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andreas.wegscheider@cern.ch

MD 2563: Optics measurement and corrections with half integer tune

Andreas Wegscheider, Jaime Coello de Portugal, Joschua Dilly, Stéphane Fartoukh, Elena Fol, Ana Garcia-Tabares, Ewen H. Maclean, Yannis Papaphilippou, Dario Pellegrini, Tobias Persson, Rogelio Tomás

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Summary

This note reports on the optics measurement and correction actions that were performed during the study of the LHC at a working point close to the half integer resonance.

Contents

Objective:	Study of possibility to run the LHC close to half integer tune
MD#:	2563
FILL#:	6430
Beam Process:	`RAMP-SQUEEZE-6.5TeV_ATS-2017_V3_V1@0_[START]_HalfIntegerTune`
Date:	28/11/2017
Start Time:	08:00
End Time:	15:00
Beams:	1 and 2

Table 1: MD parameters

1 Introduction

The latest update of the HL-LHC parameter tables foresees to operate with high chromaticity and octupoles. This has a dramatic effect on the dynamic aperture. Although it was possible to recover the DA by optimising the tune, the sensitivity to tune drifts highly increased due to the needed tune space.

Simulations performed with the current LHC settings showed that close to the half integer, more space is available to accommodate the working point [1]. The third integer is indeed limited by the presence of the nearby 10th order resonance, but this is not the case for the half integer.

The merit of the MD is to confirm the possibility to operate the LHC with a working point close to the half integer, as previously tested in 2011 [2, 3] exploring the lifetime sensitivity to tune drifts, with possible benefits both for the LHC and for the HL-LHC. Today much more experience, methodology and tools [4, 5, 6, 7, 8, 9] are available to correct and control this optics.

2 Measurement Summary

An overview of the MD parameters is given in Table 1.

The OMC actions for the MD envisaged the commissioning of beam optics with a working point near the half integer. This includes coupling correction and global optics corrections. A detailed list of the measurement can be seen in Table 3.

Setup and first measurements

The MD started with nominal ATS [10] injection optics [1] matched to the tunes $(Q_x,\ Q_y) = (0.31,\ 0.32)$. The optics of the RF insertion was rematched for both beams in order to shift the IR phase by $(\delta Q_x,\ \delta Q_y) = (+0.10,\ +0.11)$. As a result a new injection optics was made available [2] corresponding to the new working point $(Q_x,\ Q_y) = (0.41,\ 0.43)$ with no change on the nominal β functions (outside of IR4). In particular the betatron phase differences

[1] `/afs/cern.ch/eng/lhc/optics/runII/2017/opticsfile_new.1`
[2] `/afs/cern.ch/eng/lhc/optics/runII/2017/MDhalfinteger/opticsfile_inj_62.41_60.43.madx`

$\mu_x - \mu_y$ inside the arcs and from arc to arc were not changed w.r.t. the nominal injection optics (since the tune split was kept quasi-constant and the change of optics localised in IR4). This justified the re-use of the nominal coupling correction knobs.

Because the changes are restricted to IR4 it was decided to tentatively re-use the nominal injection corrections obtained in the LHC commissioning earlier this year.

After injecting, the optics were changed to the newly created half-integer settings. The nominal injection corrections were trimmed in at the beginning of the MD. Driving the beam with the AC dipole was not possible because the driven tunes were outside the AC dipole's frequency bandwith $\nu_d \in [0.245, 0.355]$ [11]. The MKQ had to be set up for optics measurements. Meanwhile, coupling corrections were performed using the ADT-AC-dipole.

ADT-AC-dipole kicks for coupling and comparison to free kicks

The ADT measurement proposed the corrections shown in Table 2. After applying these

	real	imaginary
Beam 1	-0.0037	-0.0046
Beam 2	-0.0055	$+0.0021$

Table 2: Applied coupling corrections

corrections the remaining coupling was below 10^{-3} in both beams. Thus, the re-use of the nominal coupling knobs was fully confirmed. At the same time this was an occasion to compare ADT-AC-Dipole and free kicks in order to check the quality of the ADT-AC-Dipole compensation.

Performing free kicks for optics measurement and correction

β beating with nominal injection corrections was acceptable in beam 1 but high in beam 2 so a new correction was performed. Since the global phase advance has changed significantly w.r.t. nominal settings, it was decided to recalculate new corrections from the virgin machine. The nominal injection corrections were removed and kicks for measurement were performed.

While the corrections were calculated, OP measured lifetime with different tunes, ranging from (0.41, 0.45) to (0.43, 0.47). Results of the lifetime measurement can be found in [12].

After having finished the calculation of global optics correction they were trimmed in and kicks for verification were performed. The β beating in beam 1 could be reduced to an rms of 5.4 % in both planes with a peak of less than 20 % which is an improvement in the vertical plane compared to the nominal correctoins. The horizontal plane shows worse but comparable results. The final β beating of beam 2 – which was also initially significantly higher – could not be reduced to such a good value with around 15 % rms in both planes and a peak of 30 % – 35 %. Comparing the new corrections with the old ones, beam 2 profitted significantly from the dedicated corrections, especially in the vertical plane.

A summary of the values is given in Table 4 and a plot of the β beating can be seen in Fig. 1.

Figure 2 shows a comparison of nominal injection corrections and the newly calculated ones. In both beams the horizontal β beating is not remarkably better but in the vertical planes both beams show a clear improvement, especially beam 2. This is surprising since

08:04	Begin of MD, FILL 6430, tunes (0.41, 0.43) Nominal injection global corrections are in.
08:20	Starting setup of MKQ because using AC dipole is not possible
08:28	Automated coupling correction with ADT Beam1: **re** -0.0037, **im** -0.0046 Beam2: **re** -0.0055, **im** $+0.0021$
09:28	Chromaticities set to (2, 2)
09:39	Beta Beating measurement with ADT-AC-Dipole kicks.
09:49	Removing nominal injection global corrections
09:50 – 10:32	Chromaticity correction, then: On/Off momentum kicks with the ADT
09:58 – 10:33	Kicks with MKQ for global corrections
10:43 – 11:04	Lifetime measurement with different tunes (0.41, 0.45) – (0.43, 0.47)
11:14	Optics correction trimmed in, tunes back to (0.41, 0.43) chromaticities set to (2, 2)
11:15 – 11:42	Kicks after global correction, on/off momentum using the opportunity to compare ADT-AC-Dipole and free kicks
11:48 – 12:02	Analysing beta beating and dispersion before / after correction results are summarised in Table 4 and visualised in Figure 1, 3 and 4

Table 3: Measurement summary

		virgin machine		nominal inj. corrs		dedicated corrections	
		peak	**rms**	**peak**	**rms**	**peak**	**rms**
Beam 1	**hor**	30%	12.4%	14%	4.7%	15%	5.4%
	vert	50%	29.0%	17%	7.0%	20%	5.4%
Beam 2	**hor**	75%	35.4%	43%	18.1%	35%	16.3%
	vert	105%	46.6%	45%	22.1%	30%	14.1%

Table 4: Improvement of the β beating through global corrections

the optics only differ by the tune settings. It can be concluded that even for a small change in optics dedicated optics measurement and correction can be of benefit for the quality of the machine's operation.

On- and Off-momentum measurements were carried out and the normalised dispersion (Fig. 3) and dispersion (Fig. 4) were calculated.

The comparison of ADT-AC-dipole and free kicks (cf. Figure 5) shows a good agreement between the two methods.

3 Conclusions

Optics measurements were performed for the ATS optics at injection energy at a working point close to the half integer resonance. In comparison to the previous test [2, 3] the measurement quality increased significantly. Efficient optics corrections could be carried out. A dedicated correction for the given optics turned out to be superior to the correction obtained for nominal optics.

Given the still high amount of β beating after the corrections, especially in beam 2, another iteration of optics corrections would be needed to understand the source of these errors and to further correct.

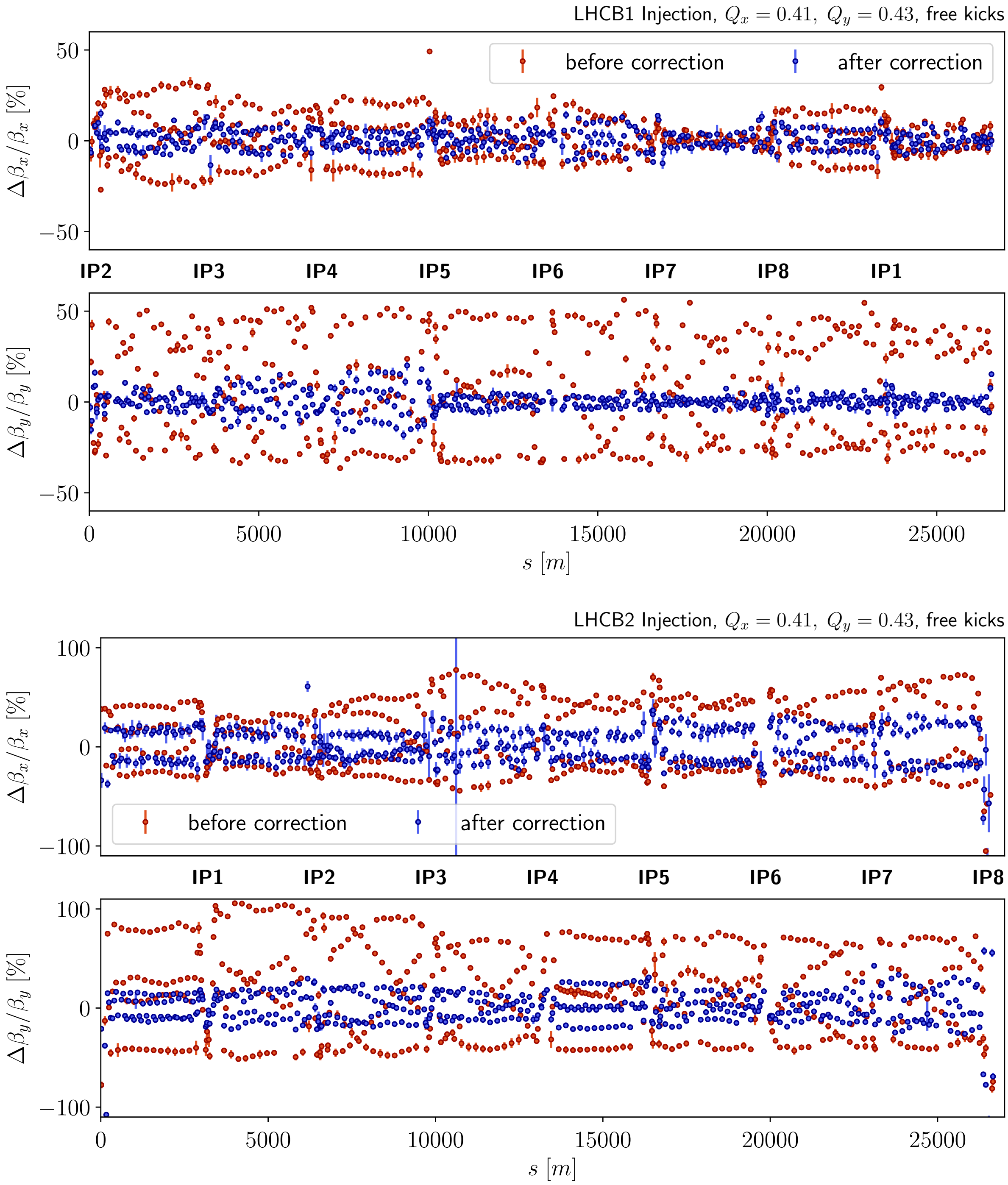

Figure 1: Comparison of β beating before and after global corrections.

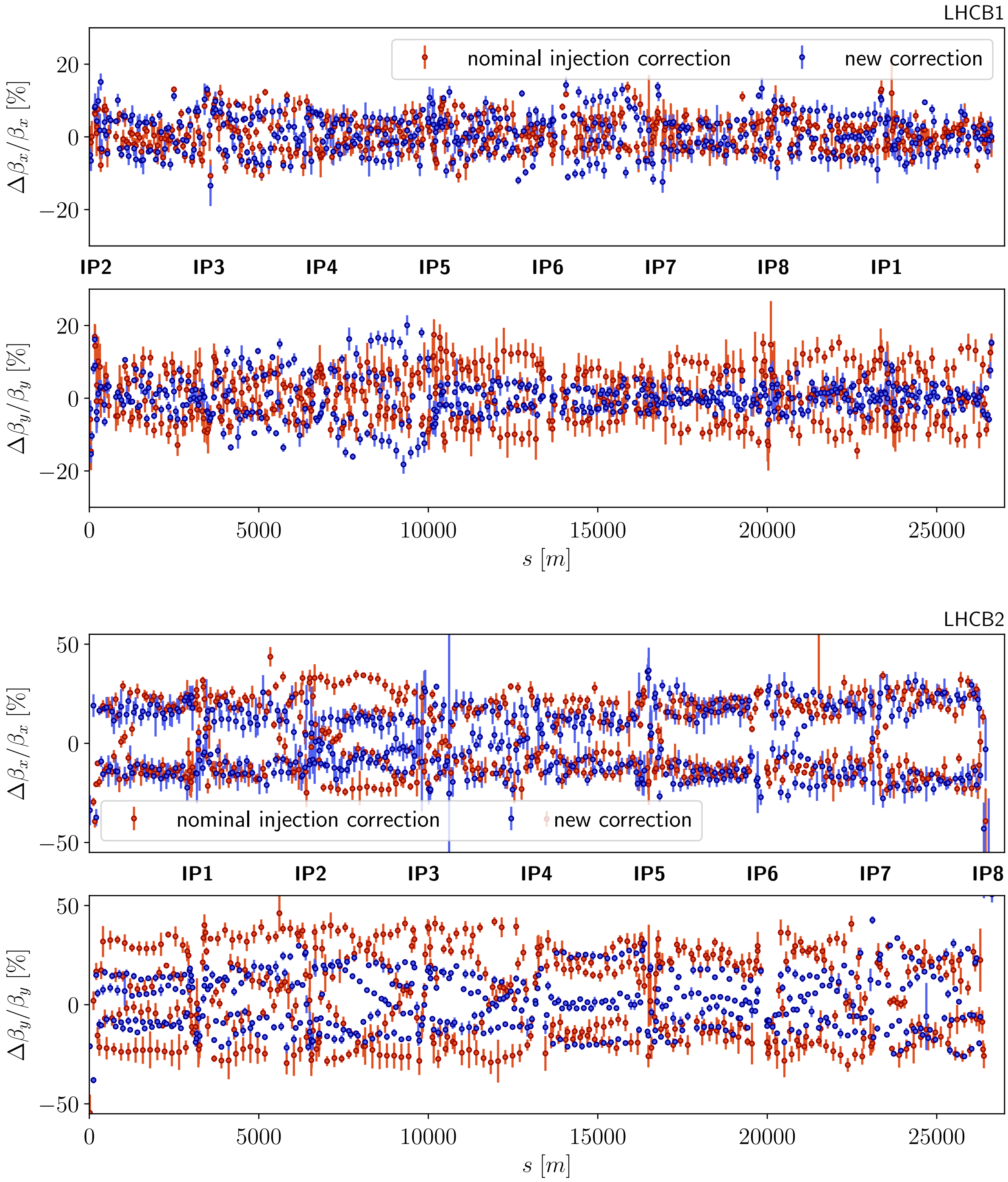

Figure 2: Comparison of β beating with nominal injection corrections and dedicated corrections at the new working point.

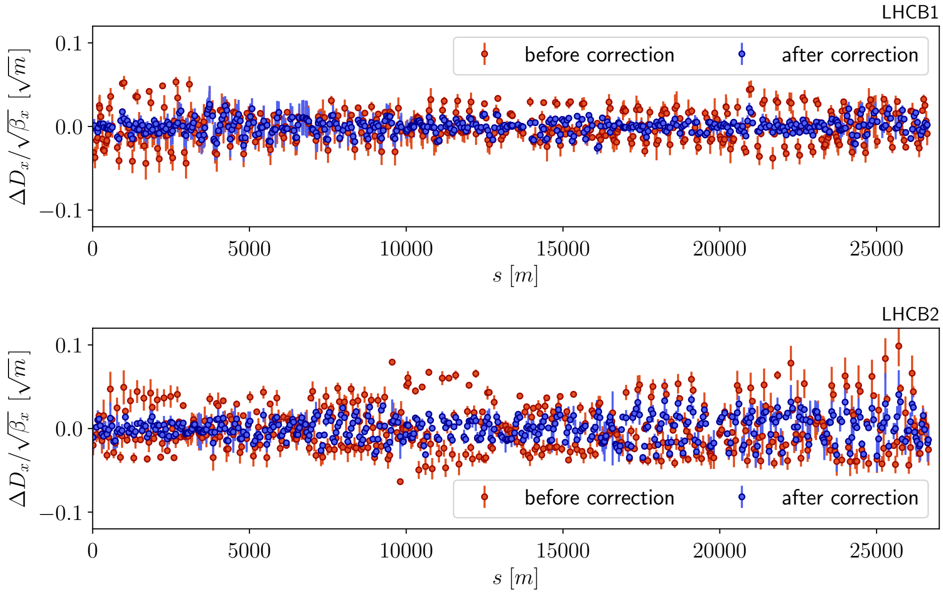

Figure 3: Normalised dispersion before and after global corrections.

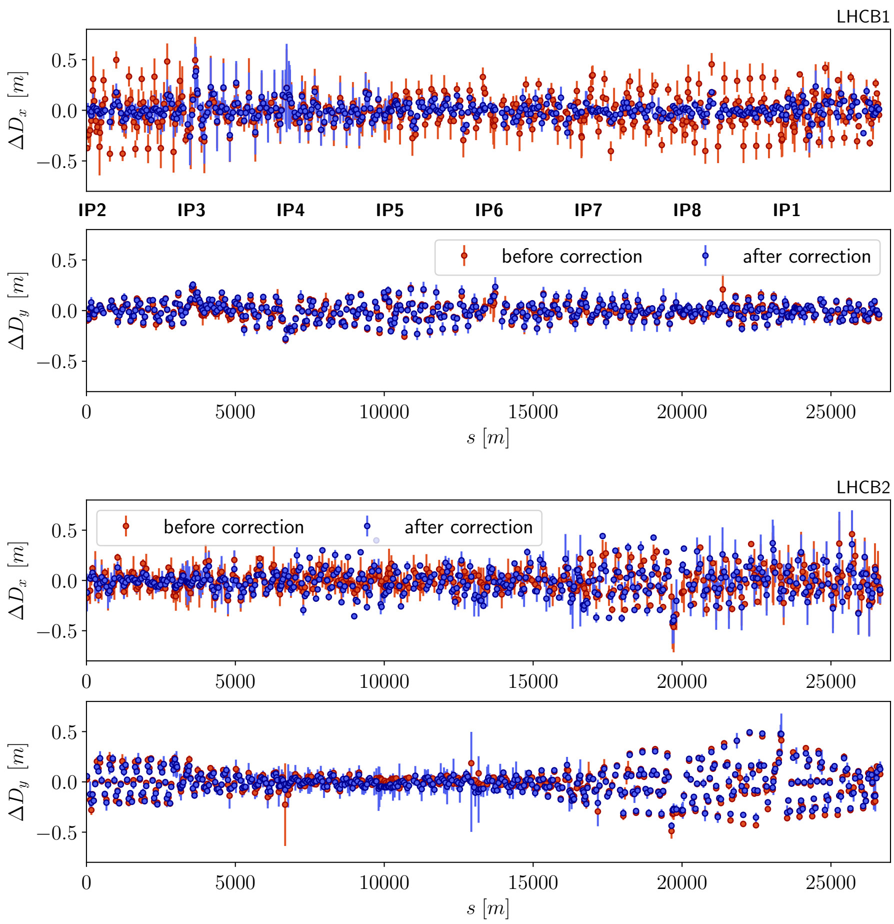

Figure 4: Dispersion before and after global corrections.

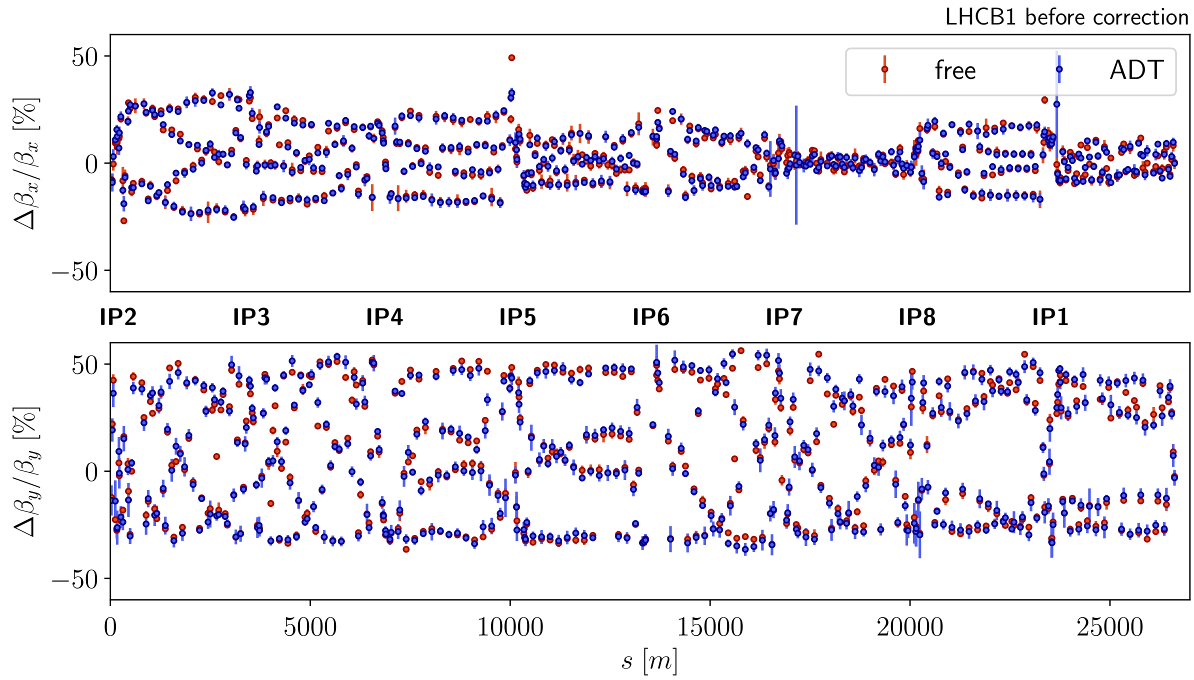

Figure 5: β beating with ADT-AC-Dipole and free kicks.

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