EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

*Large Hadron Collider Project*

**LHC Project Report 932**

# OPTICS FLEXIBILITY AND DISPERSION MATCHING AT INJECTION INTO THE LHC

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**Abstract**

The LHC requires very precise matching of transfer line and LHC optics to minimise emittance blow-up and tail repopulation at injection. The recent addition of a comprehensive transfer line collimation system to improve the protection against beam loss has created additional matching constraints and consumed a significant part of the flexibility contained in the initial optics design of the transfer lines. Optical errors, different injection configurations and possible future optics changes require however to preserve a certain tuning range. Here we present methods of tuning optics parameters at the injection point by using orbit correctors in the main ring, with the emphasis on dispersion matching. The benefit of alternative measures to enhance the flexibility is briefly discussed.

*Presented at*
*EPAC'06, Edinburgh, UK,*
*June 26-30, 2006*

CERN,
CH-1211 Geneva 23,
Switzerland
Geneva, June 2006

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*Abstract*

The LHC requires very precise matching of transfer line and LHC optics to minimise emittance blow-up and tail repopulation at injection. The recent addition of a comprehensive transfer line collimation system to improve the protection against beam loss has created additional matching constraints and consumed a significant part of the flexibility contained in the initial optics design of the transfer lines. Optical errors, different injection configurations and possible future optics changes require however to preserve a certain tuning range. Here we present methods of tuning optics parameters at the injection point by using orbit correctors in the main ring, with the emphasis on dispersion matching. The benefit of alternative measures to enhance the flexibility is briefly discussed.

## INTRODUCTION

Matching the optical parameters of the transfer line to the LHC optics at the injection point is crucial for optimum performance. Any optics mismatch would result in unwanted emittance blow-up and finally deteriorate beam quality and luminosity. The LHC design goal is to keep the emittance increase from the SPS extraction up to collision in LHC below 7% (from 3.5 to 3.75 $\mu$m normalised emittance).

We already know from earlier studies [1–3], that a good matching has been achieved for the current design optics, but that the flexibility to optics changes has become rather limited after adding additional constraints (collimation system). Larger changes may require repositioning of magnets and collimators. The design optics parameters are listed in Table 1.

Here we study to which extent dispersion bumps in the LHC can be used to match changes in dispersion at the interaction point. This will be illustrated for injection from TI 2 and using horizontal bumps in the LHC. The results for TI 8 or vertical orbit bumps are very similar.

## TI 2 & IR2 LAYOUT, PARAMETERS AND CONSTRAINTS

The insertion region IR2 is shown in Fig.1. The beam coming from the SPS via TI 2 is deflected *horizontally* at the Septum (`MSI`) and then kicked *vertically from below* onto the LHC orbit at the Injection Kicker (`MKI`). The injection point (`LHCINJ.B1`) is $1.3$ m from the last `MKI` kicker element.

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Table 1: Optics parameters at injection points. The range in dispersion covers planned changes in separation and crossing angles.

| *Expected range of parameter at* | | | LHCINJ.B1 | LHCINJ.B2 |
|---|---|---|---|---|
| Hor. orbit | $x$ | [mm] | − 1.107 | ± 0.958 |
| Ver. orbit | $y$ | [mm] | ± 1.136 | − 0.527 |
| Hor. $\beta$-function | $\beta_x$ | [m] | 57.44 | 53.23 |
| Ver. $\beta$-function | $\beta_y$ | [m] | 67.37 | 75.20 |
| Hor. dispersion | $D_x$ | [cm] | − 10.2/− 15.0 | − 8.0/− 18.0 |
| Ver. dispersion | $D_y$ | [cm] | − 3.4/ 5.3 | 0.0/ 5.2 |

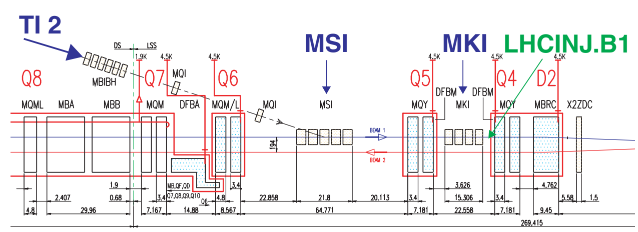


Figure 1: Horizontal view of the IR2 region of the LHC. Beam 1 is injected onto the LHC orbit at the MKI (injection kicker, located between Q5 and Q4) via a *vertical* kick.

The optics solution in IR2 must obey a wide range of boundary conditions, which are fulfilled by the LHC optics V6.5. Details can be found in [4, Sec. 4.2.3]. We only want to change the dispersion function at the injection point, however at the same time we have to fulfill several constraints:

- Keep optics outside of IR2 unchanged, hence $\beta_x, \beta_y, \alpha_x, \alpha_y, D_x, D_y, D'_x, D'_y, x, y, p_x, p_y$ at the entry and exit of IR2 must stay constant.
- Keep total phase advance $\mu_{x,y}$ over the IR constant.
- Provide vertical phase advance of 90° between `MKI` and injection absorber `TDI`, and a vertical phase advance of (360°− 20°) and (180°+ 20°) between `TDI` and the other auxiliary collimators.
- Remain within the corrector strength limits.
- Orbit and beam size must not exceed aperture limits of LHC, which are very tight at injection energy ($7.5\,\sigma$).

At injection, with the exception of early commissioning and special conditions, the separation bumps and crossing angles will be turned on as shown in Fig.2.

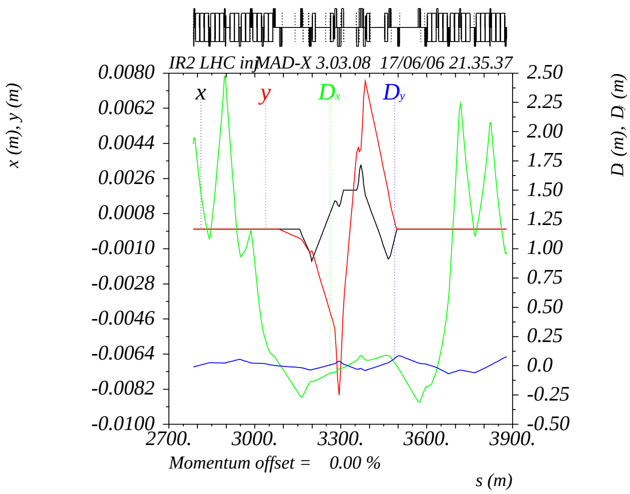


Figure 2: Crossing scheme and Dispersion for Beam 1 at injection for IR2.

## DISPERSION

The dispersion function $D(s)$ describes the momentum-dependent part of transverse particle motion. Off-momentum particles receive a different bending force in a dipole field and the resulting change in orbit is given by the dispersion function

$$D(s) = \frac{\sqrt{\beta(s)}}{2\sin\pi Q} \oint \frac{\sqrt{\beta(t)}}{\rho(t)} \cos\left(|\Phi(t) - \Phi(s)| - \pi Q\right) dt, \tag{1}$$

where $\beta$ is the local $\beta$-function, $\Phi$ is the local phase advance, $Q$ is the tune and $\frac{1}{\rho}$ is the local curvature. From this we see that any change in local bending angle $k_0 = \frac{1}{\rho}$ (e.g. in an orbit corrector) will change the dispersion function all around the machine; it will create a *dispersion wave*. This will be used to adjust the dispersion function at the injection point.

## TUNING POSSIBILITIES IN LHC

A strategy to adjust the dispersion function at the injection point is to

- create a closed orbit bump left of the IP in order to generate a dispersion wave,
- create a second closed orbit bump right of the IP to close the dispersion wave, i.e. keep it local in IR2,
- and finally fine-tune the bumps to match the constraints.

At a point with left–right symmetric optics, a closed dispersion correction can be achieved both with symmetric or anti-symmetric orbit bumps. The LHC optics is not symmetric with respect to the injection points and we have to apply more general, only approximately symmetric same– or opposite–sign orbit bumps.

### *Anti-symmetric orbit bumps*

Fig. 3 shows an approximately anti-symmetric solution using a 3-corrector bump left and a 4-corrector bump right of IP2. The dispersion wave has a zero-crossing close to the injection point and we have to discard this option.

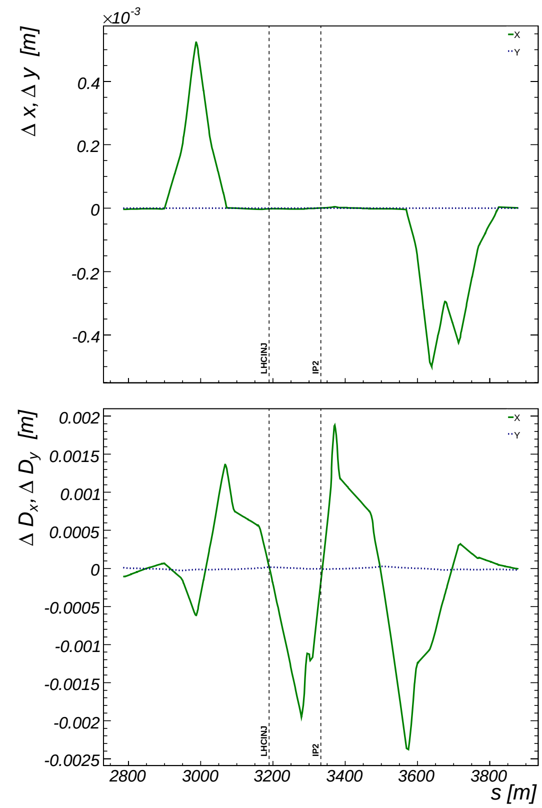


Figure 3: Anti-symmetric orbit bump solution: Changes in orbit (top) and resulting dispersion (bottom).

### *Symmetric orbit bumps*

The dispersion wave created by the first orbit bump can also be closed by a second *symmetric* orbit bump. This solution is shown in Fig. 4.

We see that a symmetric bump allows to control the dispersion at the injection point and that changes of the $\beta$ function are rather small. We also see that orbit deviation and dispersion are of similar size. As the LHC aperture at injection is very tight, we have to conclude that pairs of bumps around the IP will not be practical to adjust the dispersion at the level of several centimetres.

### *Resonant orbit bumps*

We saw that pairs of orbit bumps are not sufficient to adjust the dispersion at the injection on the level of 10 cm. We also investigated if resonant correction [5] can be applied using many bumps which coherently add up contributions to the dispersion wave. For the LHC which is limited in aperture in the arcs at injection, this may well turn out to

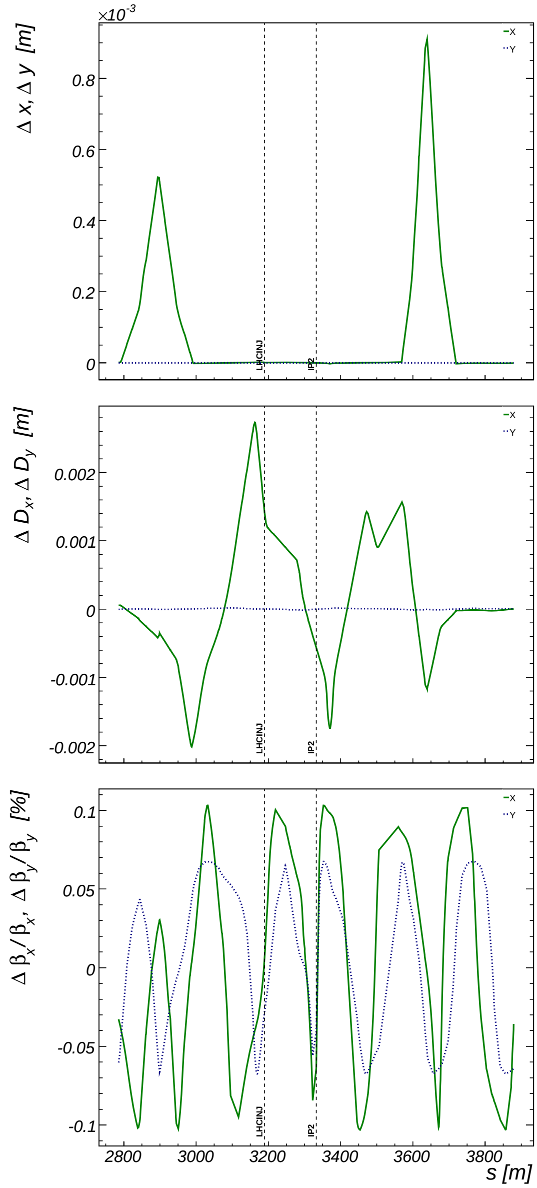


Figure 4: Symmetric orbit bump: Changes in orbit (top), resulting dispersion (middle) and changes in $\beta$ (bottom).

be not practical either. Fig. 5 shows an attempt to reduce dispersion mismatch at the injection point. The superposition of seven 1 mm-orbit bumps results in about 7 mm of dispersion change at the injection point.

## CONCLUSION AND OUTLOOK

The transfer line optics are well matched to the LHC.

The LHC aperture at injection is rather tight. In the transfer lines, the optics is strongly constrained by phase advance relations between transfer line collimators which were added at a later design stage.

There is little room for optics matching at injection. In particular, we find, that dispersion matching on the level of centimetres using orbit bumps at injection in the LHC will

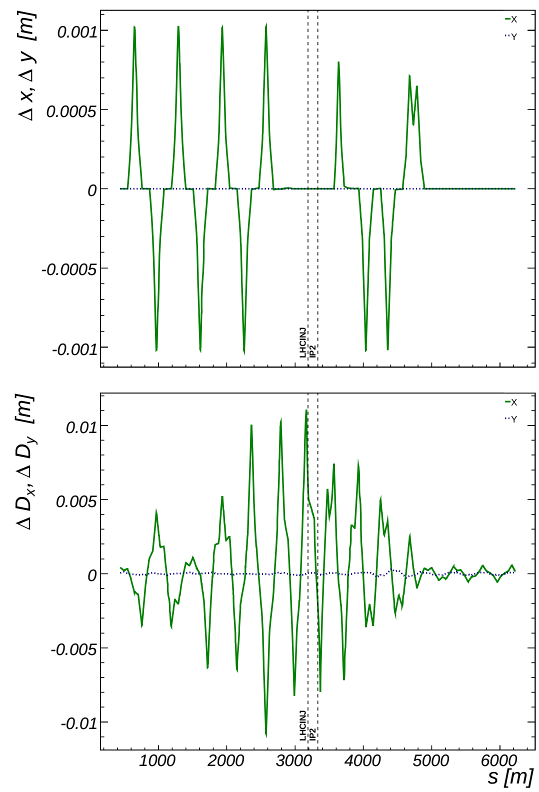


Figure 5: Using resonant orbit bumps: Changes in orbit (top) and resulting dispersion (bottom).

not be practical. We conclude that, to perfectly accommodate larger optics changes, hardware modifications will be required.

The restriction to tight phase advance relations between the transfer line collimators could be relaxed by adding more collimators. The price for a transfer line collimator (about 160 kCHF including control) is lower than the cost of a power converter and cables to control an extra quadrupole.

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