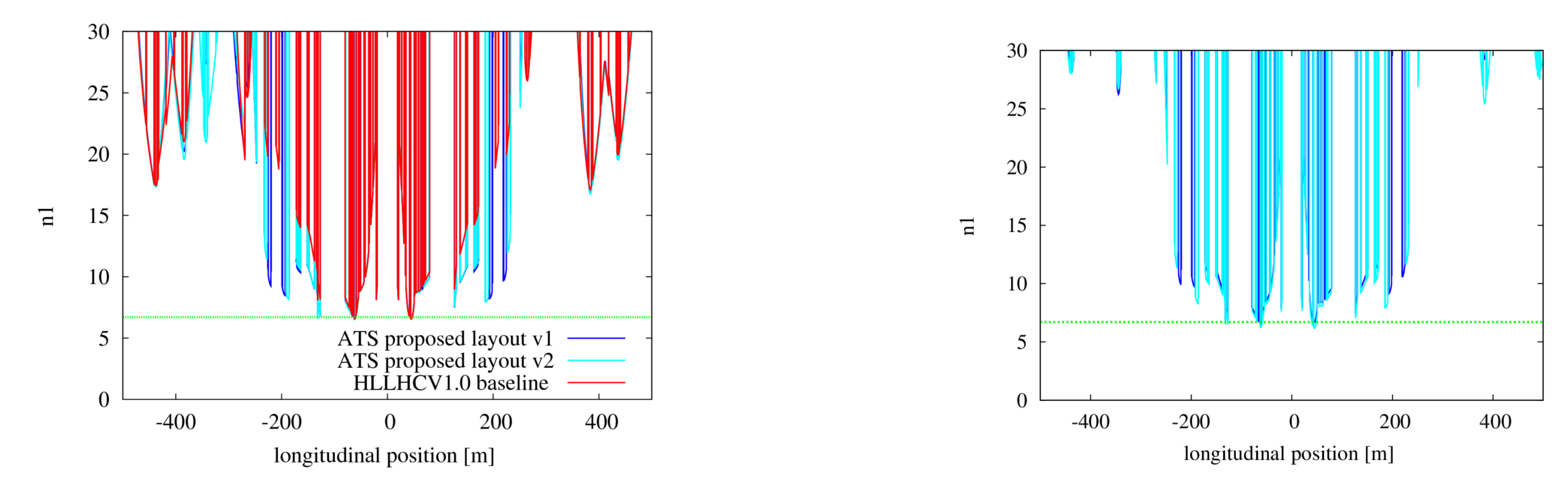
Collision optics with the proposed layouts considering or not the ATS scheme, as compared to the HLLHCV1.0 baseline optics with β^*=15 cm and a crossing angle of 590 µrad. By comparing the optics obtained with the baseline and new layouts the increase of the β function in both planes is clearly visible in the region between D2 and Q4 (around *s* = 400 m and *s* = 700 m), where the crab cavities are installed. In the non ATS optics the β functions in the inner triplet and in the matching sections are pretty similar to the ATS ones, while the beta bumps in the adjacent arcs, characteristic of the ATS scheme, are missing.



baseline — *proposed ATS v1* — *proposed ATS v2* — *proposed non ATS v1* — *proposed non ATS v2*

Apertures

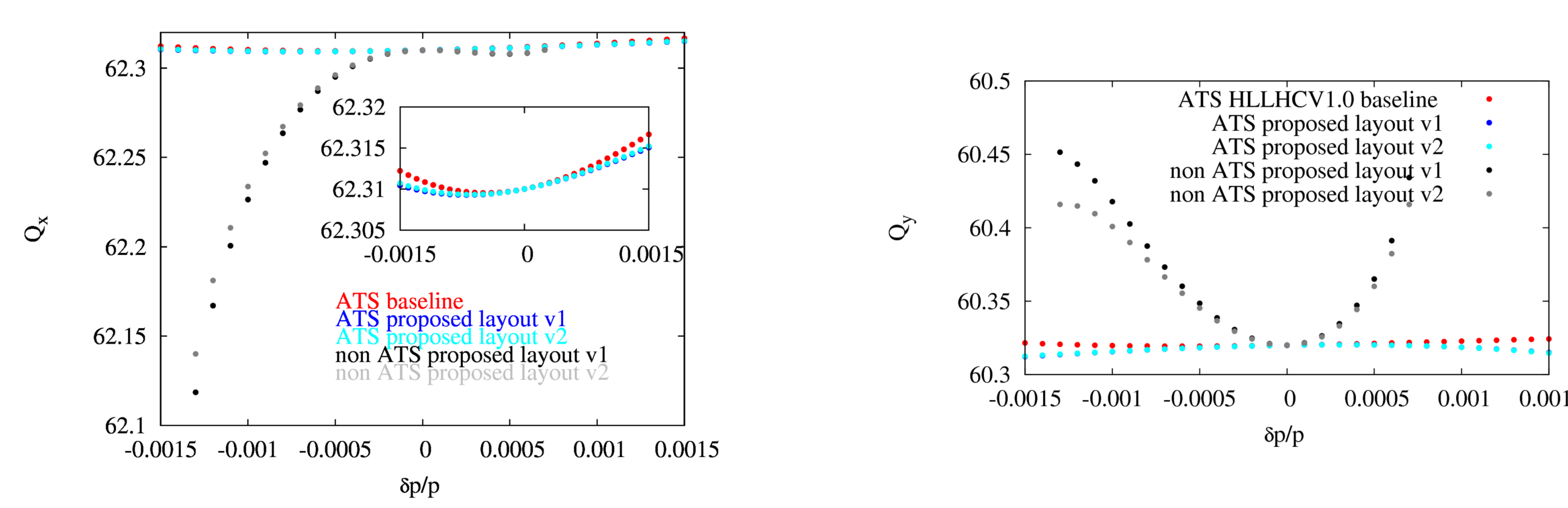
The IR1 apertures are computed using the primary collimator value n1 [7], assuming nominal LHC normalized emittance ($\gamma\varepsilon$ =3.75 µm), a total crossing angle of 590 µrad, the latest aperture model for the new HL-LHC magnets described in [3], and same beam tolerance budget (closed orbit, beta-beating, spurious dispersion) and beam halo geometry as the one described in [7]. In the case of the proposed layouts, 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 above the reference value (n1=6.7 given by the green line).



Crab cavity voltage

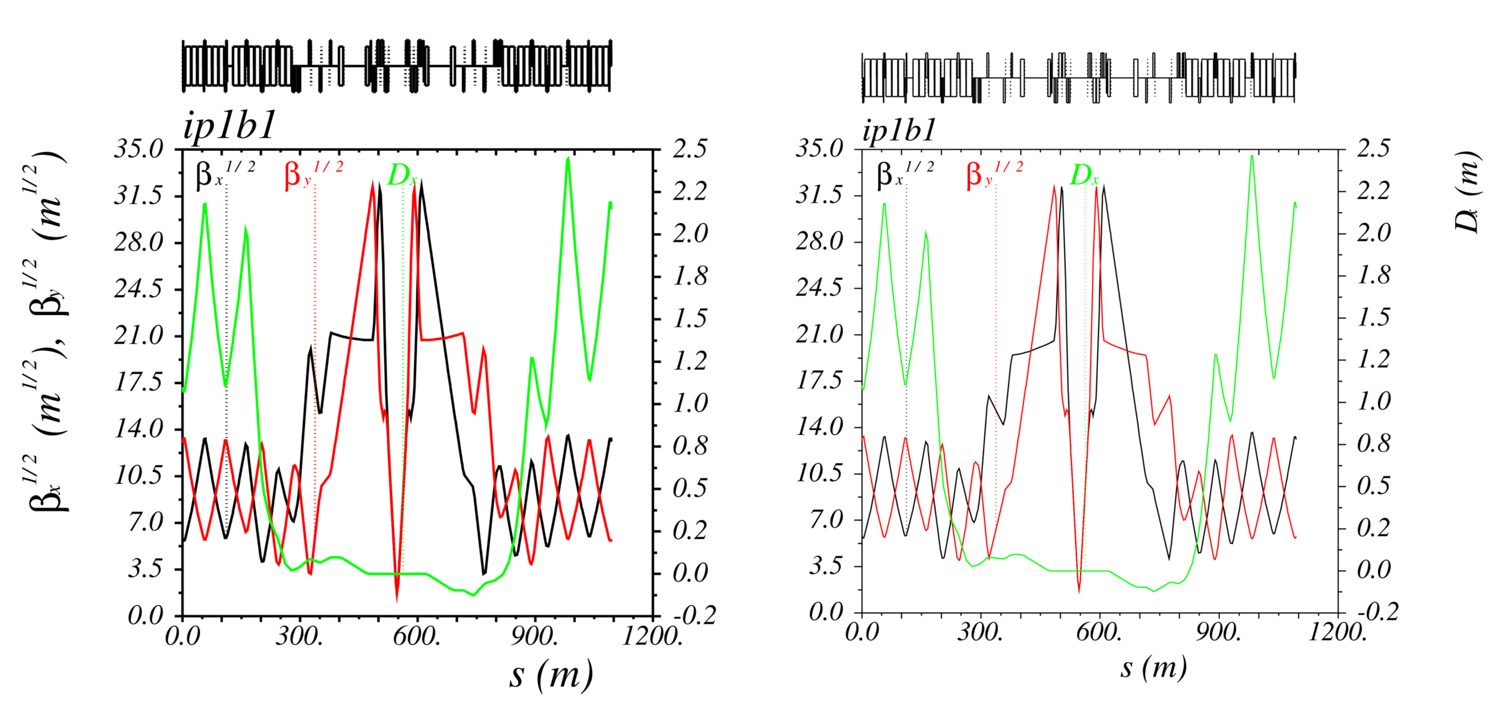
Side, IR and beam	Baseline [MV]	Proposed [MV] v1	Proposed [MV] v2	Proposed non ATS [MV] v1	Proposed non ATS [MV] v2
H L/R 5 b 1	10.8/12.0	8.7/8.8	8.9/8.8	9.2/9.4	8.8/9.4
H L/R 5 b 2	12.0/10.8	8.8/8.7	8.8/8.9	9.4/9.2	9.4/8.8
V L/R 1 b 1	11.8/10.8	8.7/8.7	8.7/8.9	9.3/9.3	9.3/8.6
V L/R 1 b 2	10.8/11.8	8.7/8.7	8.9/8.7	9.3/9.3	8.6/9.3

Chromatic properties



Injection optics

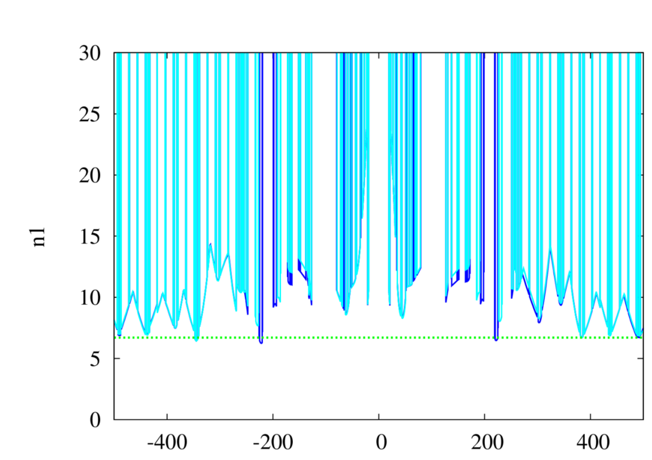
The proposed layouts and the larger apertures of the new inner triplet allow to design an injection optics with a β^* of 3 m and to easily switch to the ATS tunes and phases keeping the same β^* of 3 m. On the other hand the proposed layout, optimized using the pre-squeeze stage of the ATS scheme, gives 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) for the layout **v1**.
In the case of the layout **v2** we observe Q4 and Q5 running close to their maximum and the additional Q7 and Q7 close to the minimum.



proposed ATS v1 β^* = 3 m — *proposed ATS v2 β^* = 3 m*

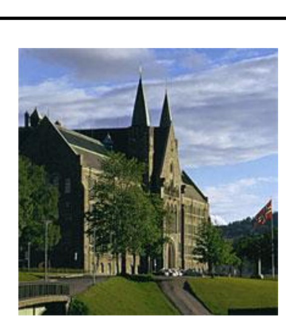
Apertures

The apertures are computed in units of n1 [7], 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 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). The second option of the matching section layout **v2** shows a clear improvement on the required apertures in Q6.



Conclusion

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 (**v1**) or arranging Q4, Q5, Q6 and the additional Q7 in doublet configuration (**v2**).
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. The two configurations compared here gives more or less the same performance. At injection the doublet configuration of Q4, Q5, Q6 and the additional Q7 (**v2**) is better in terms of apertures with respect to the Q4, Q5 and Q6 arranged in triplet (**v1**).



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