BPM displacement monitor

4th Dec. 2007, KEKB review committee

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1. Introduction

- As reported at the previous KEKB review committee, movement of beam position monitors(BPMs) due to the thermal stress of vacuum chambers has been observed both in LER and HER even though they are fixed to quadrupoles.

- As the beam orbit is continuously corrected based on the beam position measured by the BPMs, the displacement of the BPMs changes the beam position relative to magnets, then changes a linear optics. Especially the orbit error at a sextupole generates a dipole, quadrupole and skew-quadrupole component. Expected problems are,

  1) optics deviation in physics run from the corrected optics, because the optics is corrected at small current of 30 mA in order to avoid the hardware damage due to the beam loss during the correction,

  2) fluctuation of the optics in physics run if the saw-tooth pattern of the beam current is enhanced,

  3) change of the optics after recovery from the beam abort or startup after machine maintenance until the operation moves to the steady state.

•In order to measure the displacement of the BPMs and apply the correction to the BPM data, 232 gap detectors (118 in LER, 114 in HER) are in operation in this autumn run. Most of the detectors were installed in this summer shutdown.

measured displacement	the number of detectors	
	HER	LER
Sextupole to BPM*	104	108
QCS to BPM	2	2
Quad in Nikko straight section to BPM	4	4
(Vacuum duct to floor	8	0)

*All sextupoles are equipped with the gap detector.

•Main purpose is to correct the BPM movement near the sextupoles in order to maintain relative position between the origin of a BPM and a nearby sextupole.

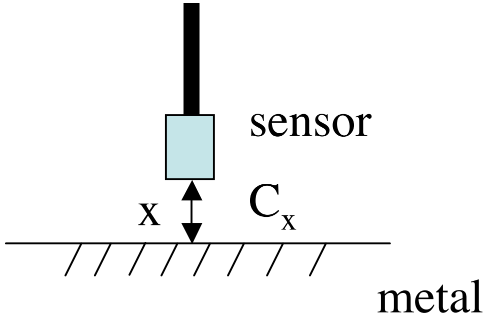
2. Monitor system

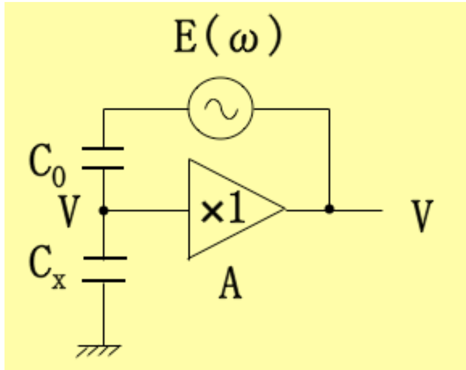
1) Gap detector

a) Specifications

method	electrostatic (capacitive)
channels	2
range (mm)	0.5 - 2.5
resolution (μm)	< 0.2
nonlinearity (%)	< ±0.3
frequency response (Hz)	0 - 100
temperature coefficient (μm/deg.)	< 0.2

Gap detector developed at KEK.



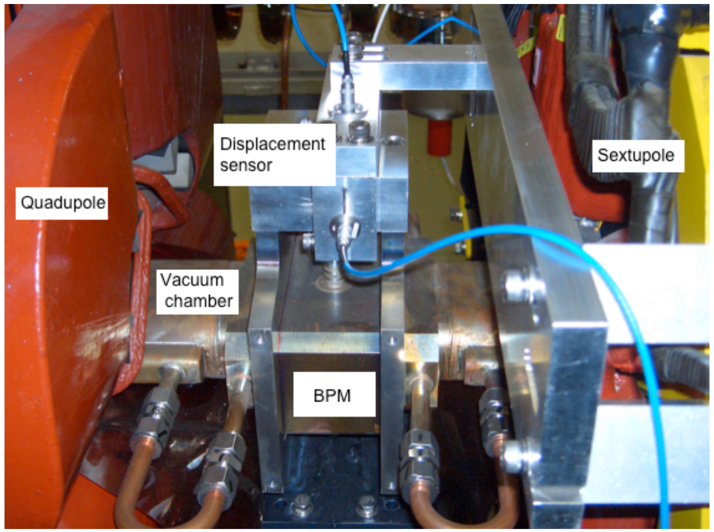


$$C_x = \varepsilon_0 \frac{S}{x},$$

$$V = \frac{C_0}{C_x} E = \frac{C_0 E}{\varepsilon_0 S} x$$

C_x = 0.89 - 0.18 pF

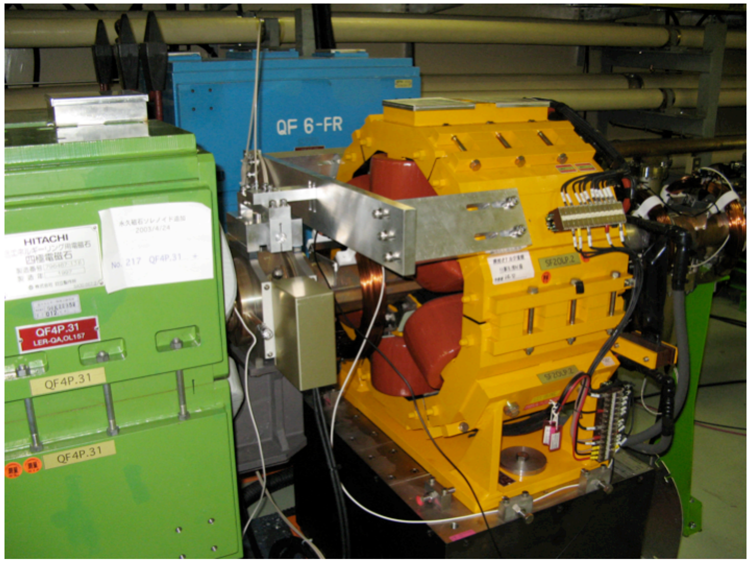
S: Area of sensor



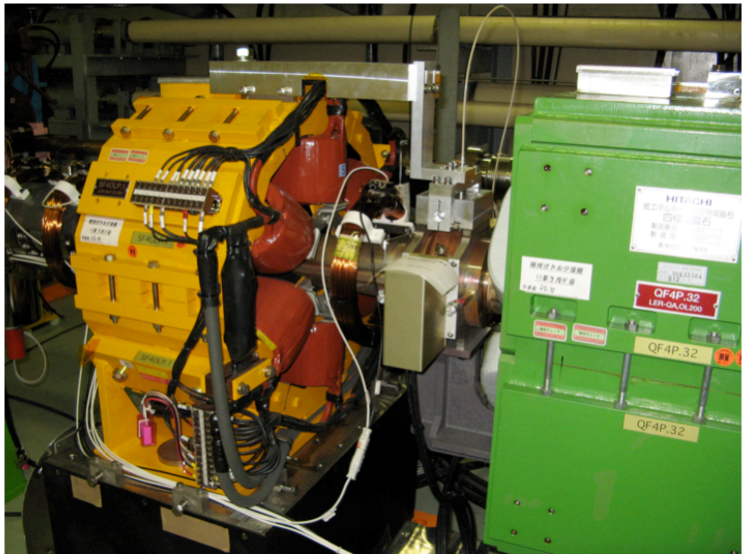
2) Fixing arm

- The gap sensors are fixed to a magnet with an aluminum arm of type A or B.
- The arm of type B, which was developed in cooperation with the magnet group, is fixed to a top surface of a quadrupole magnet to avoid the interference with parts of the magnet.

Type A



Type B

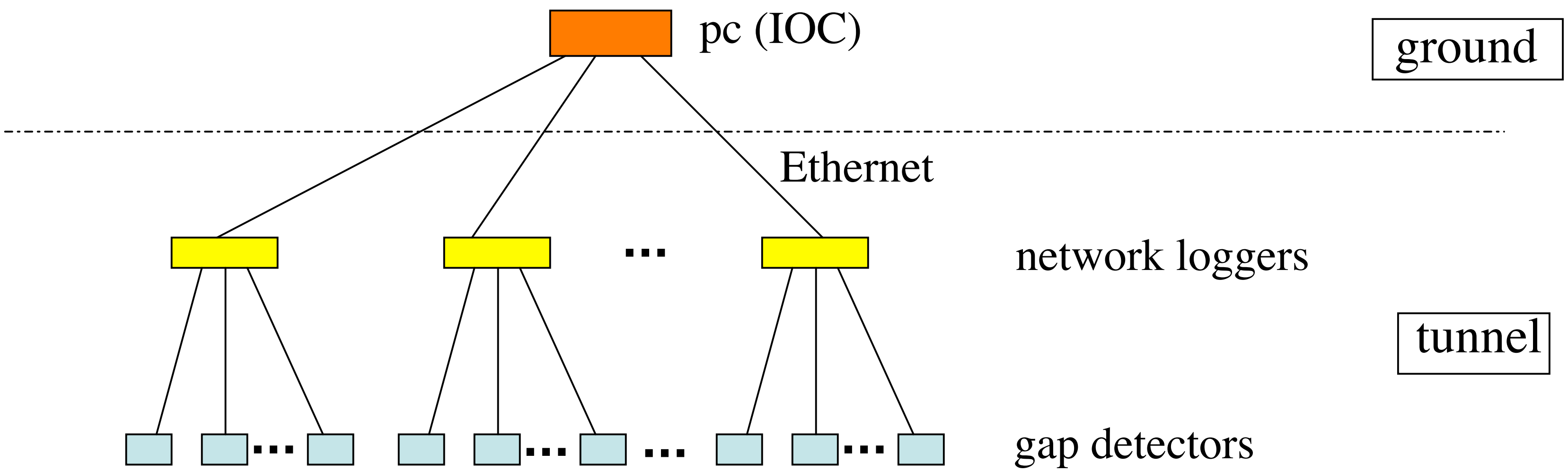


3) Data acquisition

•Signals from the gap detectors are A/D-converted, then transferred to an IOC by 12 network loggers.

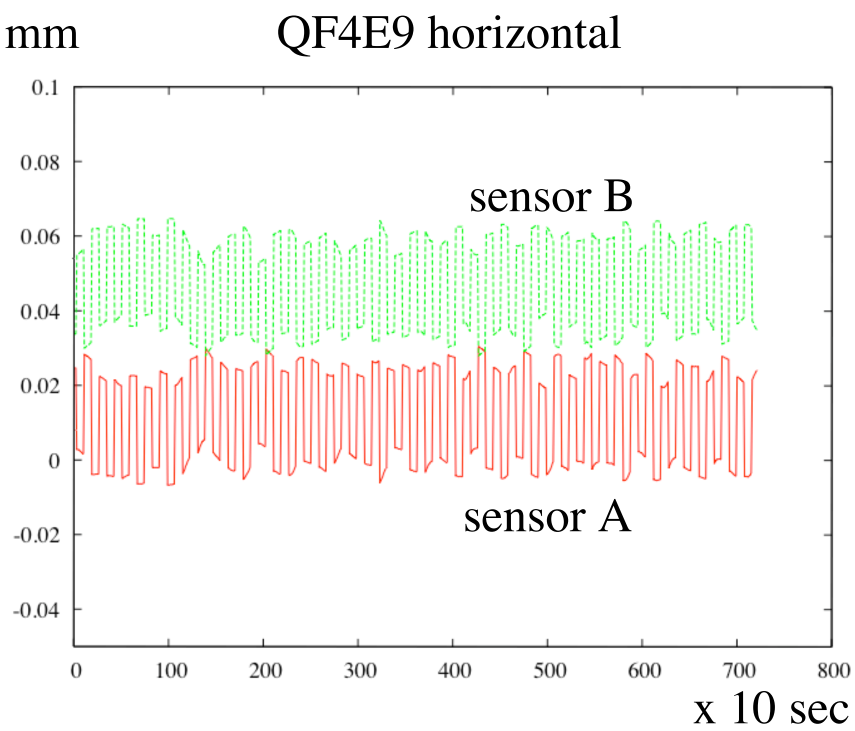
•A problem is that some loggers stop the data taking with frequency of roughly once per two weeks.

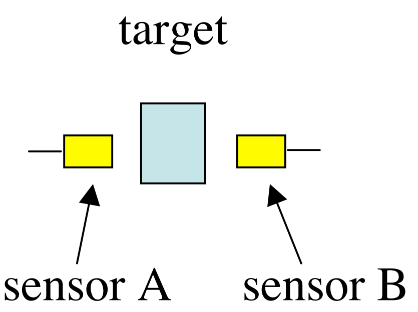
The problem might be resolved by modifying the firmware of the loggers supplied by a company. The firmware was replaced last week.



4) Alarm

- A simple alarm system has been implemented in order to detect a fault of the gap detectors. The system detects a sudden change of the data or no change of the consecutive data in an interval.
- As the system is not redundant, namely one sensor for one direction, a decision whether "abnormal" data is due to the fault or the real movement is not easy as shown in an example below.
- Operation experience might be necessary to have a sophisticated alarm system.



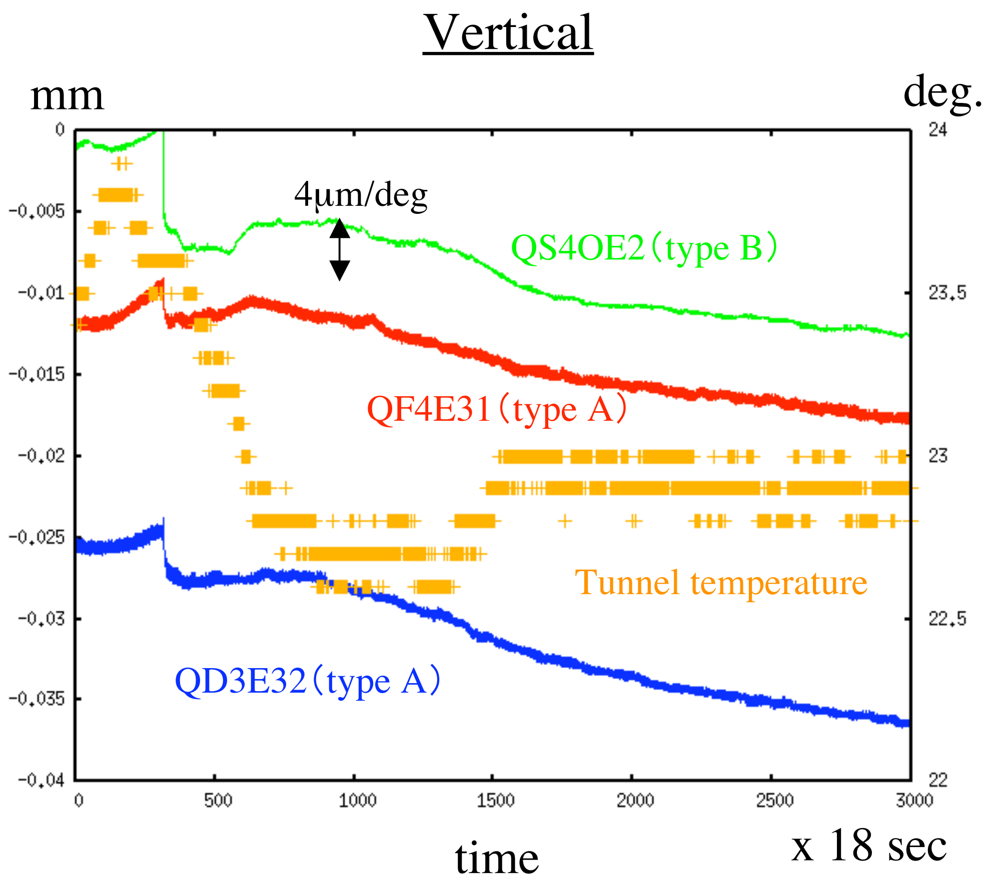


The data look showing a fault of a detector, but a target really moves with respect to sensors.

5) Measurement error by temperature change

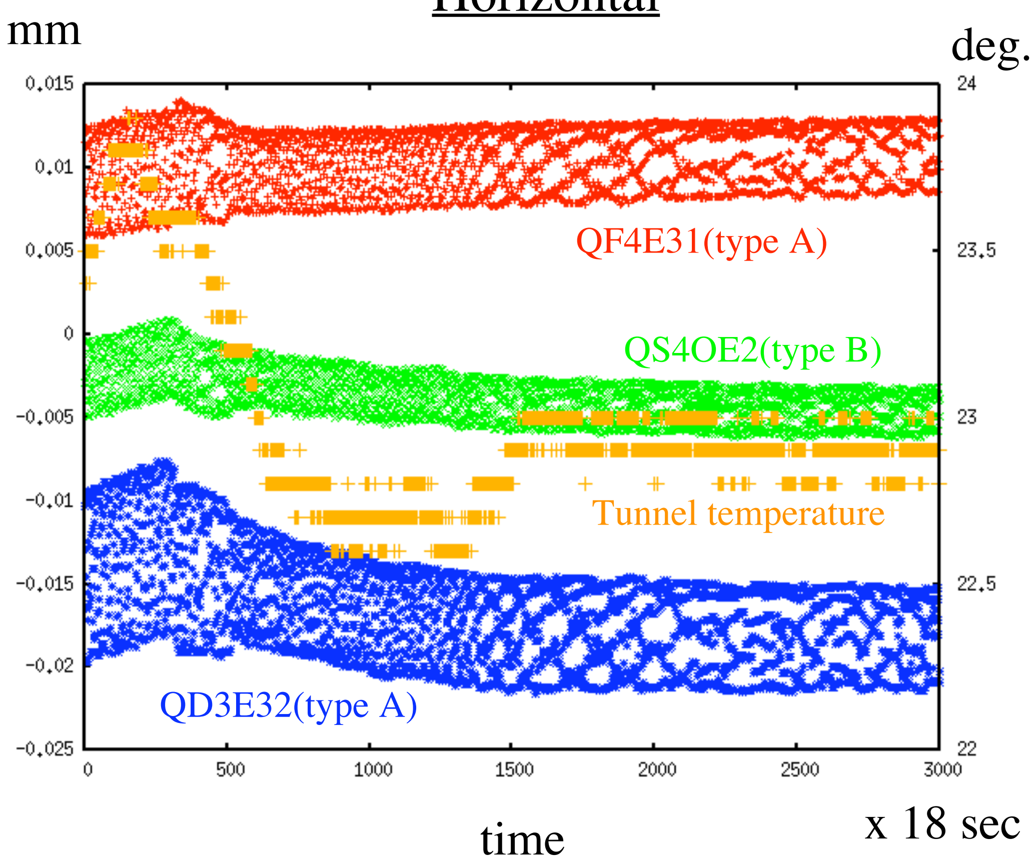
a) Deformation of the fixing arm

- Temperature dependence of the gap data was measured immediately after the stop of the beam operation. No beams were in the rings.



Temperature dependence will be roughly same (4μm/deg.) in type A and B.

Horizontal



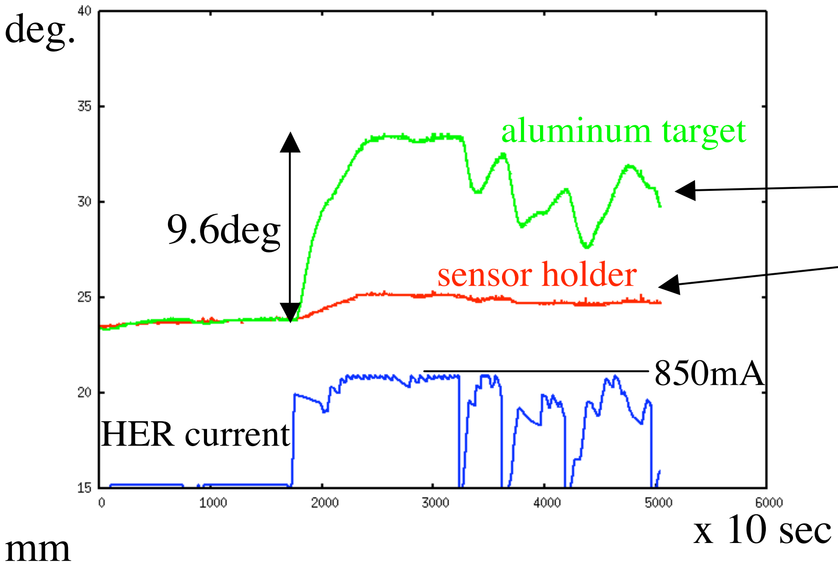
Change of the gap was not observed in the temperature change of 0.7 deg..

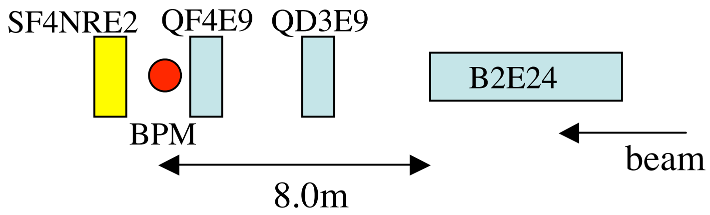
- Deformation of the fixing arm by temperature change

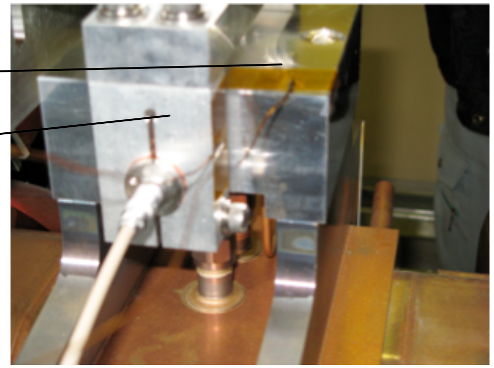
Horizontal : < 1μm/deg., Vertical : 4μm/deg.

b) Thermal expansion of the target

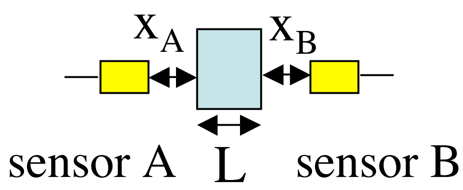
Horizontal displacement vs. target temperature

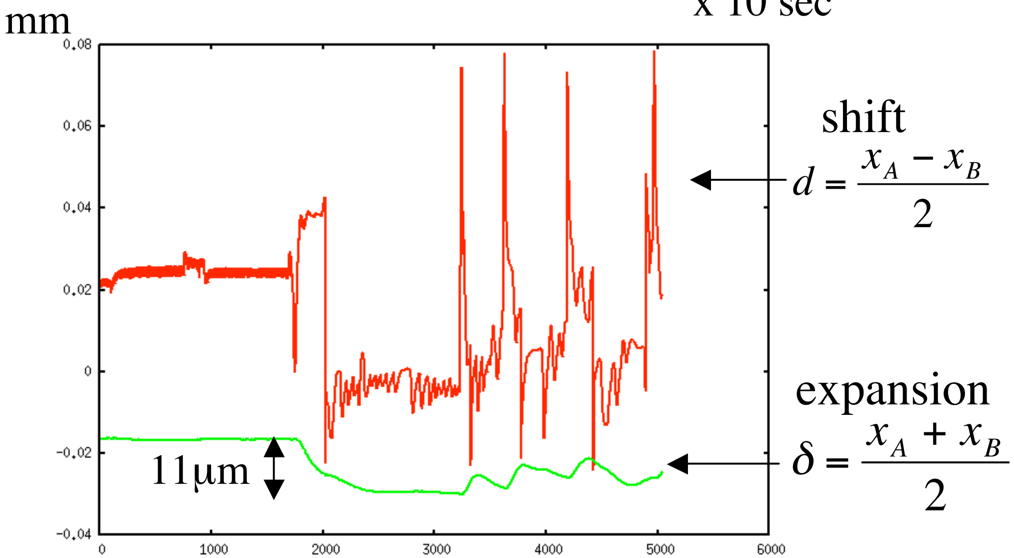






target





$\Delta L = 2\Delta\delta = 22\mu m$ from data

Estimated thermal expansion= 26 μm

Horizontal measurement error by the expansion of the target = δ ≈ 10 μm (1.1μm/deg.)

Estimated vertical measurement error by the expansion of the target ≈ 8 μm (0.8μm/deg.)

c) Summary of the temperature effect

i)Fixing arm

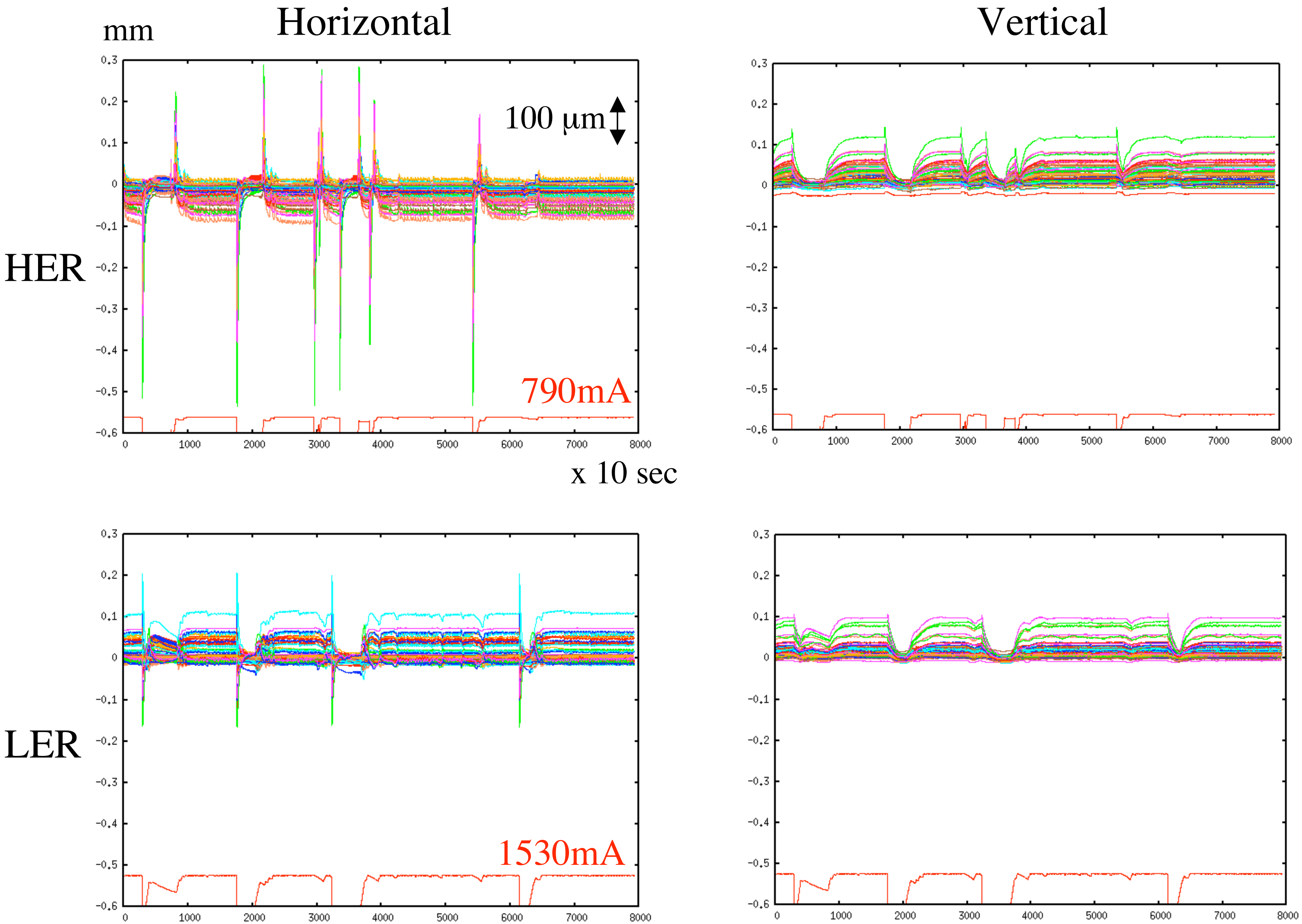
- Temperature of the arm is not much affected by the beam current. It would be determined by the tunnel temperature.
- The deformation of the arm is estimated to be < 1μm/deg. horizontally, 4μm/deg. vertically.
- As the stability of the tunnel temperature in operation is less than 1 deg., the error of the measurement would be < 1μm horizontally, < 4μm vertically.

ii)Target

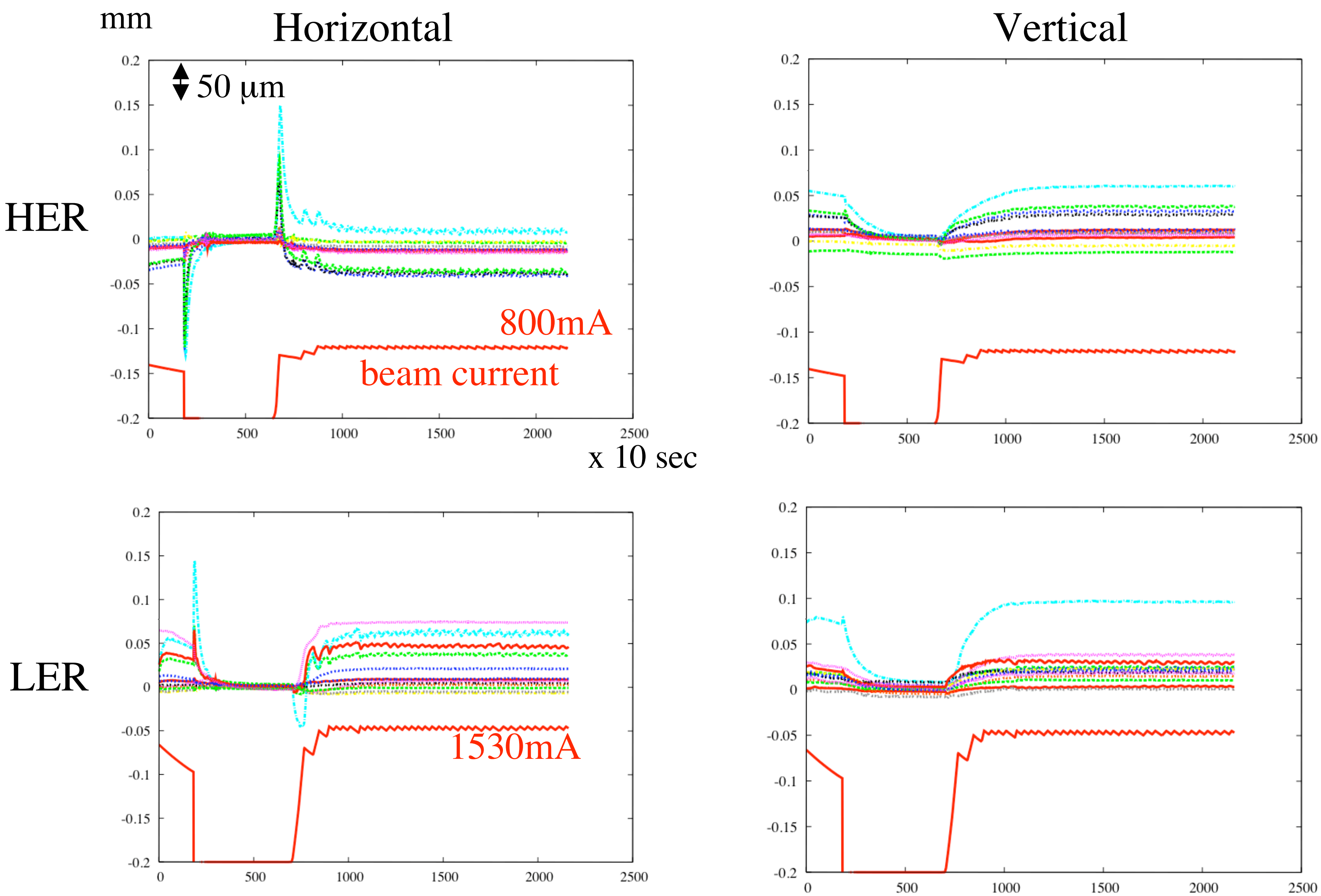
- Thermal expansion of the target is estimated to be 1μm/deg. horizontally and 0.8μm/deg. vertically.
- It brings the measurement error of about 10 μm during re-fill of the beam because the temperature of the target depends on the beam current, probably due to the temperature change of the cooling water of vacuum ducts.
- The error depends on the distribution of SR power, the pipe network of the cooling water and the beam current. We need more data to understand the error.

3. Displacement data

Whole ring



South tunnel



•The data show the large horizontal movement in HER. The maximum horizontal movement amounts to 500μm at a beam abort and 300μm in re-filling after the abort.

The movement during the continuous injection is less than 10μm.

	HER		LER	
	hor.	ver.	hor.	ver.
max. δ at abort	500	20	200	≈ 0
max. δ in re-filling	300	≈ 0	150	≈ 0
δ from 0 current to steady state	100	100	100	100
δ in continuous injection (p-p)	10	< 5	5	< 5

δ : displacement (μm)

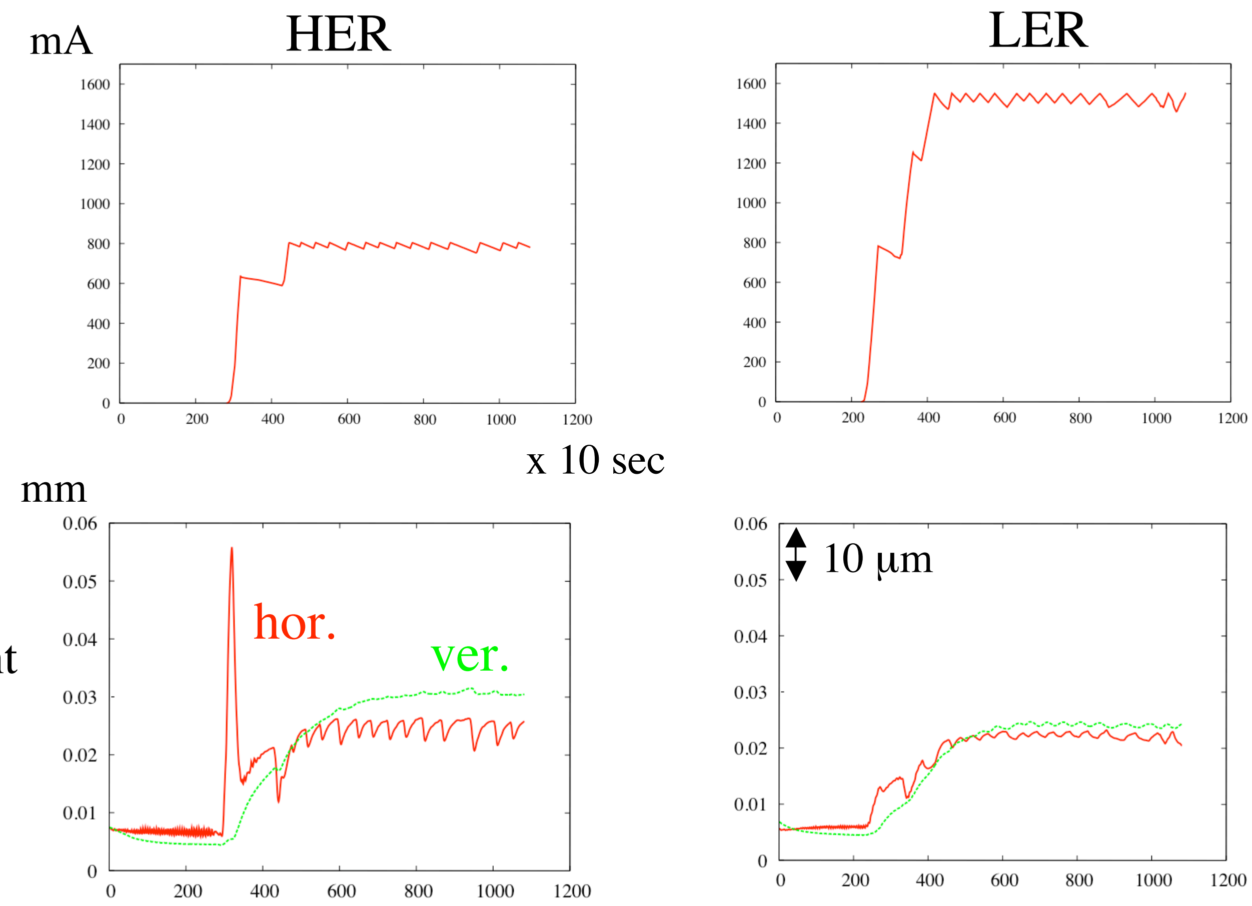
The beam current is 790 mA in HER and 1530 mA in LER.

4. Effect on the optics

- As we know the displacement of the BPMs with respect to the sextupoles, the effect of the BPM movement on the optics if the correction is not applied can be estimated by a simulation.
- In the simulation the position of the sextupoles was shifted by measured displacement, then optics parameters such as tunes, betas, etas and R parameters at IP were calculated by SAD.

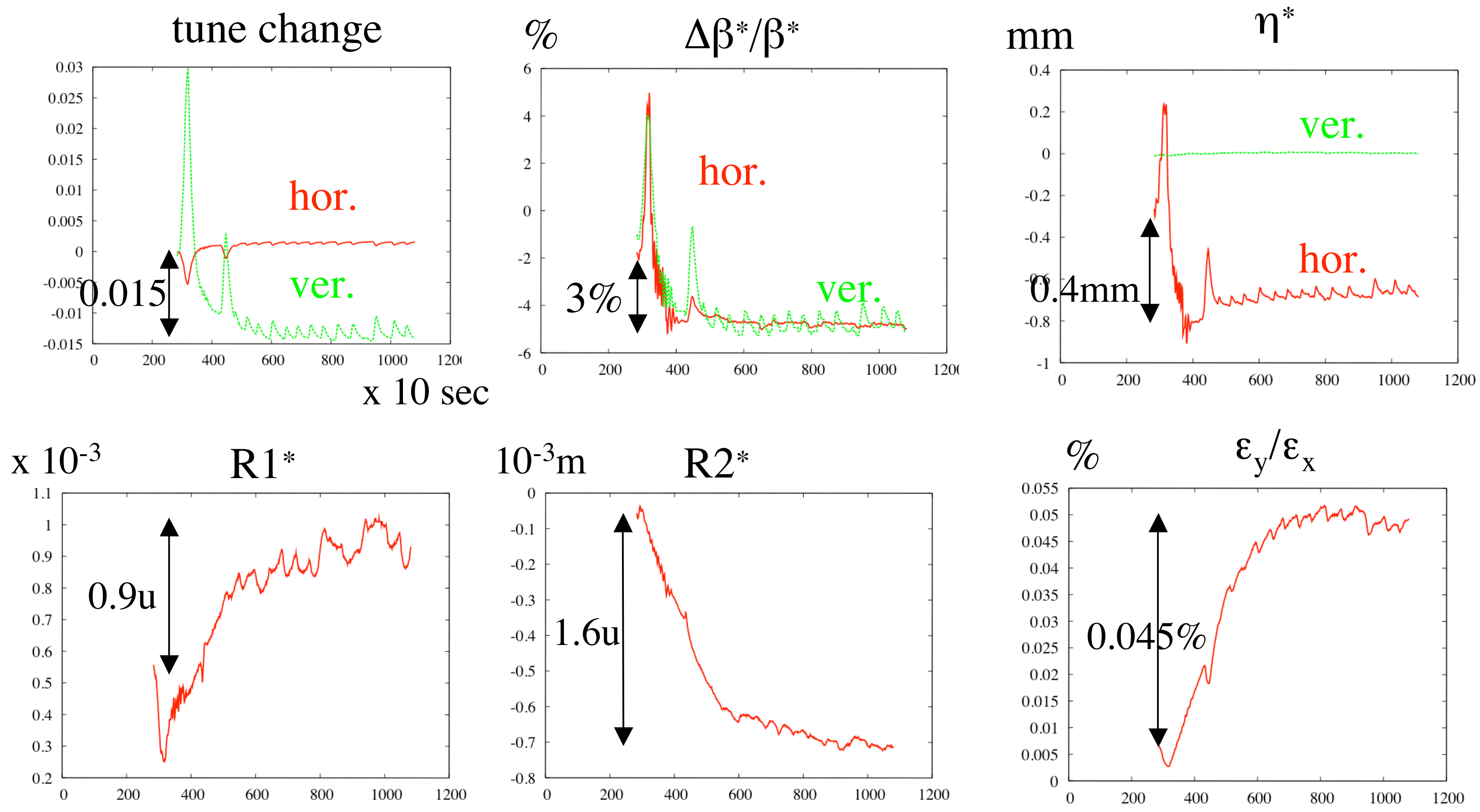
Beam current

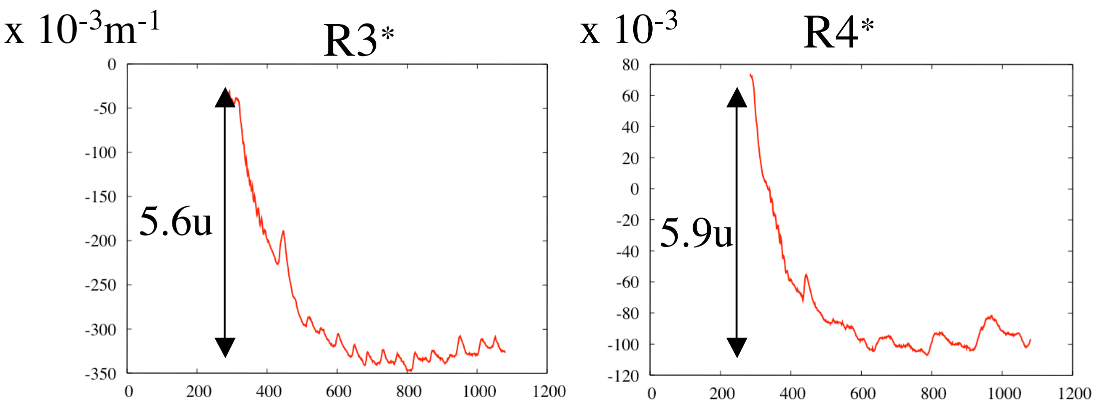
r.m.s. displacement of the sextupoles



Data used in the simulation

HER

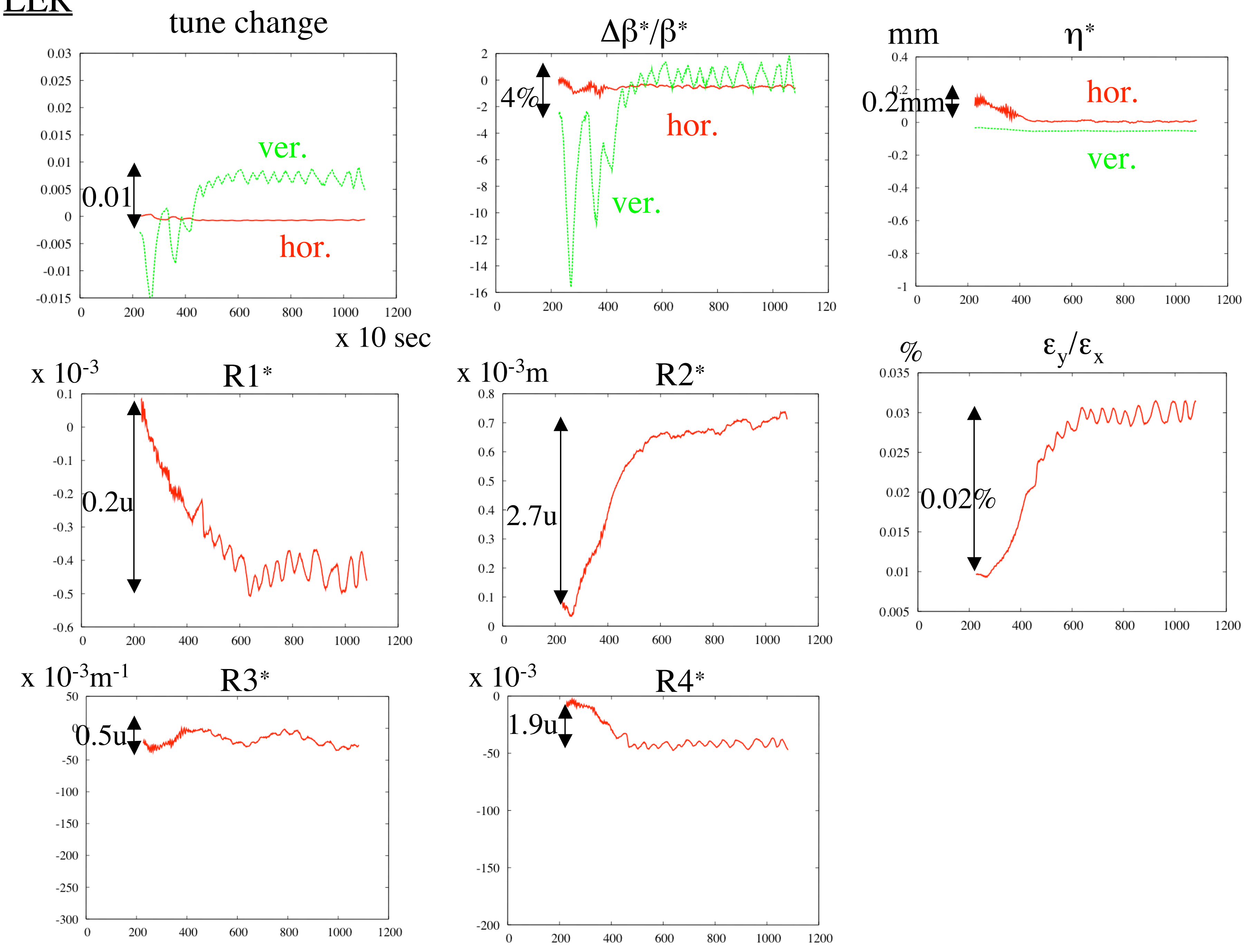




"u" is an unit used in machine tuning.
Several units are changed by "scan" to maintain good luminosity.

A star mark means IP.

LER

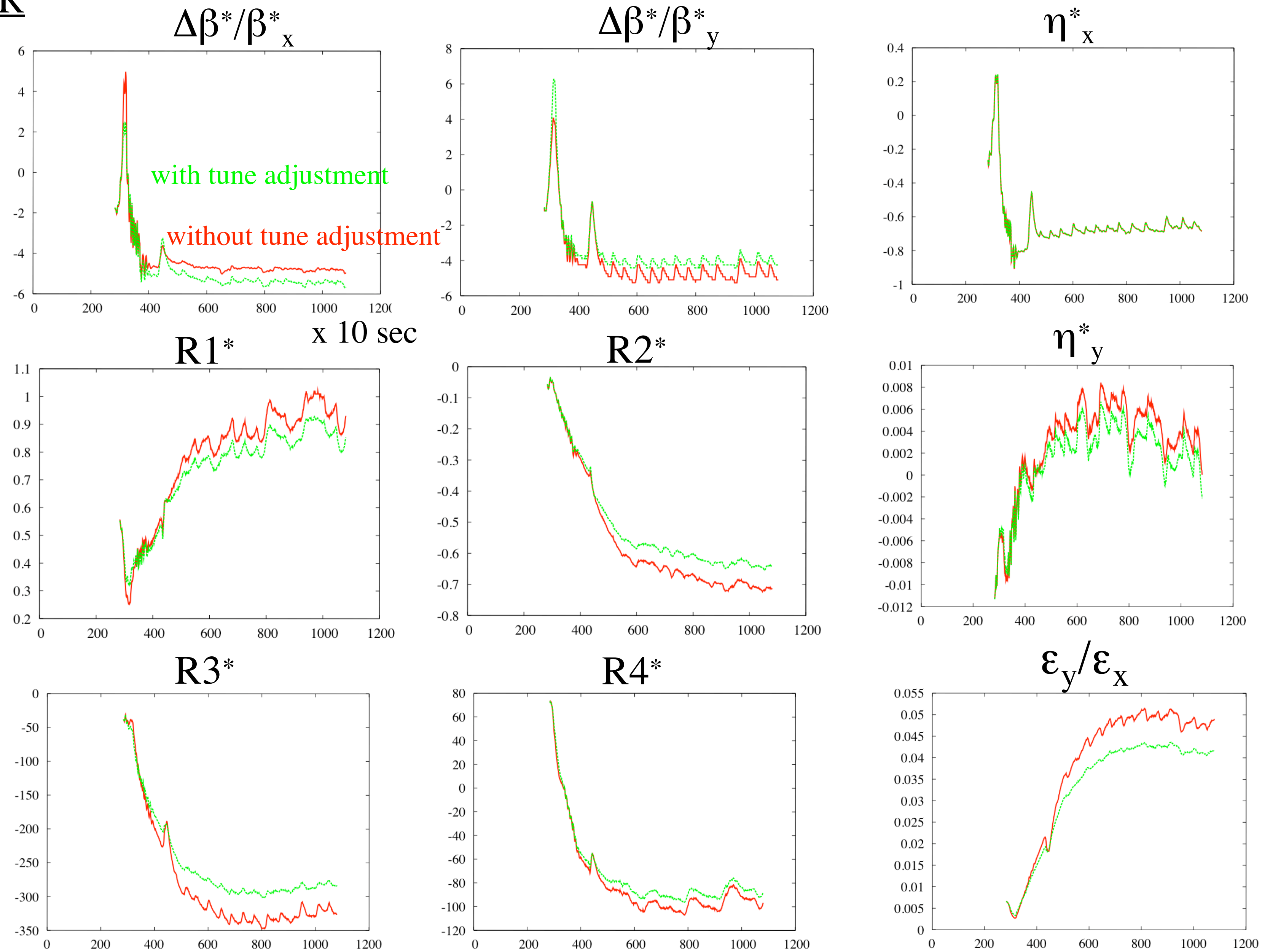

tune change
ver.
hor.
0.01
x 10 sec
Δβ*/β*
4%
hor.
ver.
mm
η*
0.2mm
hor.
ver.
x 10-3
R1*
0.2u
x 10-3m
R2*
2.7u
%
εy/εx
0.02%
x 10-3m-1
R3*
0.5u
x 10-3
R4*
1.9u

Effect of the tune adjustment

- In real operation the tunes are continuously adjusted to a target values by the tune feedback.

- The effect of the tune adjustment on the optics was simulated using the measured displacement.

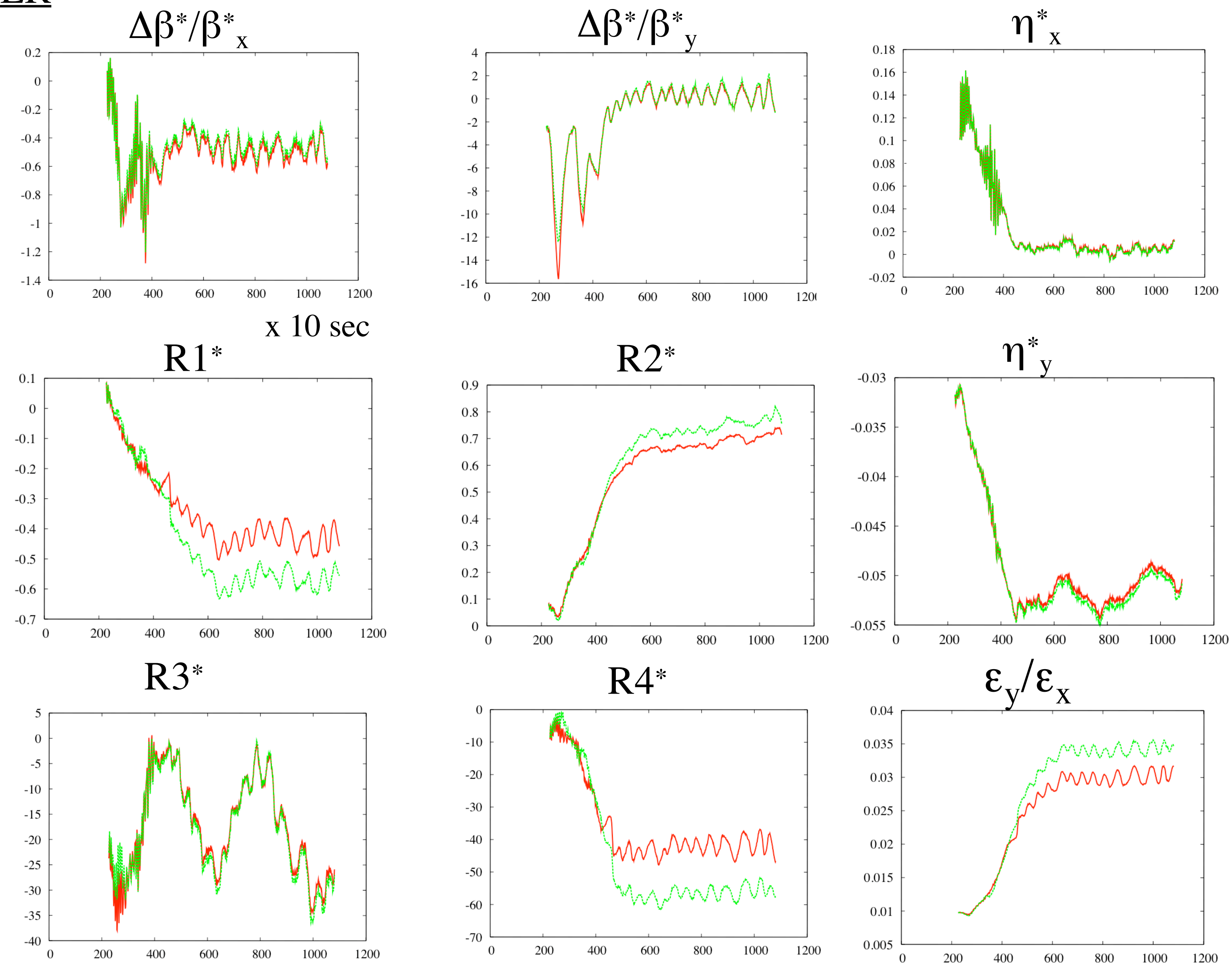
HER



•Optics parameters are not much improved by the tune adjustment.

*Vertical units are same as those in the previous figures.

LER



The effect of the tune adjustment is similar to the HER.

Summary of the simulation (tune adjustment "on")

HER

	max. change in re-fill	change from 0 current to steady state	change in continuous inj. (p-p)
$\Delta\nu_x$	0	0	0
$\Delta\nu_y$	0	0	0
$\Delta\beta_x^* / \beta_x^* (\%)$	7	3	≈ 0
$\Delta\beta_y^* / \beta_y^* (\%)$	10	2.5	0.5
$\Delta\eta_x^* (mm)$	1.4	0.4	0.1
$\Delta\eta_y^* (mm)$	0.0	0.0	0.0
$\Delta R_1^* (10^{-3})$	0.7(1.3u)	0.4 (0.7u)	0.1(0.2u)
$\Delta R_2^* (10^{-3} m)$	0.6 (1.6u)	0.6 (1.6u)	0.1(0.3u)
$\Delta R_3^* (10^{-3} m^{-1})$	250 (4.7u)	250 (4.7u)	20(0.4u)
$\Delta R_4^* (10^{-3})$	170 (5.3u)	170 (5.3u)	20(0.6u)
$\varepsilon_y / \varepsilon_x (\%)$	0.04	0.04	0.003

R parameters considerably changes from 0 to steady beam current.

During the stable continuous injection, the change of the parameters is small.

LER

	max. change in re-fill	max. change from 0 current to steady state	change in continuous inj. (p-p)
$\Delta\nu_x$	0	0	0
$\Delta\nu_y$	0	0	0
$\Delta\beta_x^* / \beta_x^* (\%)$	1.4	0.3	0.2
$\Delta\beta_y^* / \beta_y^* (\%)$	12	2	2
$\Delta\eta_x^* (mm)$	0.2	0.2	0.01
$\Delta\eta_y^* (mm)$	0.0	0.0	0.0
$\Delta R_1^* (10^{-3})$	0.7 (0.2u)	0.7 (0.2u)	0.1 (0.0u)
$\Delta R_2^* (10^{-3} m)$	0.8 (3.6u)	0.8 (3.6u)	0.1 (0.5u)
$\Delta R_3^* (10^{-3} m^{-1})$	40 (0.6u)	40 (0.6u)	40 (0.6u)
$\Delta R_4^* (10^{-3})$	60 (2.2u)	50 (1.9u)	5 (0.2u)
$\varepsilon_y / \varepsilon_x (\%)$	0.024	0.024	0.003

Similar behavior of the parameters to HER is seen.

5. Summary

- The gap detectors were installed at all sextupoles in order to measure the movement of the BPM with respect to the sextupole, then apply the correction to the BPM data.

- Large systematic error of about 10 μm due to thermal deformation of the target and the fixing arm exits during re-fill of the beam. We need more data such as the temperature of the targets to understand the error.

- The data show that the maximum horizontal movement in HER amounts to 500μm at a beam abort and 300μm in re-filling of the beam after the abort.

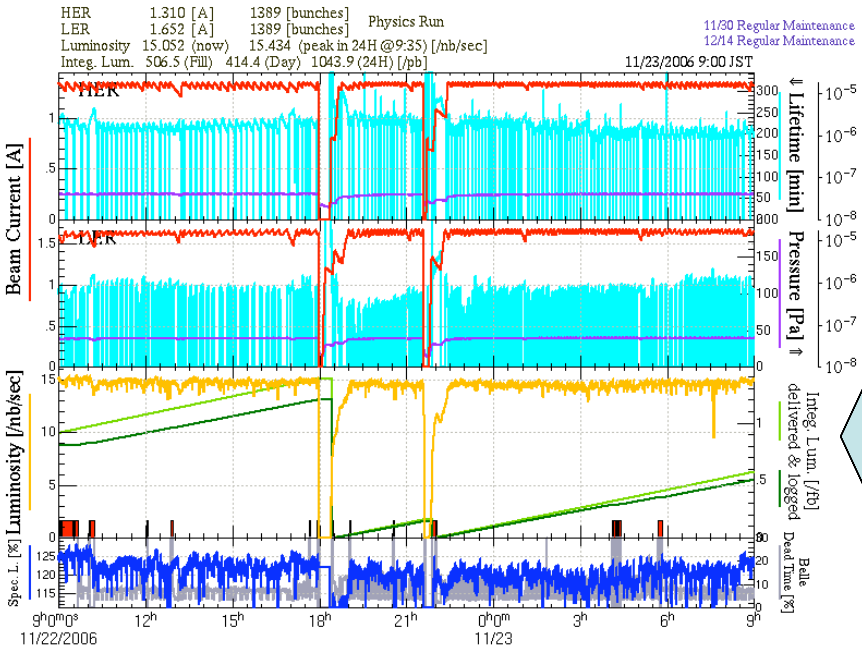
  The movement during the continuous injection is less than 10μm.

- The simulation according to the measured displacement shows that, if the correction to the BPM data is not applied,

  1) from 0 current to steady current, vertical tunes change 0.01 - 0.015, beta function changes several % and R parameters at IP change several operation units which is in a range of parameter scan in the operation,

  2) the change of the beta functions, etas and R parameters would not be cured by the tune feedback.

•Effect of the displacement correction on the luminosity is not clear though the simulation shows that the R parameters considerably change between small and high current operation. Luminosity strongly depends on machine conditions, tuning and so on. A statistical analysis may be useful to clarify the effect of the correction.



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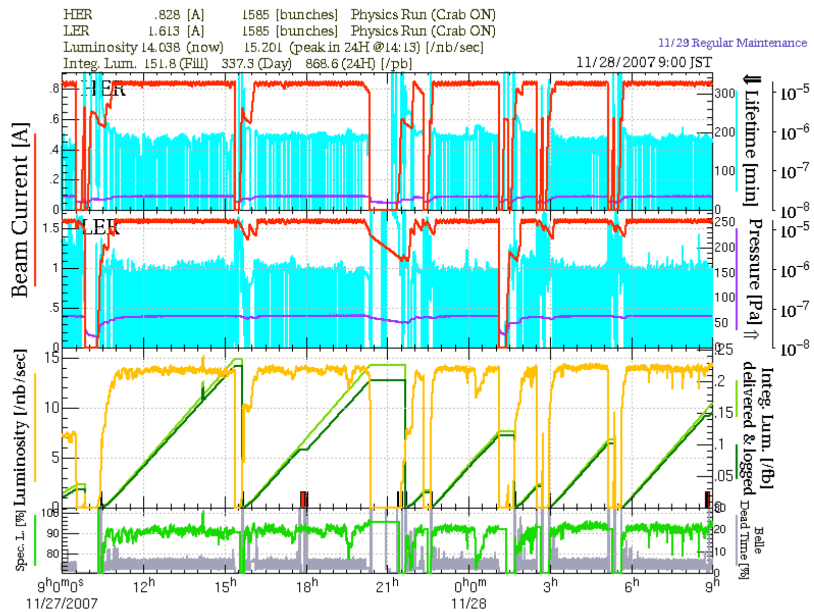

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How much does the recovery of the luminosity after the abort differ ?