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Response Matrix and Dispersion Study of the TI2 Transfer Line

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Abstract

The optics of the TI 2 transfer line was studied with beam trajectories during its commissioning in October 2007. The optics and the quality of the steering magnets and of the beam position monitors were determined from steering magnet response measurements. A strength error of the main quadrupoles was identified with this technique. The dispersion was measured and found to be close to the nominal value.

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1 Introduction

The transfer line TI 2 from the SPS to LHC ring 1 was commissioned in October 2007, 3 years after the transfer line TI 8 from the SPS to LHC ring 2. The beam time was devoted to studies of the line optics and aperture studies.

This note present results of a response data and dispersion analysis of the transfer line.

2 Response Measurements

The observation of the trajectory response to controlled dipole corrector magnet deflections is a simple, yet powerful method to gain insight into the optics model of a ring or of a transfer line [1, 2]. From a systematic measurement of the response for each corrector magnet information can be obtained on the optics model, beam position monitor quality and orbit corrector calibrations with an appropriate data analysis. At the SPS response measurements and optics verifications have been performed successfully for the ring [2], the TT10 , the TI8 [3] and the TT41 [4] transfer lines.

A response measurement of all steering magnets (corrector) was performed as a part of the TI 2 commissioning. The data quality was good considering that all measurements were performed with pilot bunches for which the typical r.m.s. noise is 0.23 mm.

The fits immediately revealed a problem with two pairs of orbit correctors, one pair in each plane. The responses of correctors MCIAH.272 and MCIAH.274 were exchanged in the horizontal plane, and pairs MCIAV.243 and MCIAV.245 in the vertical plane. Those errors came as a surprise, since all correctors of the transfer line had been individually tested for polarity and cabling errors only a few weeks before the test.

A good fit quality was rapidly obtained with the following free parameters:

- individual calibration factors for all monitors,
- individual calibration factors for all correctors,
- strengths of the three main quadrupole strengths (one vertical and 2 horizontal strings).

The fit residuals are practically consistent with the measurement noise. The fit does not reveal any BPM scale error assuming that the average corrector calibration is correct.The individual monitor and corrector calibration spread are around 4%. The spreads can be explained by the monitor noise and agree with simulations performed with similar noise levels. The results for the strengths are given in Table 1 together with the results from the TI 8 transfer line [3]. For the vertical plane the phase advance error is close to 0.7% (the phase advance is larger than nominal) which is almost identical to the result found for TI 8. While for TI 8 there was no error in the horizontal plane, a clear phase advance error is also visible. The origin of this difference is not clear, but it is possible that the momentum setting of TI2 may have been incorrect, which could explain some of the effect. This must be confirmed by future measurements. At the entrance of the LHC, the accumulated phase advance errors are $23°$ in the horizontal and $39°$ in the vertical plane. It is also interesting to note that similar errors were found for the TT41 transfer line to the CNGS target [4], which points towards a systematic effect common to all the new SPS transfer lines.

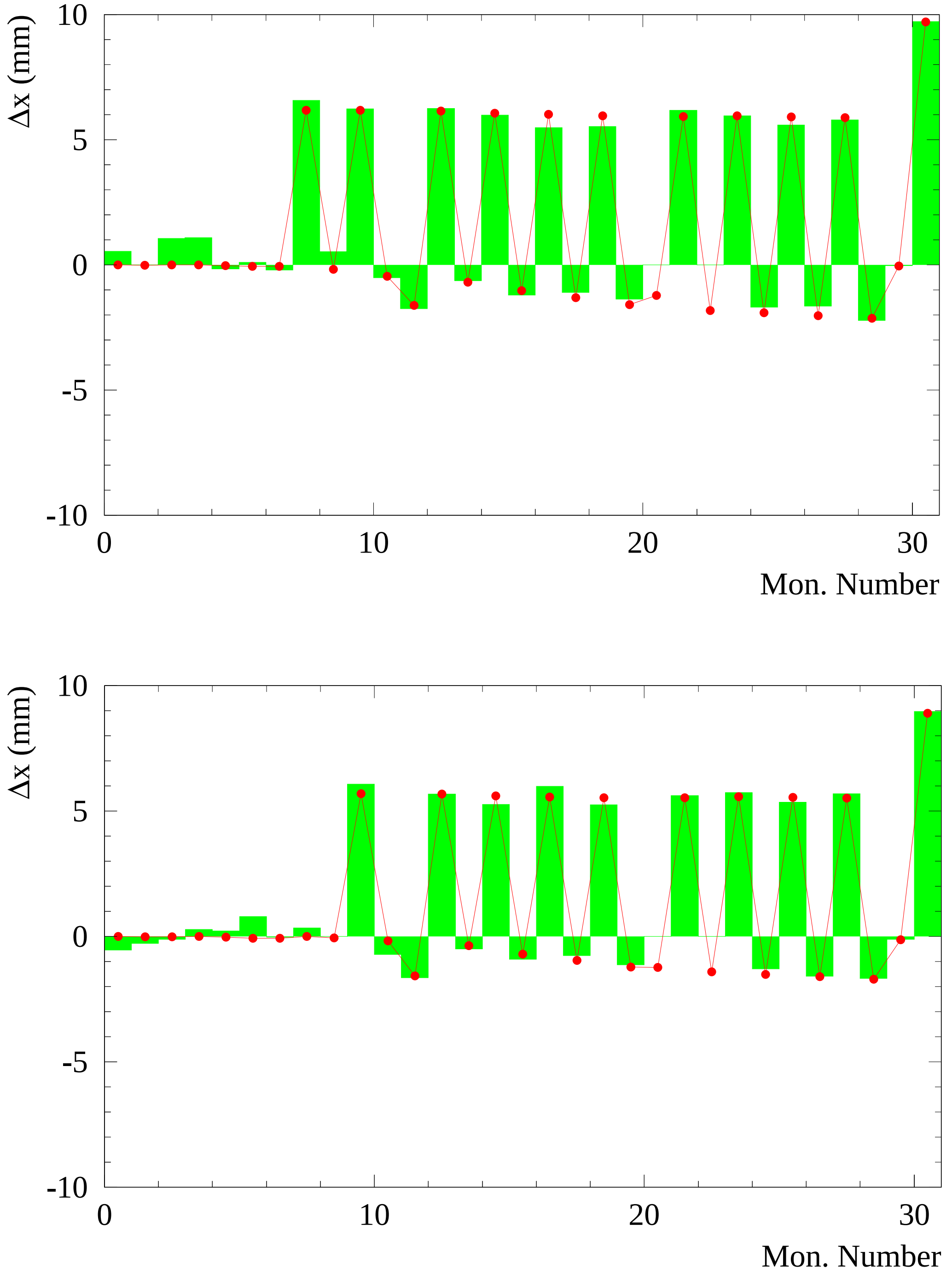

Figure 1: Example of response data for the horizontal plane (top : corrector MCIAH.208, bottom: corrector MCIAH.216). The histogram represents the data corrected by calibration factors, while the line and points correspond to the model response after fit.

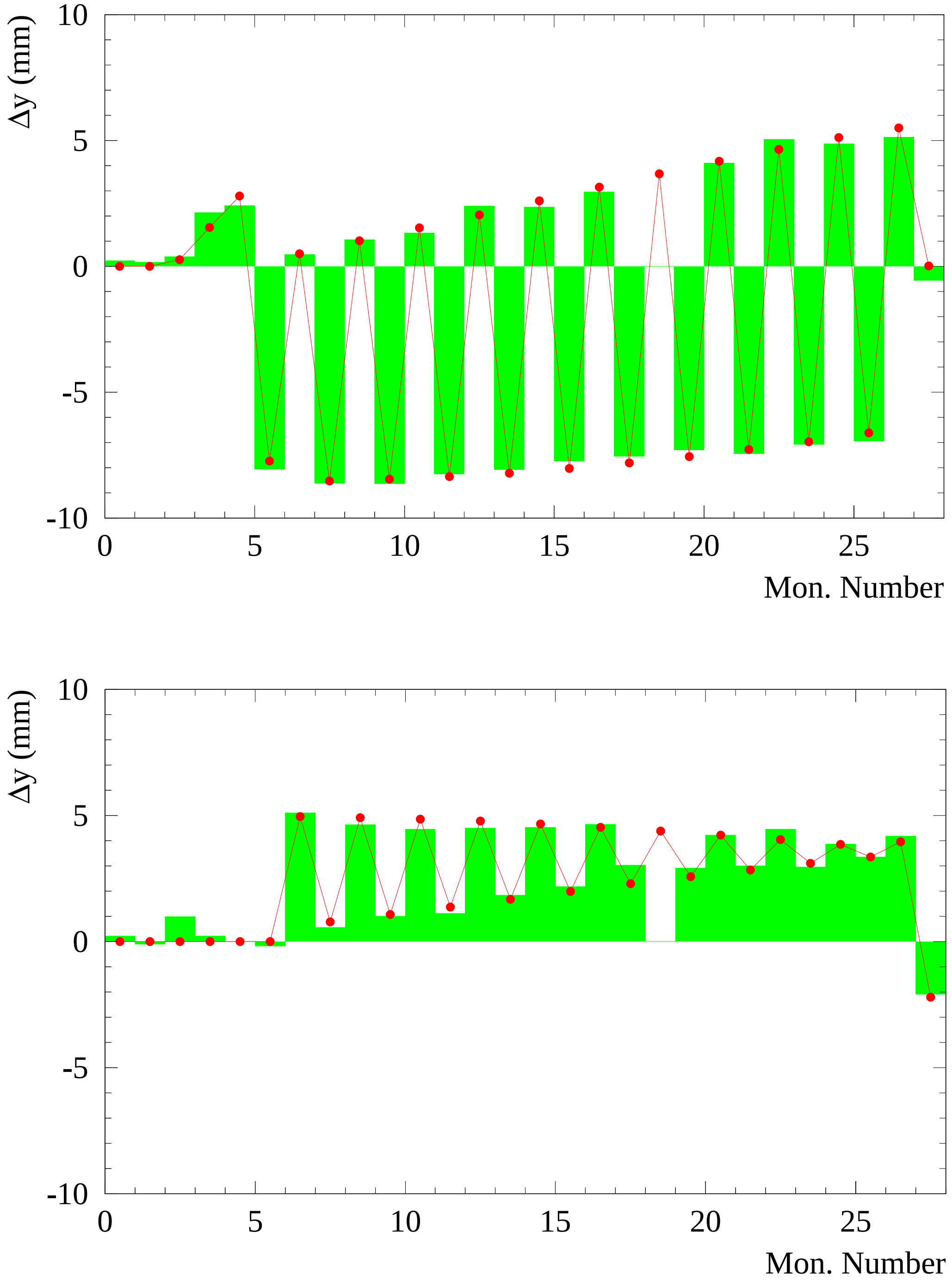

Figure 2: Example of response data for the vertical plane (top : corrector MDLV.6103, bottom: corrector MCIAV.205). The histogram represents the data corrected by calibration factors, while the line and points correspond to the model response after fit.

Fit Strength		Fit	Nominal	Line
kqid.87100	(m^{-2})	-0.03410	-0.03388	TI8
kqif.87000	(m^{-2})	$+0.03384$	$+0.03386$	
kqid.20700	(m^{-2})	-0.03411	-0.03385	
kqif.20800	(m^{-2})	$+0.03407$	$+0.03385$	TI2
kqif.26000	(m^{-2})	$+0.03397$	$+0.03385$	

Table 1: Fit results for the main quadrupole chains of TI2 and TI8 (from [3]). The results for the vertical plane are very consistent for both lines. For the horizontal plane there was no error for TI8, while there is a significant deviation for TI2. The errors on the strength are in the range of $\pm 0.0002 \mathrm{m}^{-2}$.

3 Dispersion

The dispersion was measured by recording the trajectory in TI2 as a function of the beam momentum in the SPS. The beam momentum of the SPS was changed by radial steering (RF frequency change) over an interval of -0.11% to $+0.44\%$. The dispersion was determined for each BPM individually by a fit of the position versus momentum offset in the SPS. Within the selected range the fits were linear within the estimated measurement errors.

The dispersion fit is based on the assumption that the dispersion error is due entirely to an error on the initial conditions, i.e. the origin is in the SPS ring. In that case the dispersion error $\Delta D(s)$ follows a simple betatron oscillation and can be expressed as

$$\frac{\Delta D(s)}{\sqrt{\beta(s)}} = \left(\frac{\alpha_0\, \Delta D_0}{\sqrt{\beta_0}} + \sqrt{\beta_0}\, \Delta D_0'\right) \sin\mu(s) + \frac{\Delta D_0}{\sqrt{\beta_0}} \cos\mu(s) \quad (1)$$

$$= C \sin(\mu(s) + \phi) \quad (2)$$

where the constants ΔD_0 and $\Delta D_0'$ are the errors on the initial dispersion and dispersion derivative. β, μ and α refer to the usual twiss parameters. Index $'0'$ refers to the start of the line $(s = 0)$. The constant C is useful to estimate the envelope of the dispersion error at a given point, since $\Delta D_{max}(s) = C\sqrt{\beta(s)}$. C is directly related to the dispersion mismatch factor J which expresses the geometrical emittance blowup due to the dispersion error. J is given by [5]:

$$J = 1 + \frac{C^2}{2\epsilon}\left(\frac{\sigma_p}{p}\right)^2 \quad (3)$$

where ϵ is the emittance and $\frac{\sigma_p}{p}$ the r.m.s. energy spread.

The fit result refers to the transfer line optics after correction of the main quadrupole errors described in Section 2, i.e. using the strengths given in Table 1. The individual calibration of the BPMs are not taken into account since their average scale is consistent with 1 and their spread dominated by the measurement noise. The momentum error estimate obtained from the SPS BPMs is however corrected by a factor 1.1 to take into account the scale error of the SPS BPMs. It must be noted that without this scale factor of 1.1 the fit quality is slightly better, but the actual results for the initial condition errors are small and practically within the errors given in Figure 3.

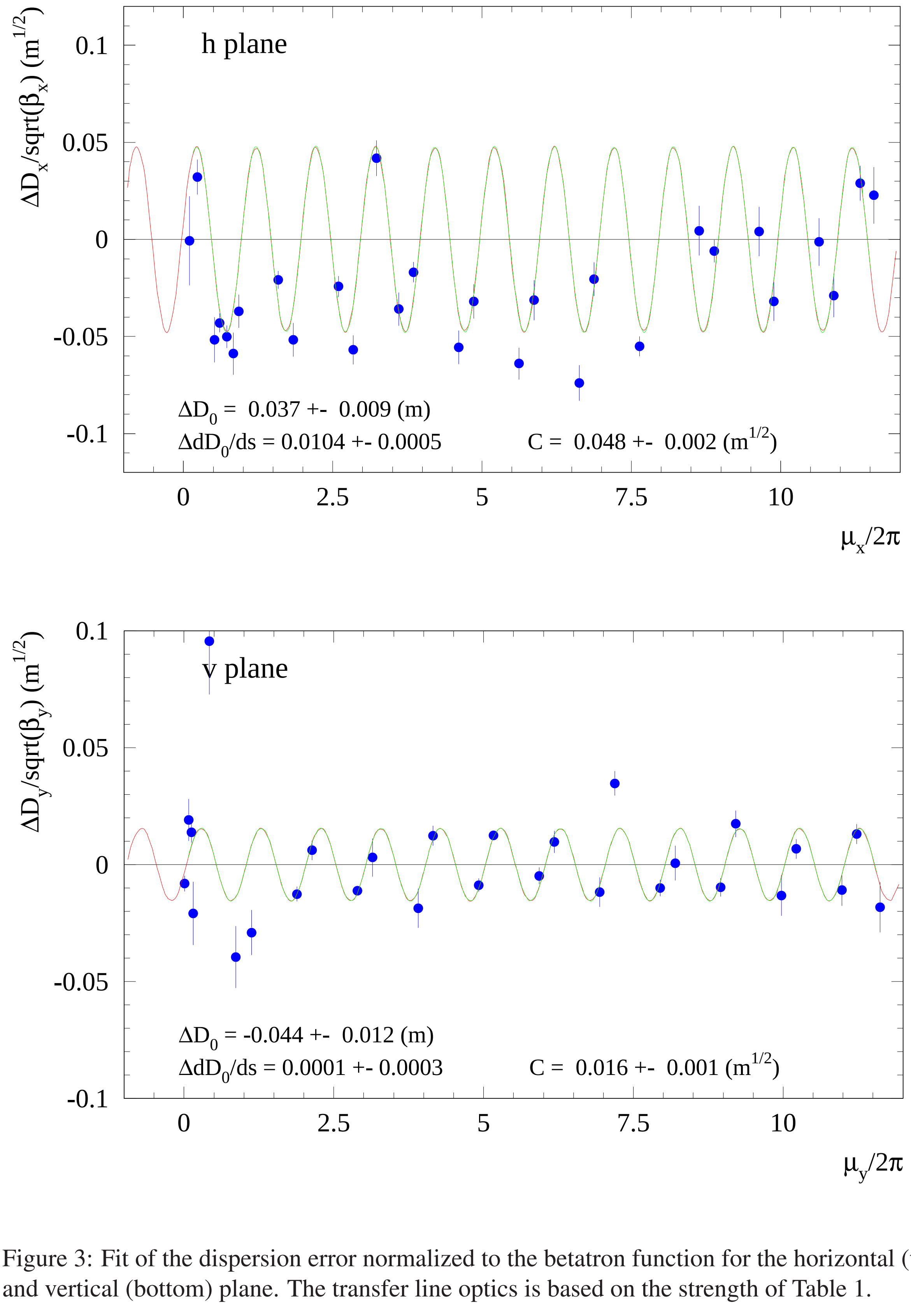

Figure 3: Fit of the dispersion error normalized to the betatron function for the horizontal (top) and vertical (bottom) plane. The transfer line optics is based on the strength of Table 1.

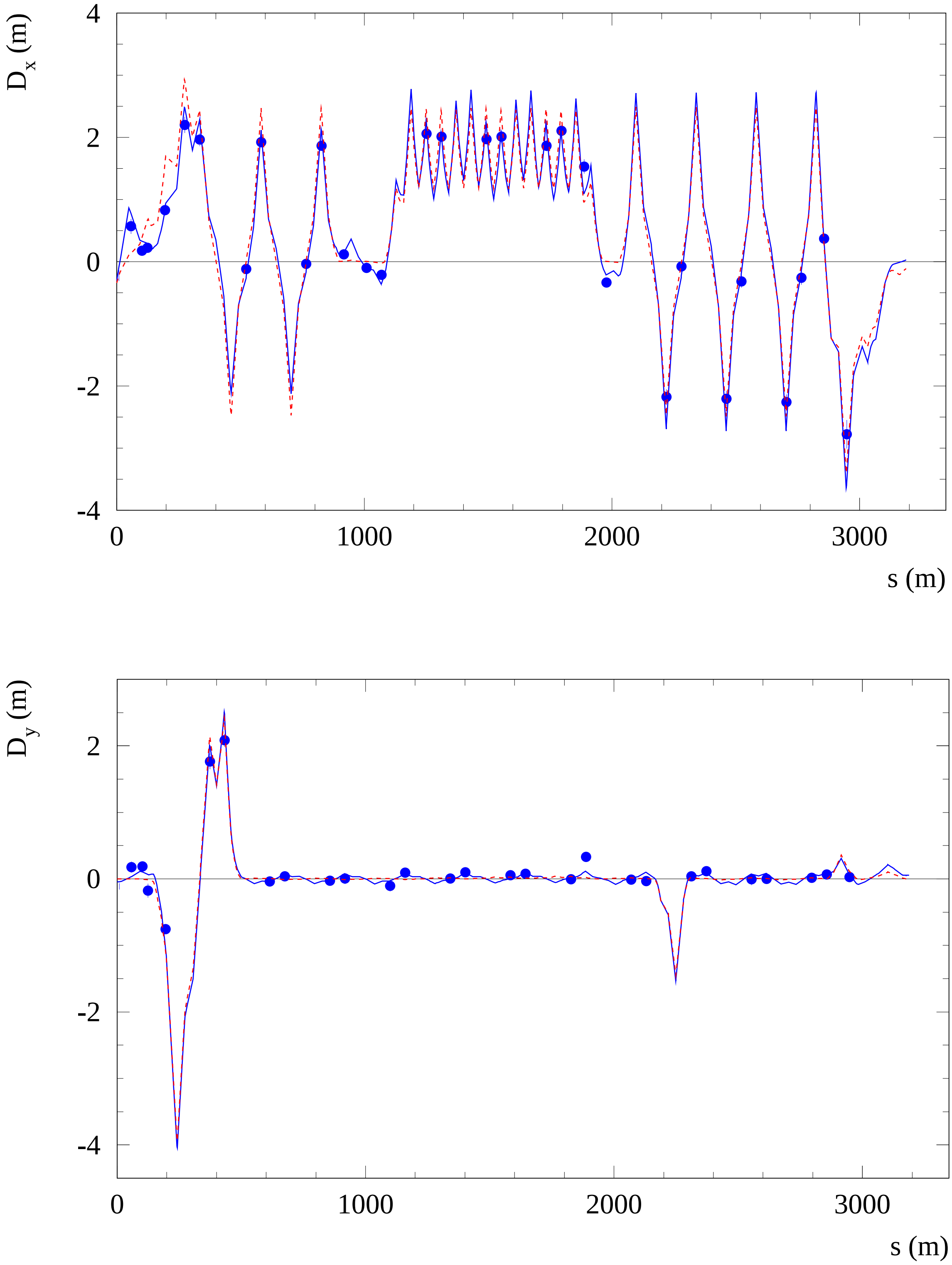

Figure 4: Fit results for the horizontal (top) and vertical (bottom) dispersion. The data points and the fitted dispersion are plotted in blue (point and solid line). The dashed red line corresponds to the unperturbed nominal dispersion.

Figure 3 presents the fit of the normalized dispersion error $(D_{meas} - D_{model})/\sqrt{\beta}$ as a function of the nominal phase advance. The errors on the initial conditions are small, in the range of 4 cm. The measured dispersion is shown together with the fit result and the nominal dispersion (with nominal quadrupole strengths) in Figures 4. The agreement is rather good all along the line. The main effect of the dispersion error is the introduction of a dispersion mismatch at the entrance of the LHC. Using the constant C introduced above, it is possible to estimate the maximum dispersion error in the LHC ($\beta = 180$ m) to be ≈ 60 cm in the horizontal plane and $\approx$ 20 cm in the vertical plane. The value for the horizontal plane is not negligible compared to the peak dispersion in the LHC arcs of 2.1 m. The associated horizontal dispersion mismatch factor is however only 1.02 (for $\epsilon^* = 3.5$ μm and $\frac{\sigma_p}{p} = 3 \times 10^{-4}$), indicating that the emittance blowup due to the dispersion error is small. The vertical dispersion mismatch factor is negligible.

4 Conclusion

The actual optics of the TI 2 transfer line is very close to the nominal model. The response data analysis reveals errors of up to $\approx$ 0.7% on the main quadrupole strengths. The error are similar to what has been observed for TI 8 and CNGS. For the CNGS transfer line the error has been successfully corrected [4]. Dispersion errors coming from the SPS ring are small, and the geometrical emittance blowup due to the dispersion mismatch is only 2%.

5 Acknowledgments

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