Overview of 2020c and 2021a/b Run

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September 1, 2021

The 25th KEKB Review Meeting

Achievements in 2020c and 2021a/b

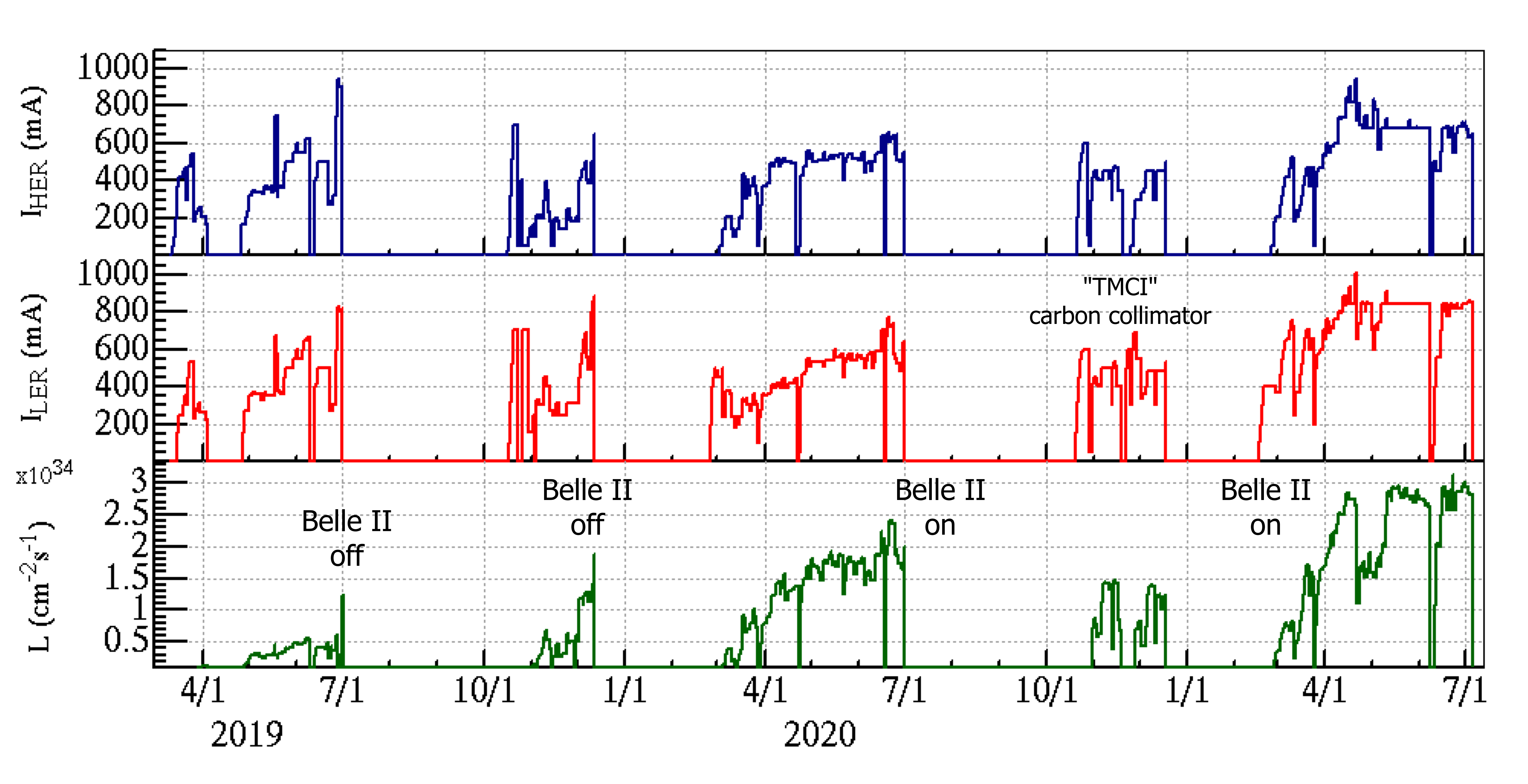
SuperKEKB Operation Summary

Peak Luminosity : 3.12 x 10^{34} $cm^{-2}s^{-1}$

a: February - March
b: April - July
c: October - December

Operation time
6 - 7 months per year

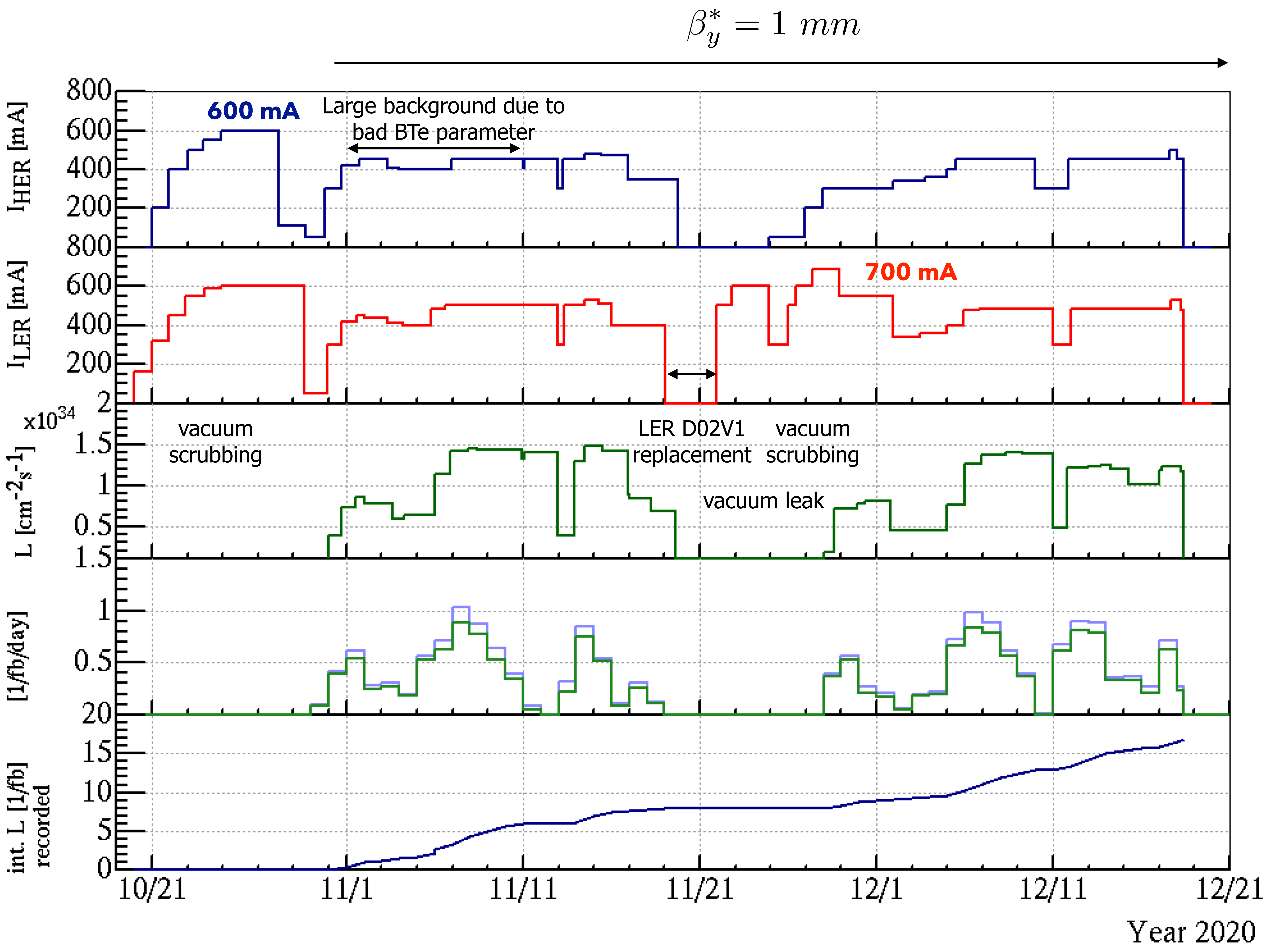
2019a/b 2019c 2020a/b 2020c 2021a/b



β_y^* 3 → 2 mm β_y^* 2 → 1 mm β_y^* 1 → 0.8 mm β_y^* 1 mm β_y^* 1 mm

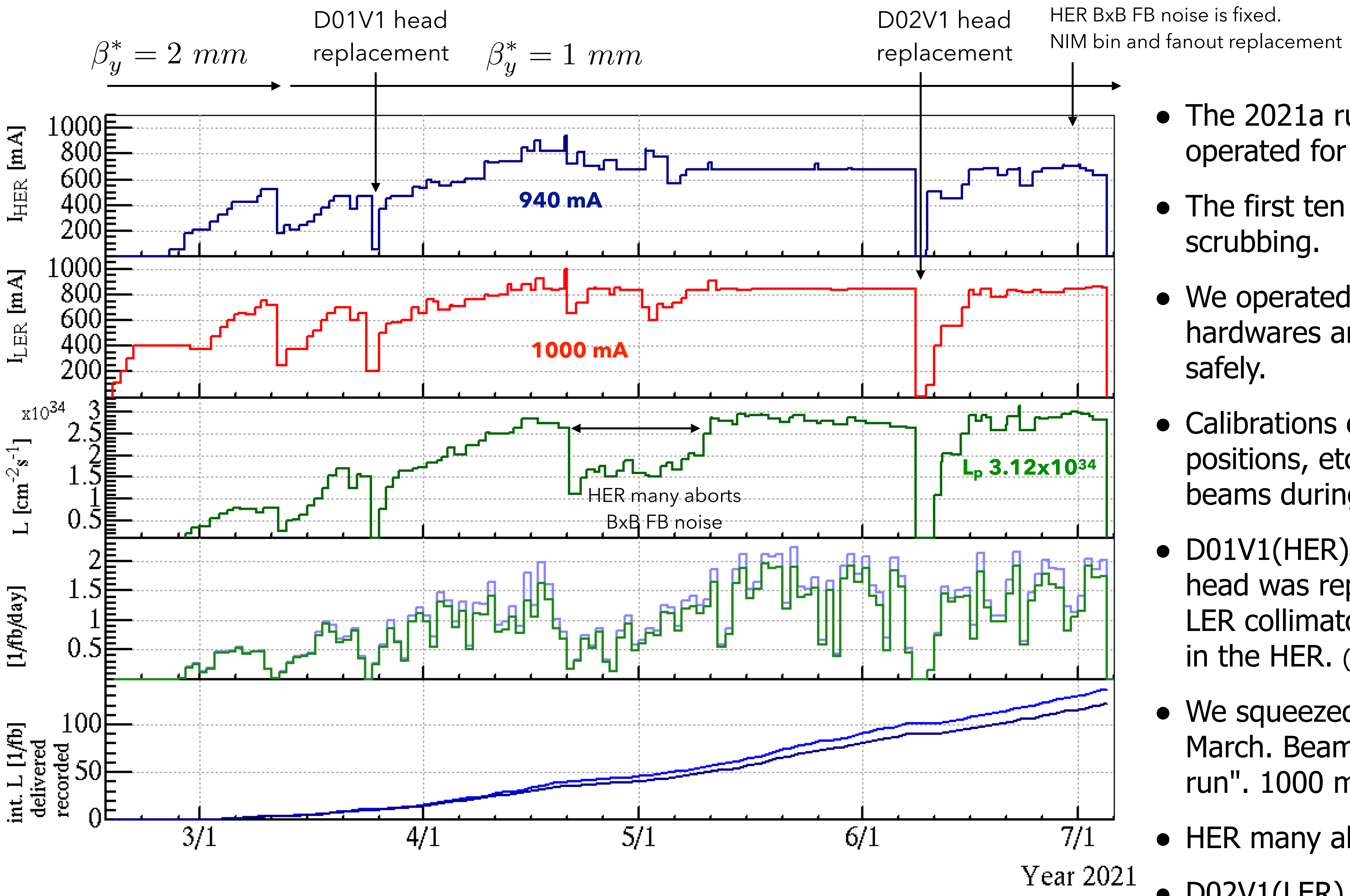
	int. L recorded	int. L delivered
Shift	747.2 pb^{-1} May 18 swing	797.6 pb^{-1} June 22 day
Day	1.964 fb^{-1} May 18	2.233 fb^{-1} May 22
7 days May 14 - 20	12.141 fb^{-1}	13.482 fb^{-1}
30 days May 18 - June 23	42.319 fb^{-1}	47.370 fb^{-1}
2021ab 140 days	123.2 fb^{-1}	138.6 fb^{-1}
total	213.5 fb^{-1}	

2020c Operation Summary



- The 2020c run started on 20th October and operated for 60 days (2 months).
- The first ten days were devoted to the vacuum scrubbing.
- D06V1 was carbon head collimator (new). We observed TMCI threshold which was 0.3 mA/ bunch.
- BTe parameter was wrong until November 11. HER background was large until the correction.
- D02V1(LER) head was replaced due to damage (November 18). The vacuum leak was found during the vacuum scrubbing in the LER. The replacement process was not good. The vacuum scrubbing was agin performed after fixing the trouble.
- Beam abort due to misfire of the injection kicker in the LER. The D06H3 collimator head was damaged due to the beam hitting.
- D06V1 carbon head was replaced with tantalum head during the winter shutdown after 2020c.

2021a/b Operation Summary



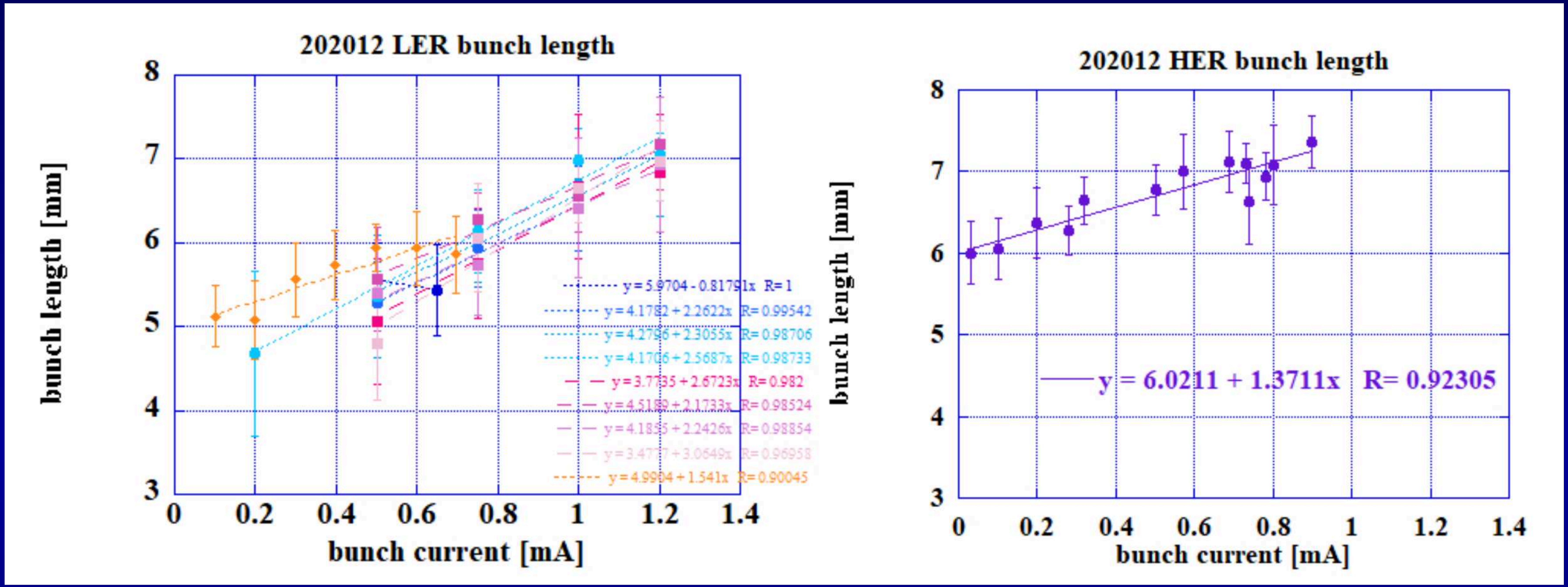
- The 2021a run started on 16th February and operated for 140 days (4 months and half).
- The first ten days were devoted to the vacuum scrubbing.
- We operated with β_y^* = 2 mm to check hardwares and to test high current operation safely.
- Calibrations of BPM and collimator head positions, etc. were also performed by using beams during the first two weeks.
- D01V1(HER) head was replaced. D01V1(HER) head was replaced. The top-jaw was for the LER collimator head and it was the short length in the HER. (March 23).
- We squeezed β_y^* down to 1 mm on 10th March. Beam currents increased with "baking run". 1000 mA / 940 mA w/o physics run
- HER many aborts from April 20 to May 3.
- D02V1(LER) head was replaced due damage (June 7).

Machine Parameters (2020b and 2021b)

	2020b : June 21, 2020		2021b : June 22, 2021		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	nm
Beam Current	712	607	790	687	mA
Number of bunches	978		1174		
Bunch current	0.728	0.621	0.673	0.585	mA
Lifetime	760	1270	540	1320	sec
Horizontal size σ_x*	17.9	16.6	17.9	16.6	μm
Vertical cap sigma Σ_y*	0.403		0.324		μm*1
Vertical size σ_y*	0.285		0.229		μm*2
Betatron tunes ν_x / ν_y	45.523 / 43.581	44.531 / 41.577	44.524 / 46.596	45.532 / 43.581	
β_x* / β_y*	80 / 1.0	60 / 1.0	80 / 1.0	60 / 1.0	mm
Piwinski angle	10.7	12.7	10.7	12.7	
Crab Waist Ratio	80	40	80	40	%
Beam-Beam parameter ξ_y	0.039	0.026	0.046	0.030	
Specific luminosity	5.43×10^{31}		6.76×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	2.40×10^{34}		3.12×10^{34}		$cm^{-2}s^{-1}$

*1) estimated by luminosity with assuming design bunch length
*2) divide *1 by √2

Bunch Length Measurement



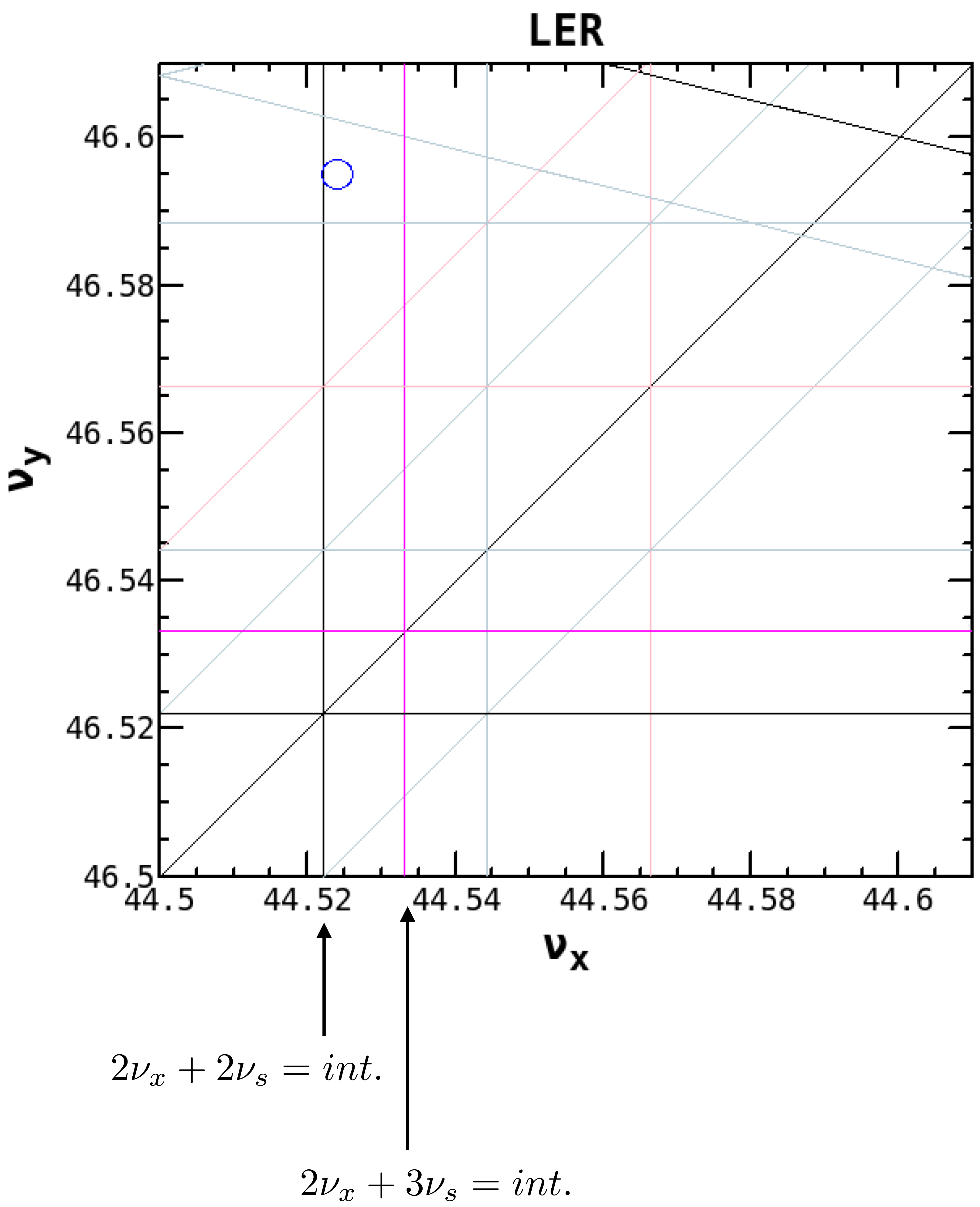
measured in 2020c
H. Ikeda

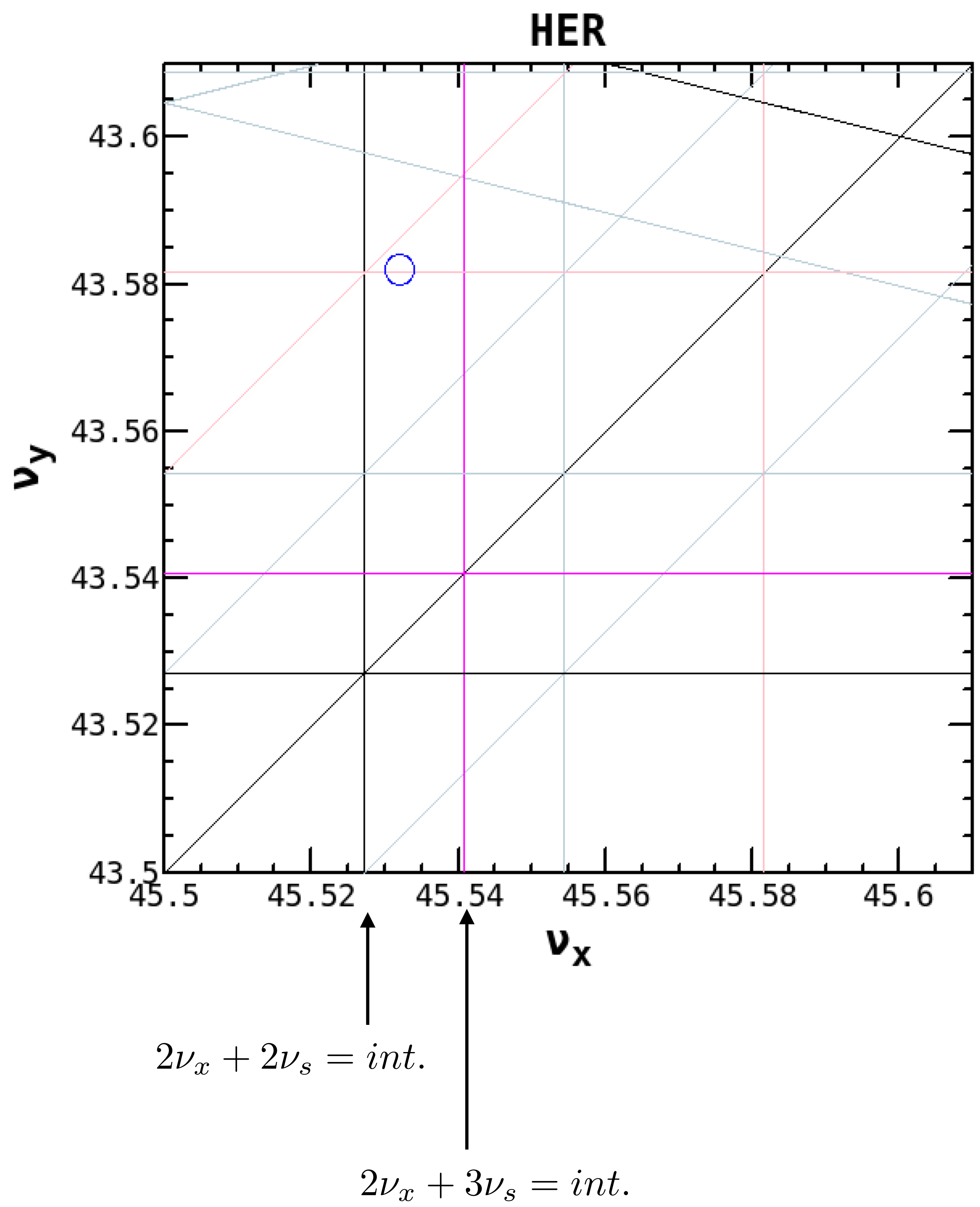
$$L \propto \frac{1}{\phi_x \sigma_z} \sqrt{\frac{\varepsilon_y}{\beta_y^*}}$$

Bunch lengthening deteriorates the luminosity.

nominal	σ_z (mm)	σ_δ	α_p	ν_s	U_0 (MeV)	V_c (MV)
HER	5.05	6.30 x 10^{-4}	4.54 x 10^{-4}	-0.0272	2.43	14.18
LER	4.60	7.53 x 10^{-4}	2.98 x 10^{-4}	-0.0233	1.76	9.13

The circle indicates nominal working point in 2021b.

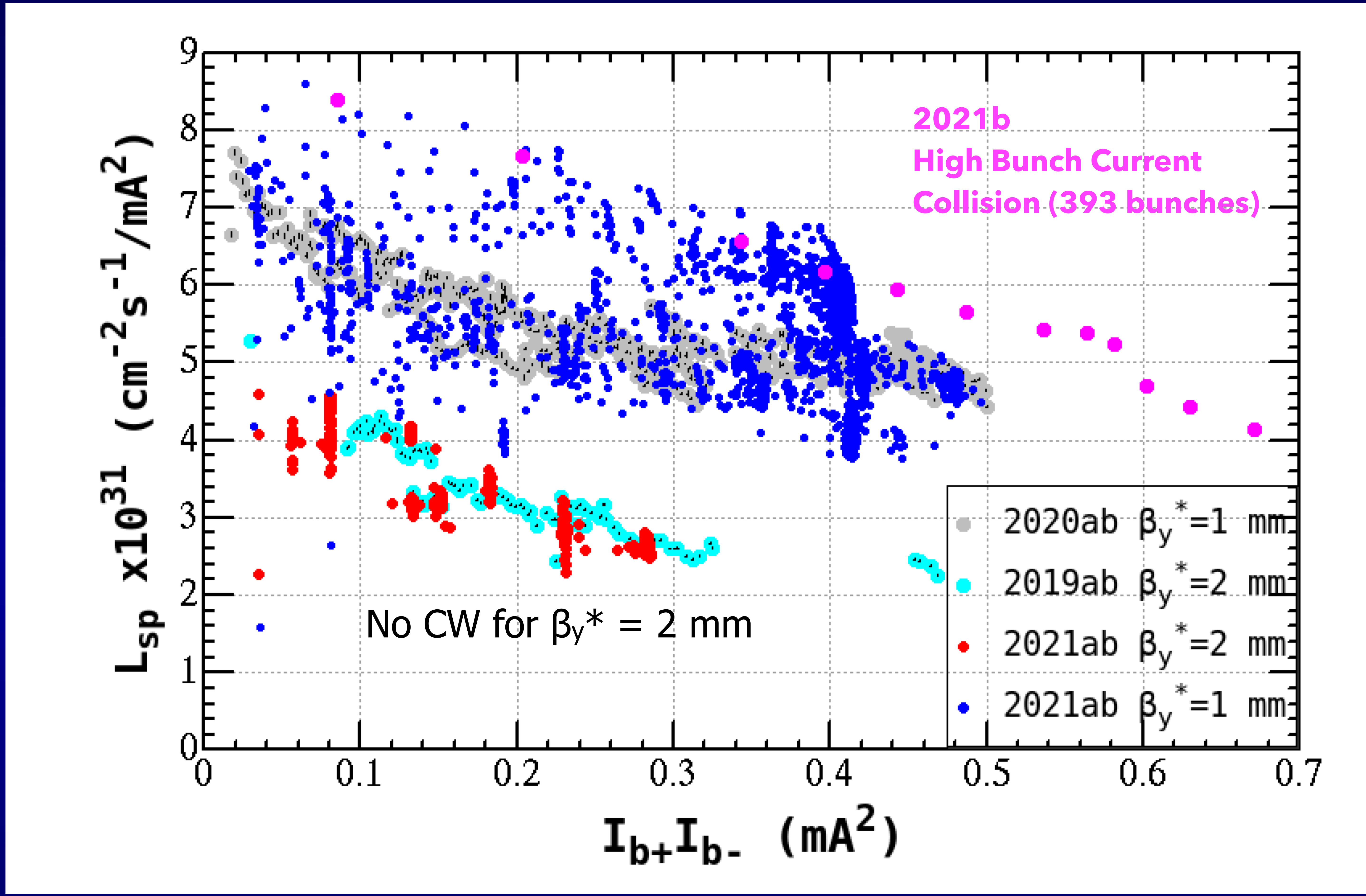




This resonance is very strong.
Injection background and SR on PXD are caused significantly.

Definition of specific luminosity

$$L_{sp} = \frac{L}{n_b I_{b+} I_{b-}}$$



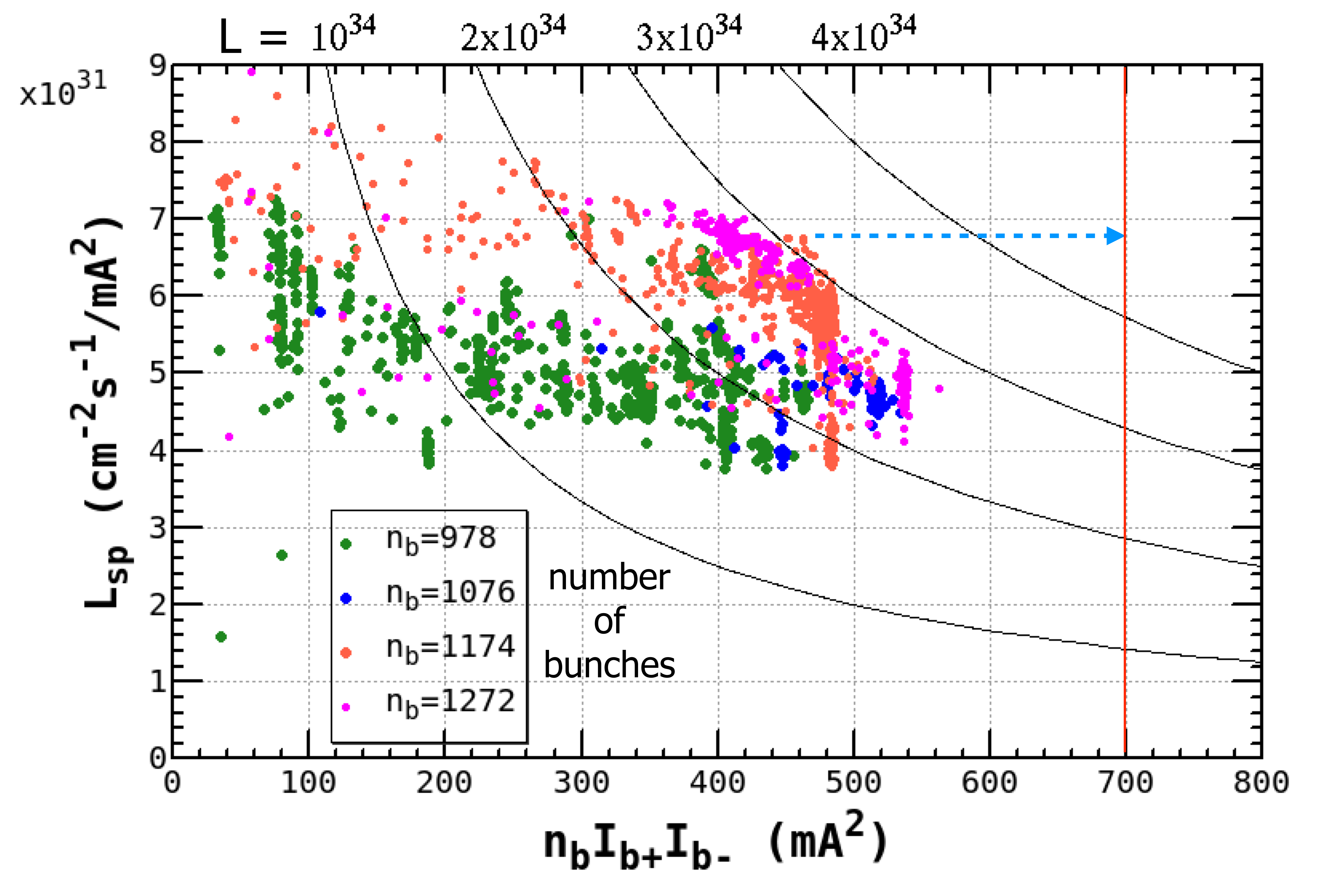
- Specific luminosity for β_y^* = 1 mm is improved compared to that of 2020ab.
- X-Y couplings at IP are improved by using local correctors with luminosity optimization.
- We also use chromatic X-Y coupling correctors.
- Bunch current product is achieved larger than 0.5 mA^2 with crab waist scheme.

Projection of Specific Luminosity in 2021a/b

Definition of specific luminosity $L_{sp} = \frac{L}{n_b I_{b+} I_{b-}}$

max of $n_b I_b + I_{b-}$ is 540 mA^2
(840 mA/818 mA, n_b = 1272)

LER / HER : 1.1 A / 1.0 A
n_b = 1565
target of 2021b
700 mA^2



Beam Background and Beam Aborts due to Beam Loss

stored beam and injection beam

radiation dose (serious) at collimators, collimator damage, Belle II detector damage

→ risks for increasing beam currents

Collimator Impedance : TMCI threshold

narrow collimator aperture (physical aperture)

The lower threshold limits bunch current.

Short Lifetime

small dynamic aperture and/or small physical aperture (collimators, QCS aperture, etc.)

Beam-Beam Blowup

Is the source of blowup the chromatic X-Y couplings ?

single beam blowup or multi bunch effect ? How about BxB FB gain ?

→ Those enhance beam-beam blowup ? How about BBHT(XZ) ?

Insufficient Understood of Injection Beam

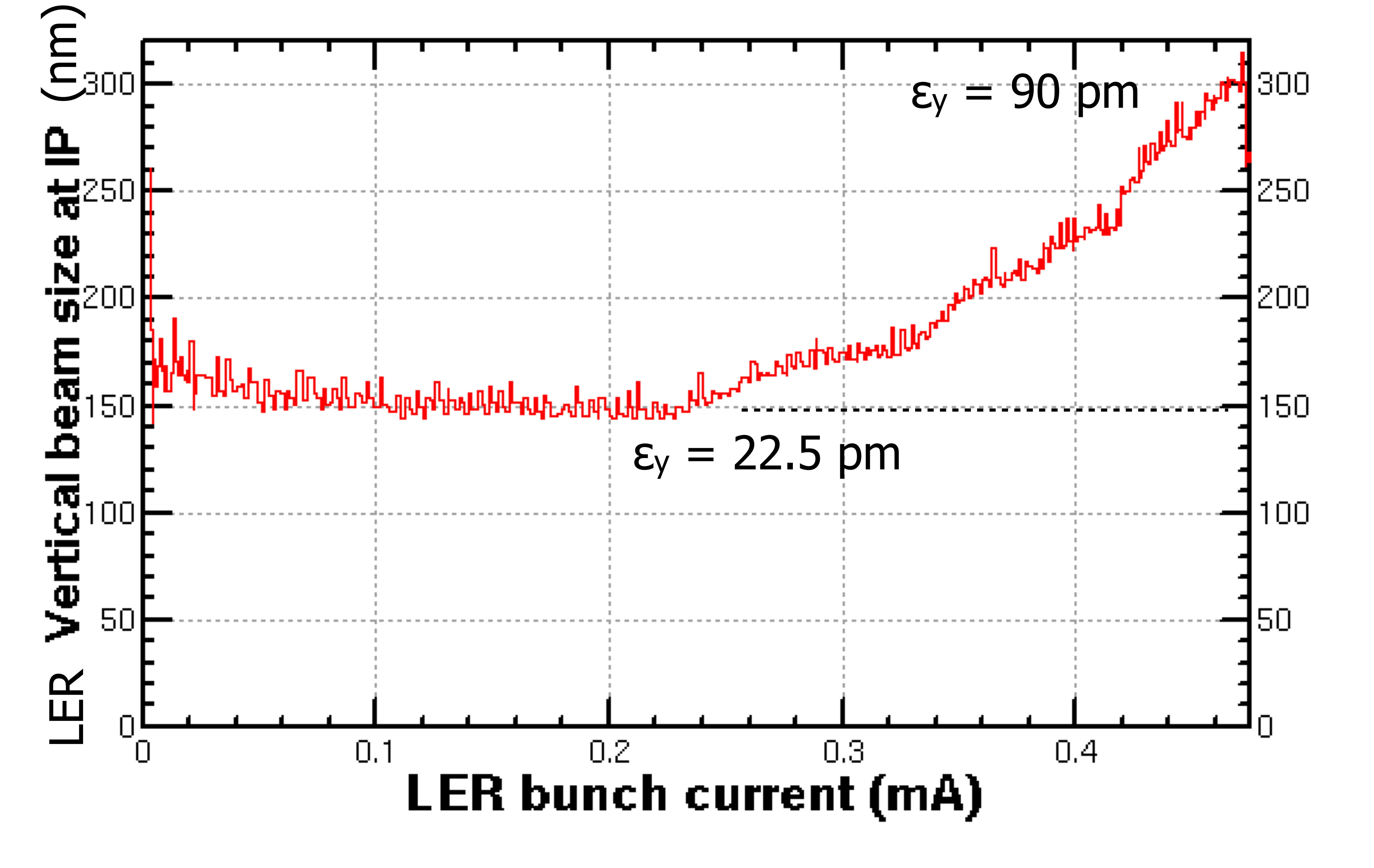
emittance, orbit fluctuation, energy spread, stability of injector linac

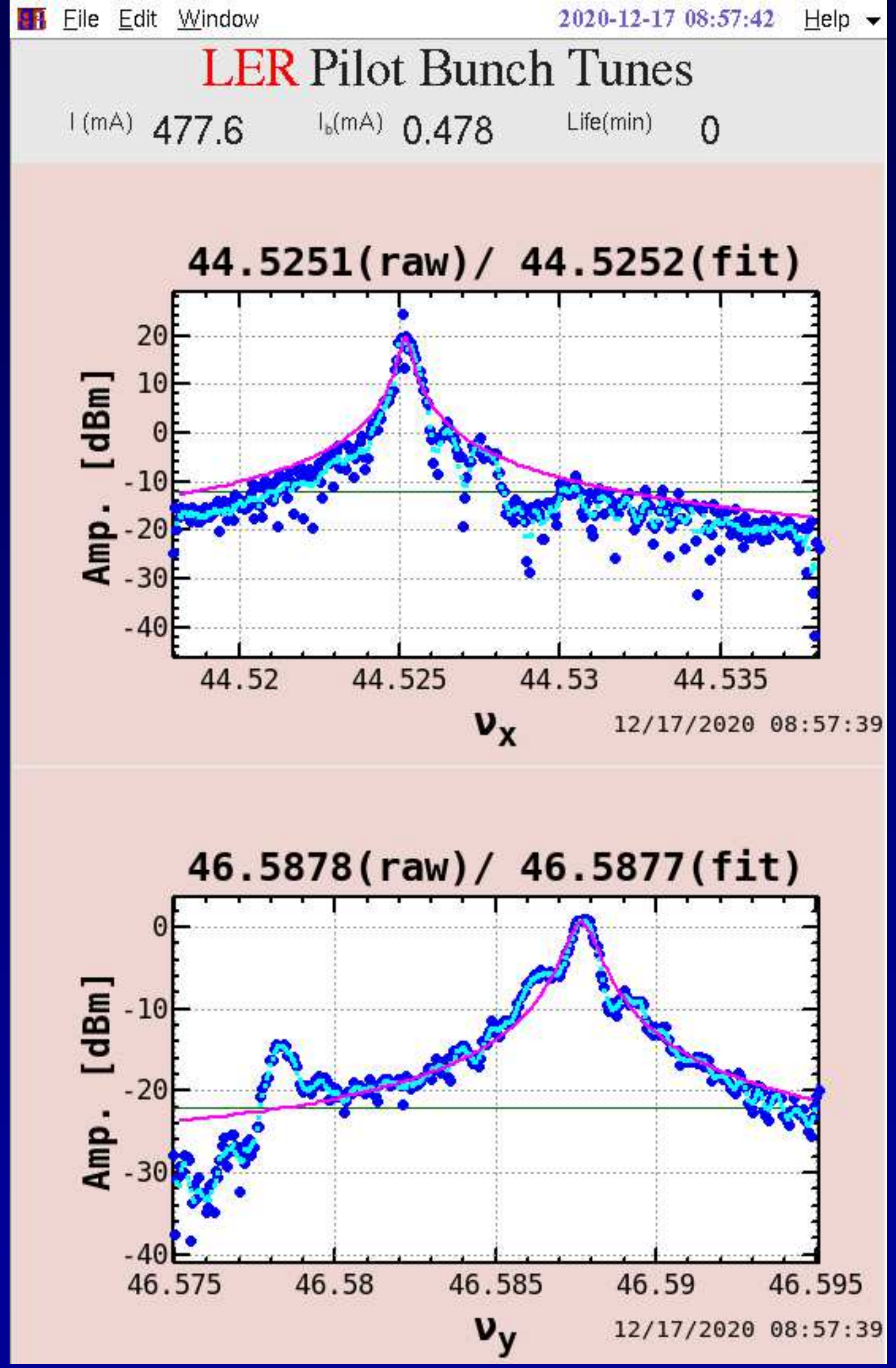
TMCI in LER

LER Collimator Impedance due to Carbon Head in 2020c

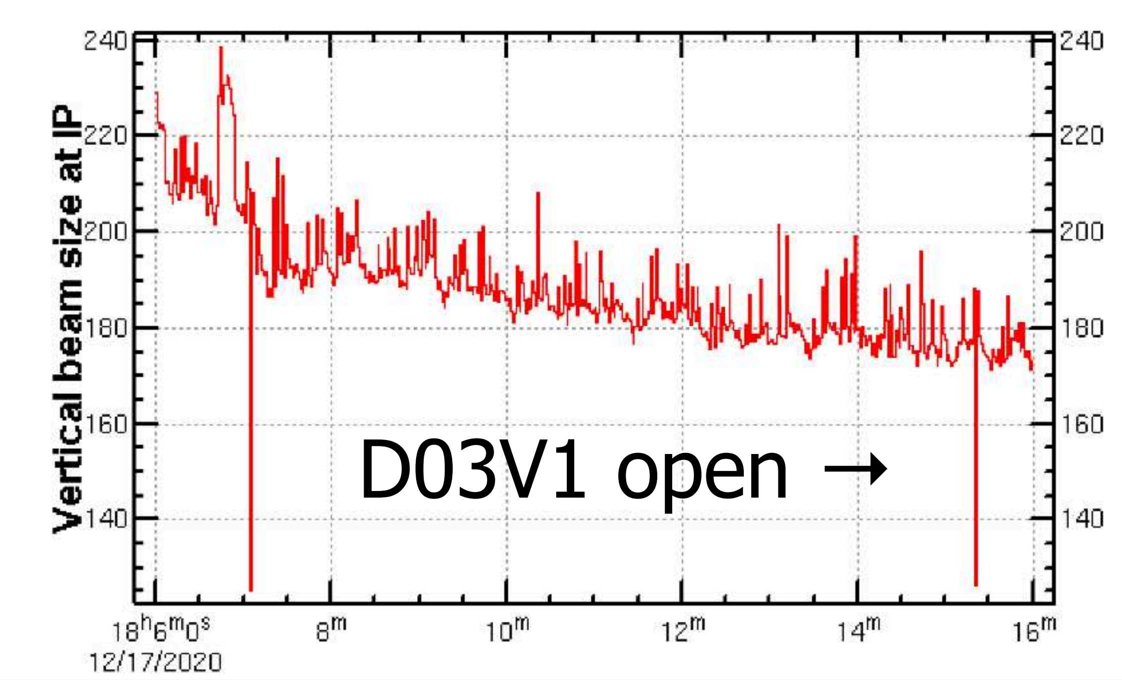
December 17, 2020 17:46 - 17:54

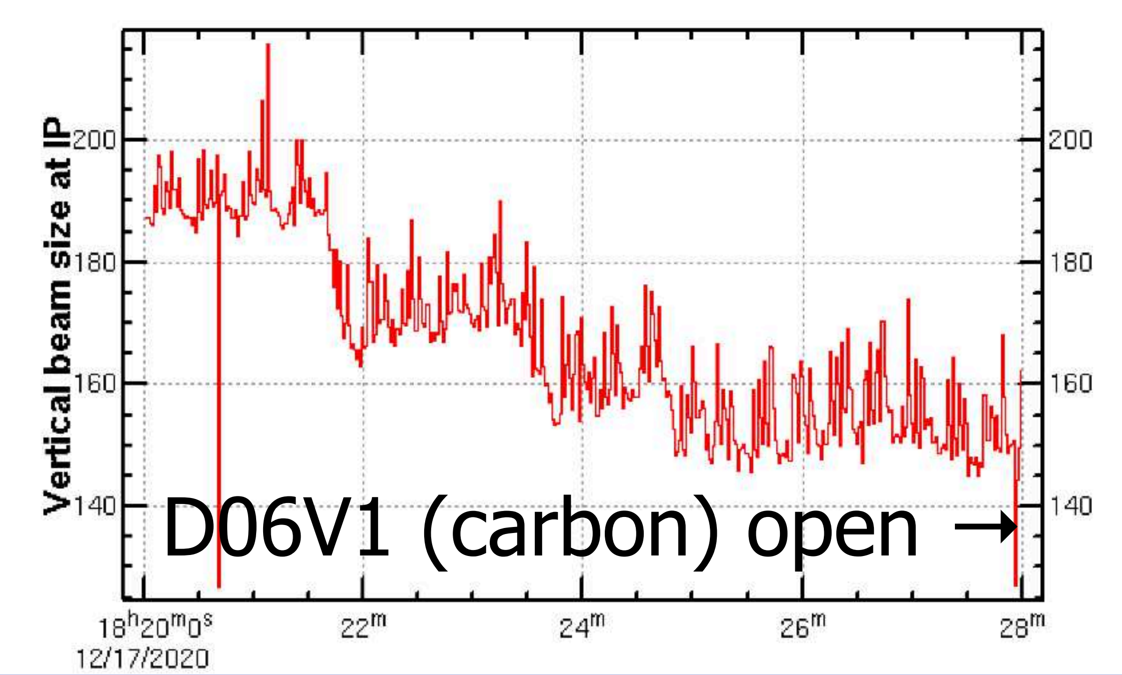
TMCI threshold

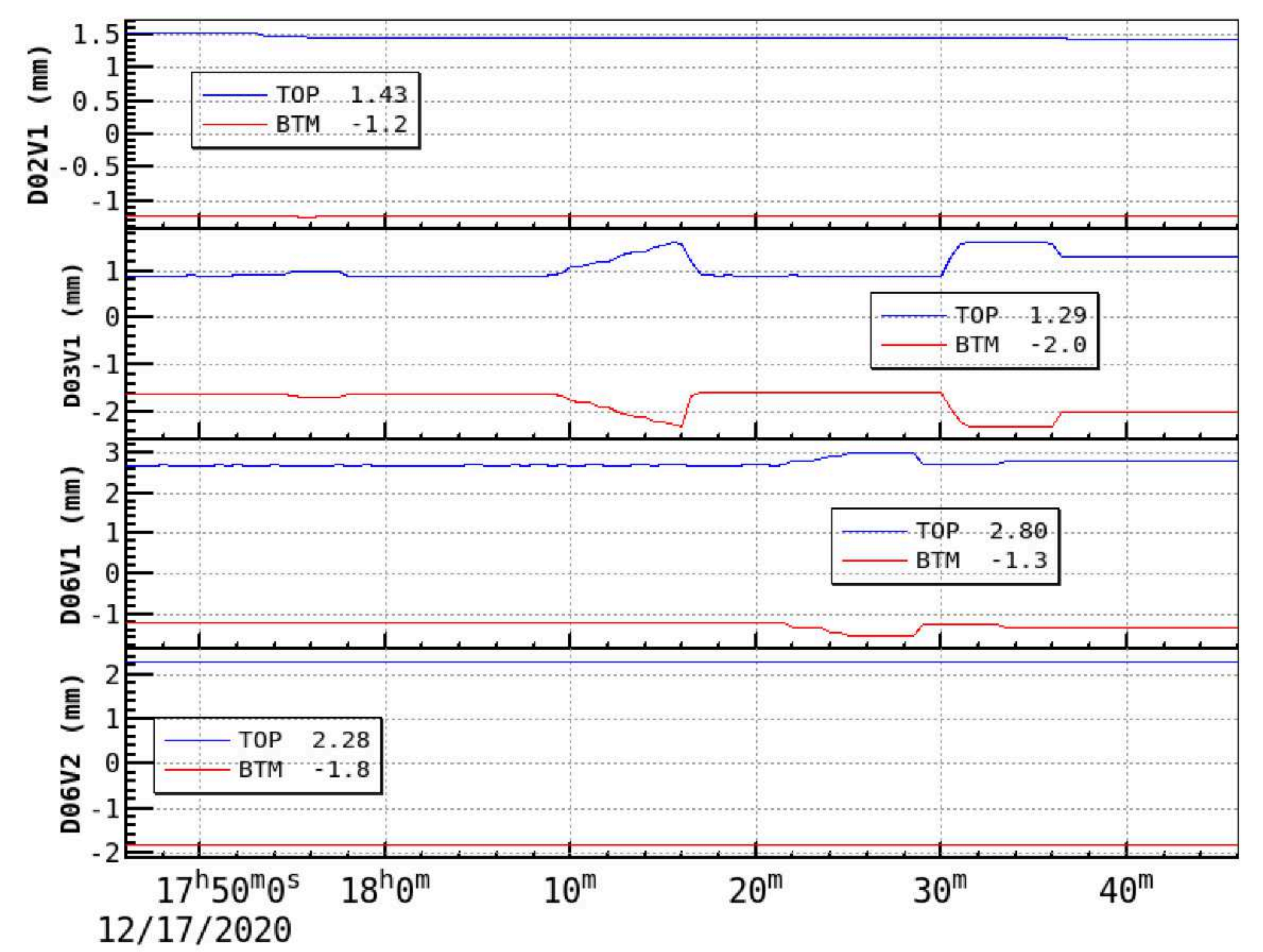




sideband





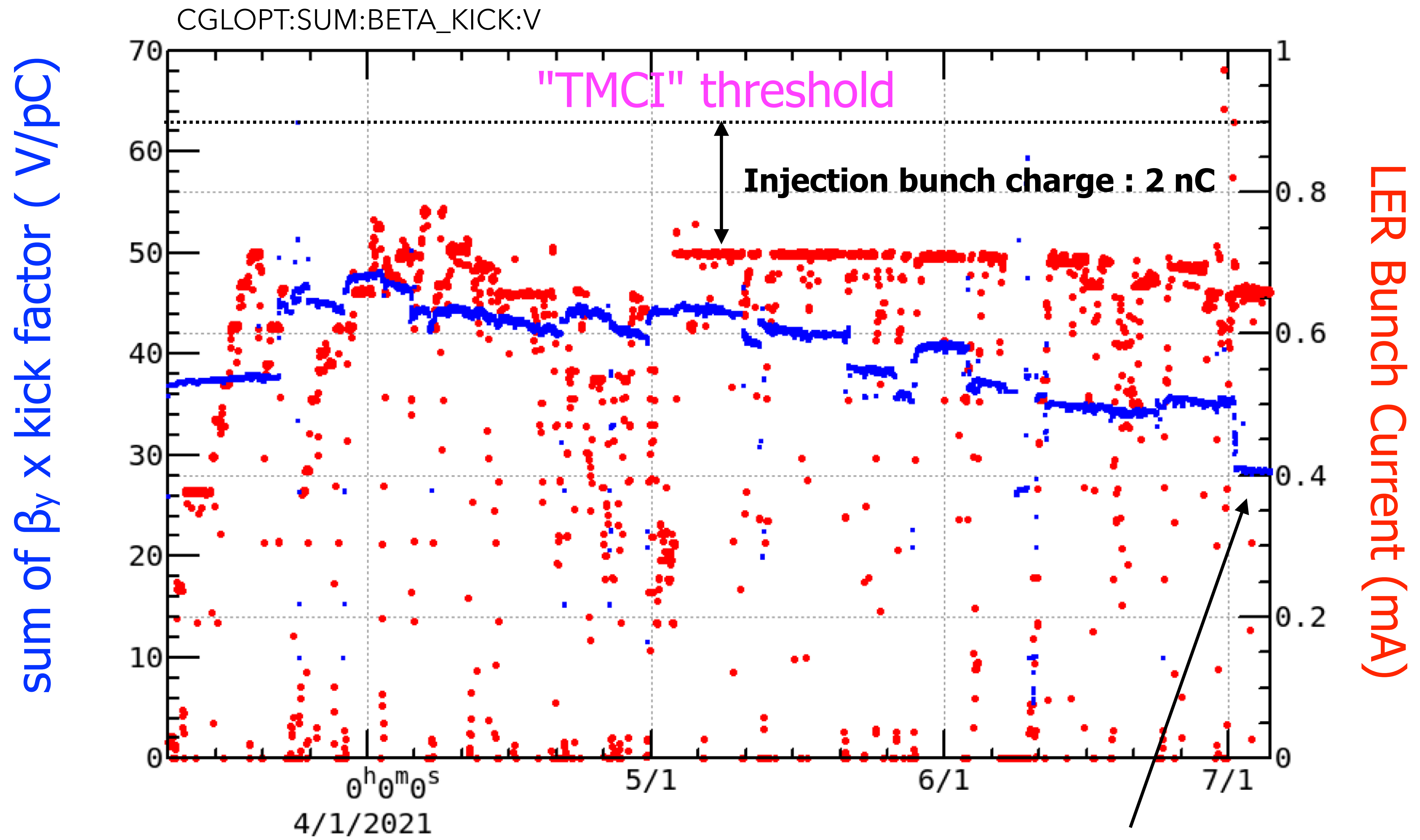


We observed TMCI in the LER at the operation beam current.
TMCI threshold depends on the collimator aperture.
The threshold also depends on the vertical tune. → localized impedance?

2021b Run

Transverse Mode Coupling Instability (TMCI)

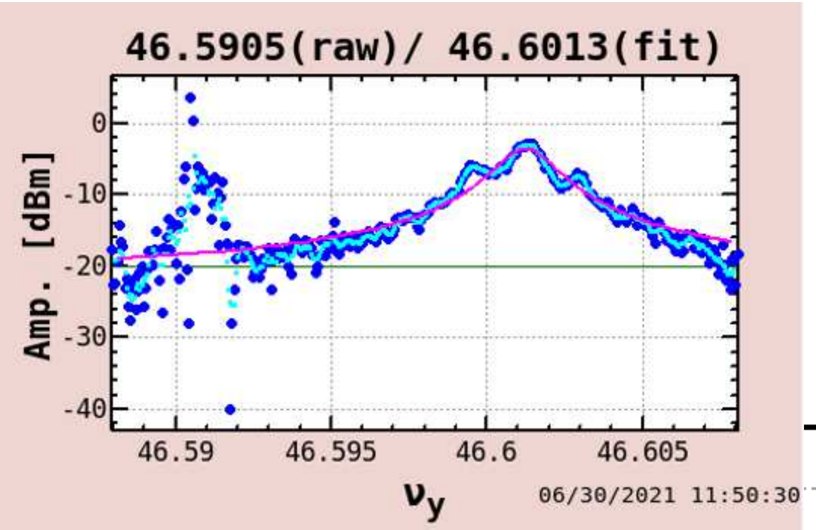
Kick factor depends on collimator aperture (vertical).



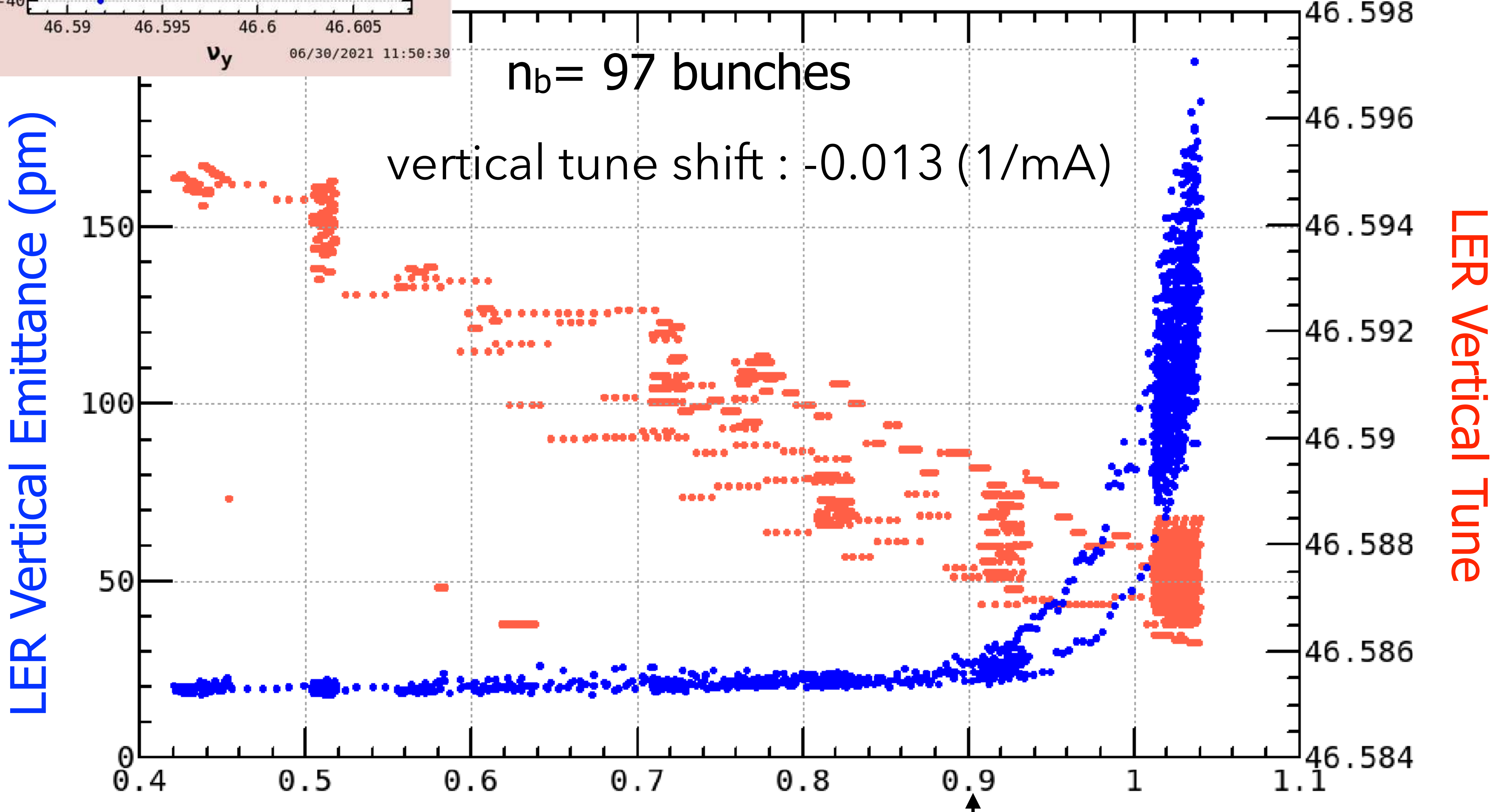
collimator opened (for test)

$$\Delta\nu_{y,th} = \frac{T_0 I_{th} \sum_i \beta_{yi}\kappa_i}{4\pi E/e} = \frac{\nu_s}{2}$$

$$f_s = \frac{\nu_s}{T_0}$$ f_s = 2.3325 (kHz)*



$\Sigma\ \beta_y\ \kappa$ = 36 (V/pC) on June 30



LER bunch current (mA)

$$I_{th} = \frac{2\pi f_s (E/e)}{\sum_i \beta_{yi}\kappa_i}$$ = 1.6 mA > 0.9 mA (measured)

The measured threshold is much lower than expected.

The kick factor is estimated by using ***GdfidL*** simulator.

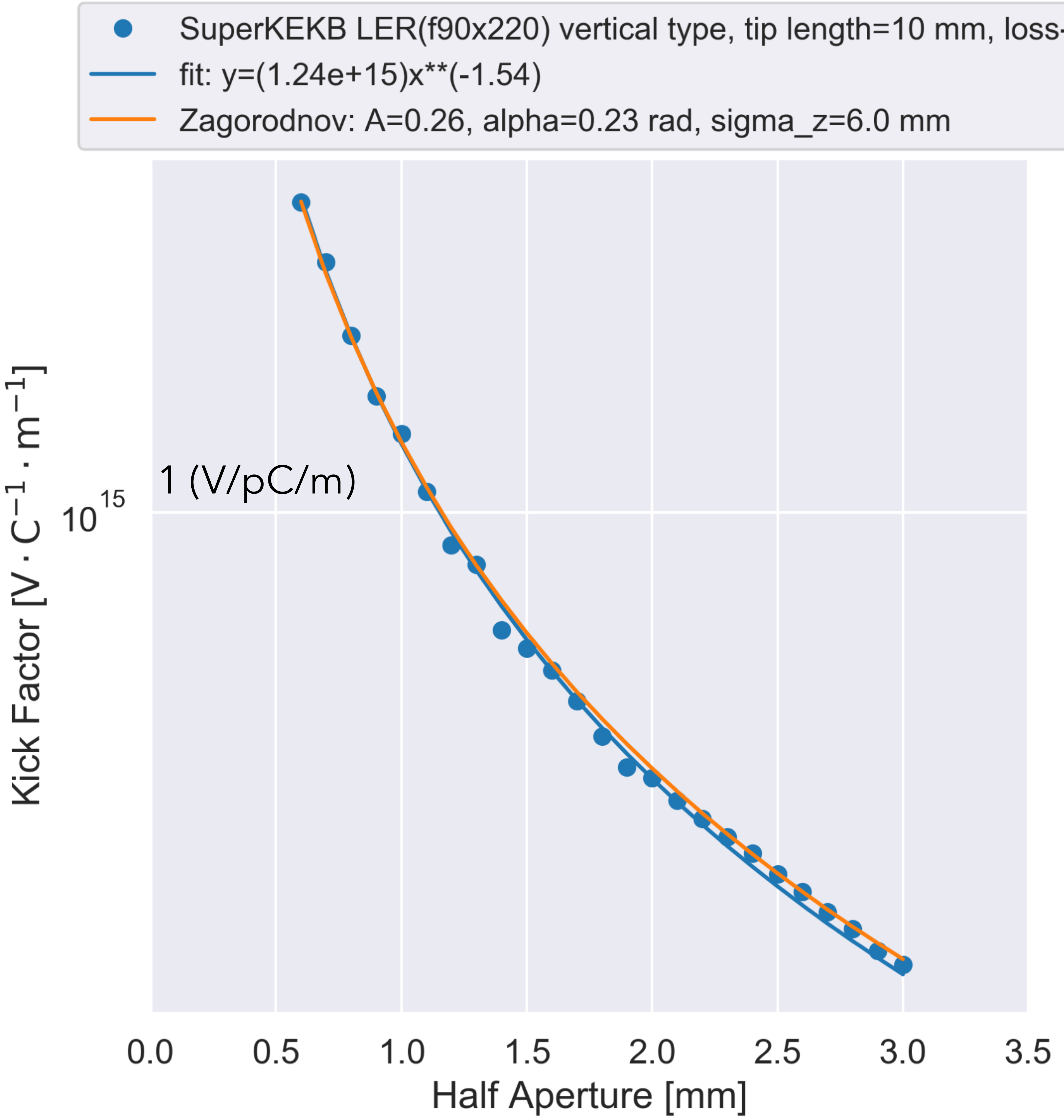
* measured value (M. Tobiyama)

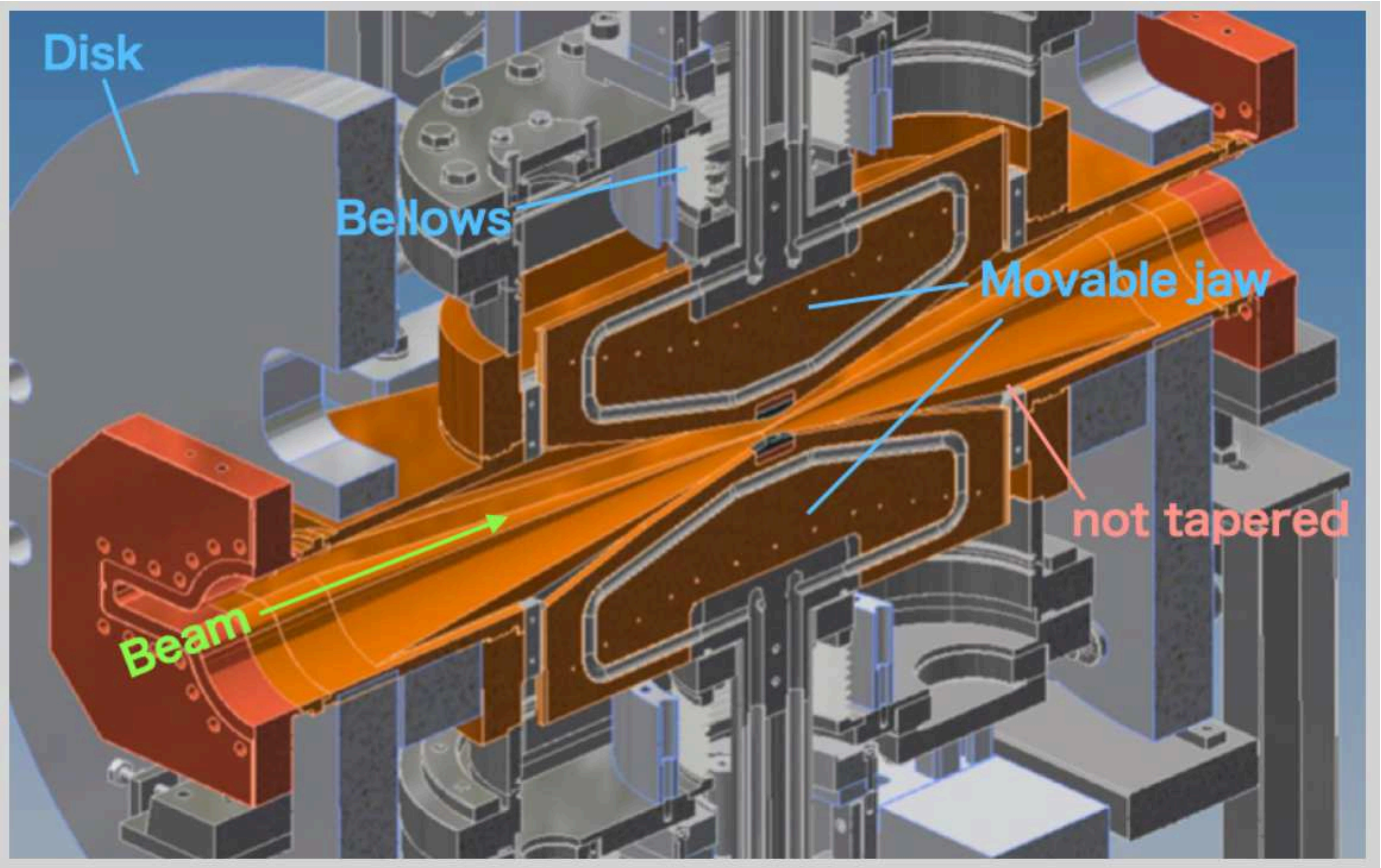
Simple TMCI formula can not explain it.

Calculation of GdfidL Electromagnetic Field Simulator

T. Ishibashi

Length(along beam axis) of head : 10 mm





Zagorodnov's equation

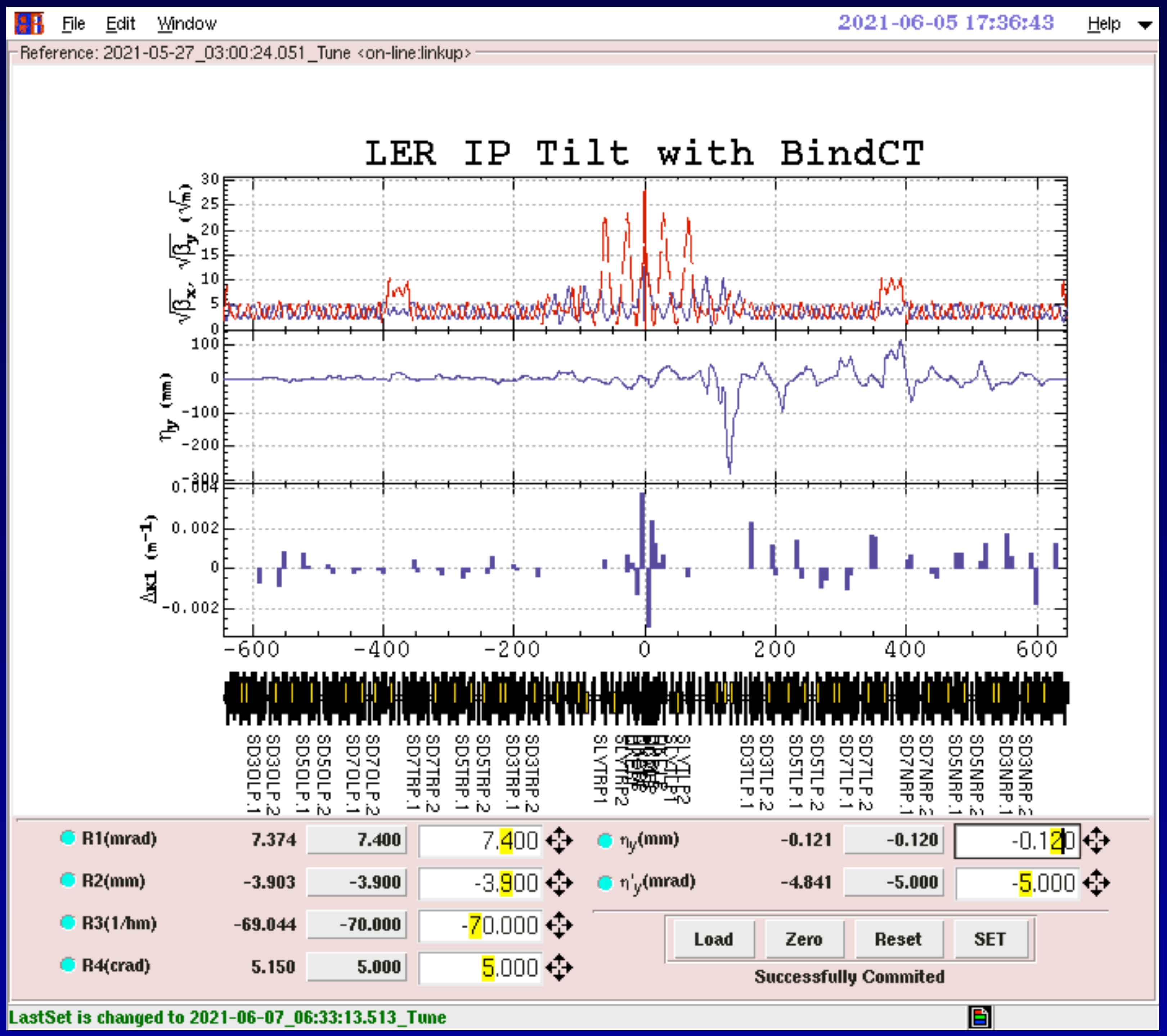
$$k_\perp = 0.215 A Z_0 c \sqrt{\frac{\alpha}{\sigma_z d^3}}$$

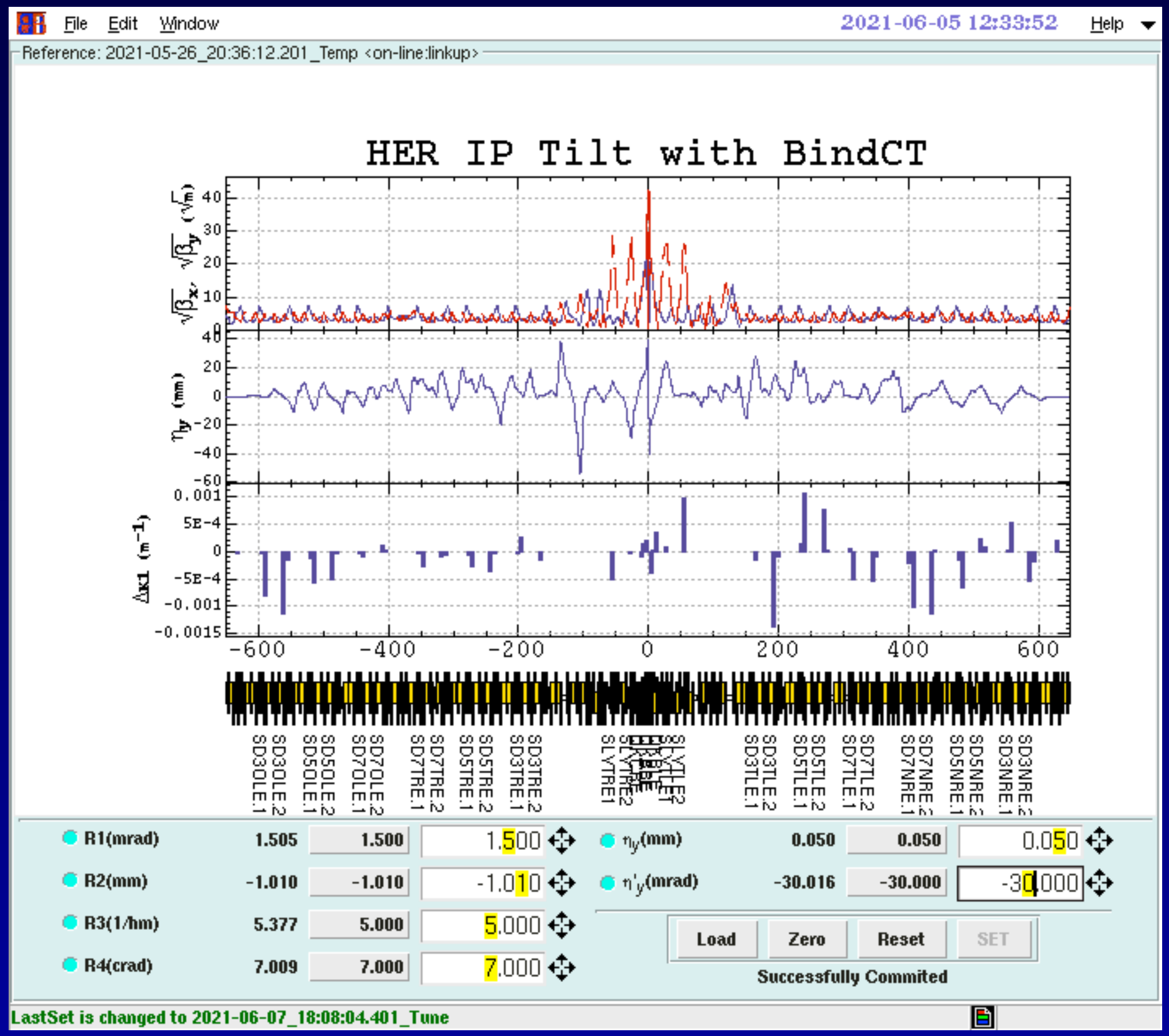
[I. Zagorodnov, Wakefield Calculations for 3D Collimators, EUROTeV-Report-2006-074.]

Luminosity Tuning

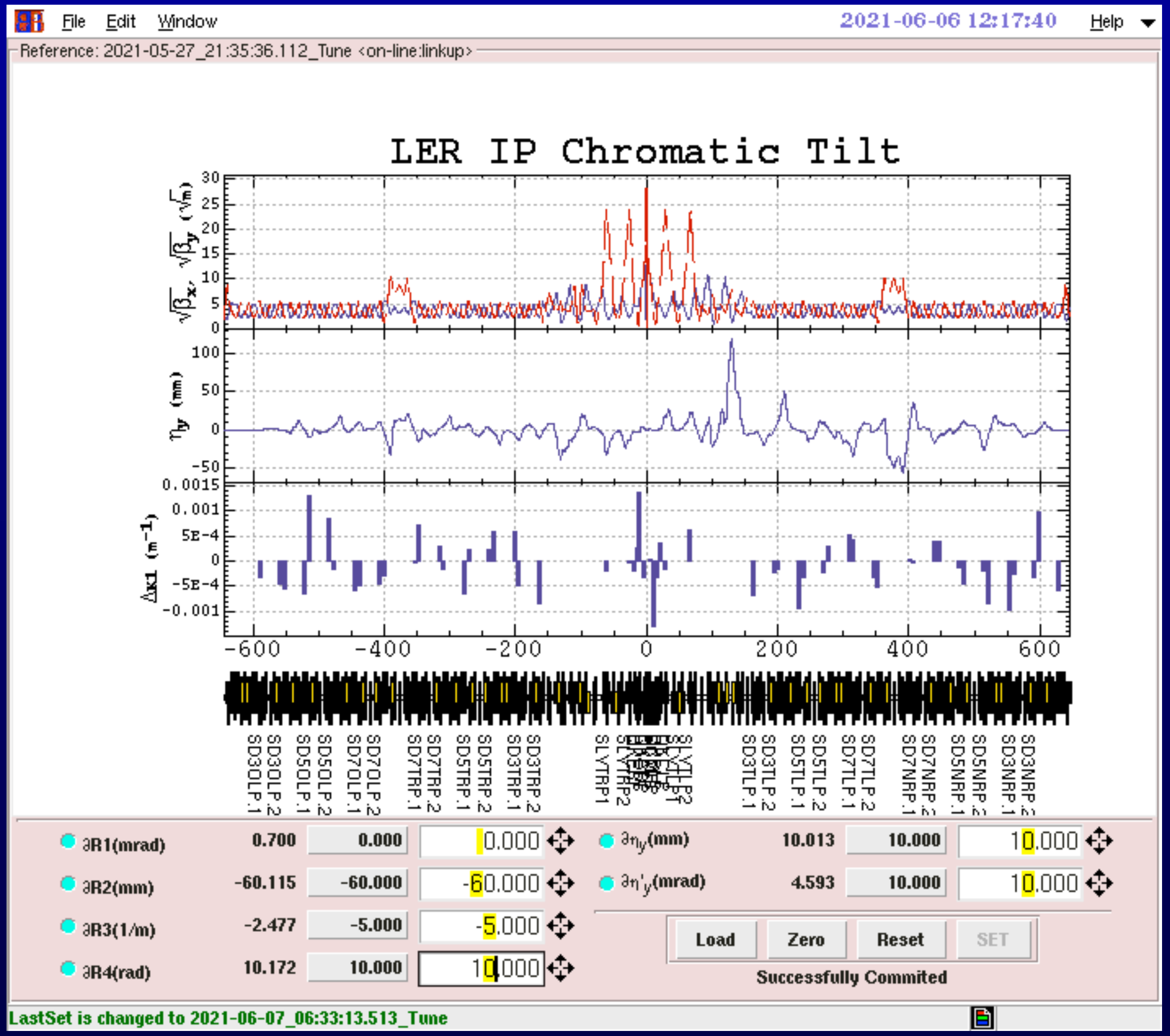
A. Morita
H. Koiso

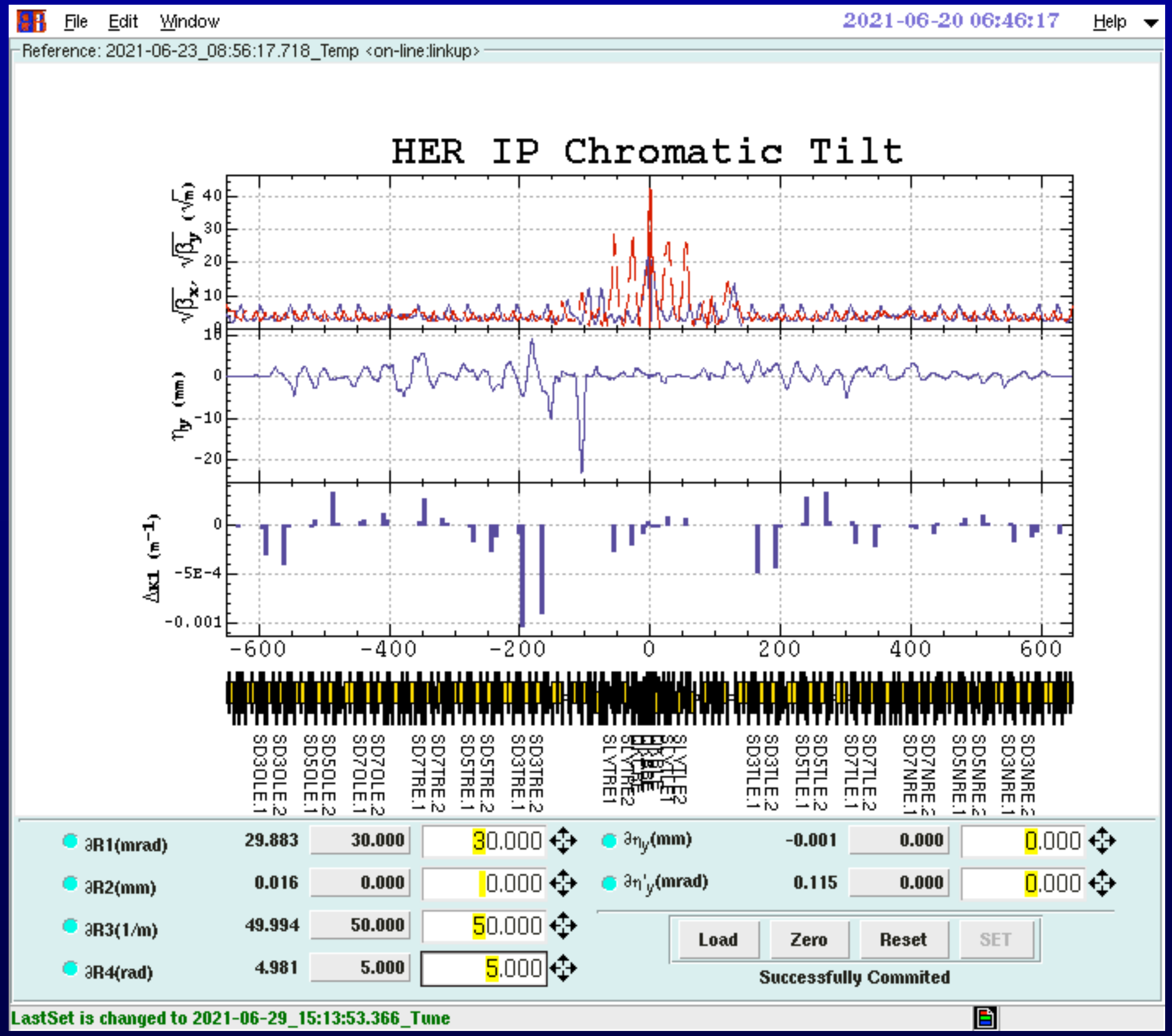
IP Knobs for X-Y couplings, dispersions





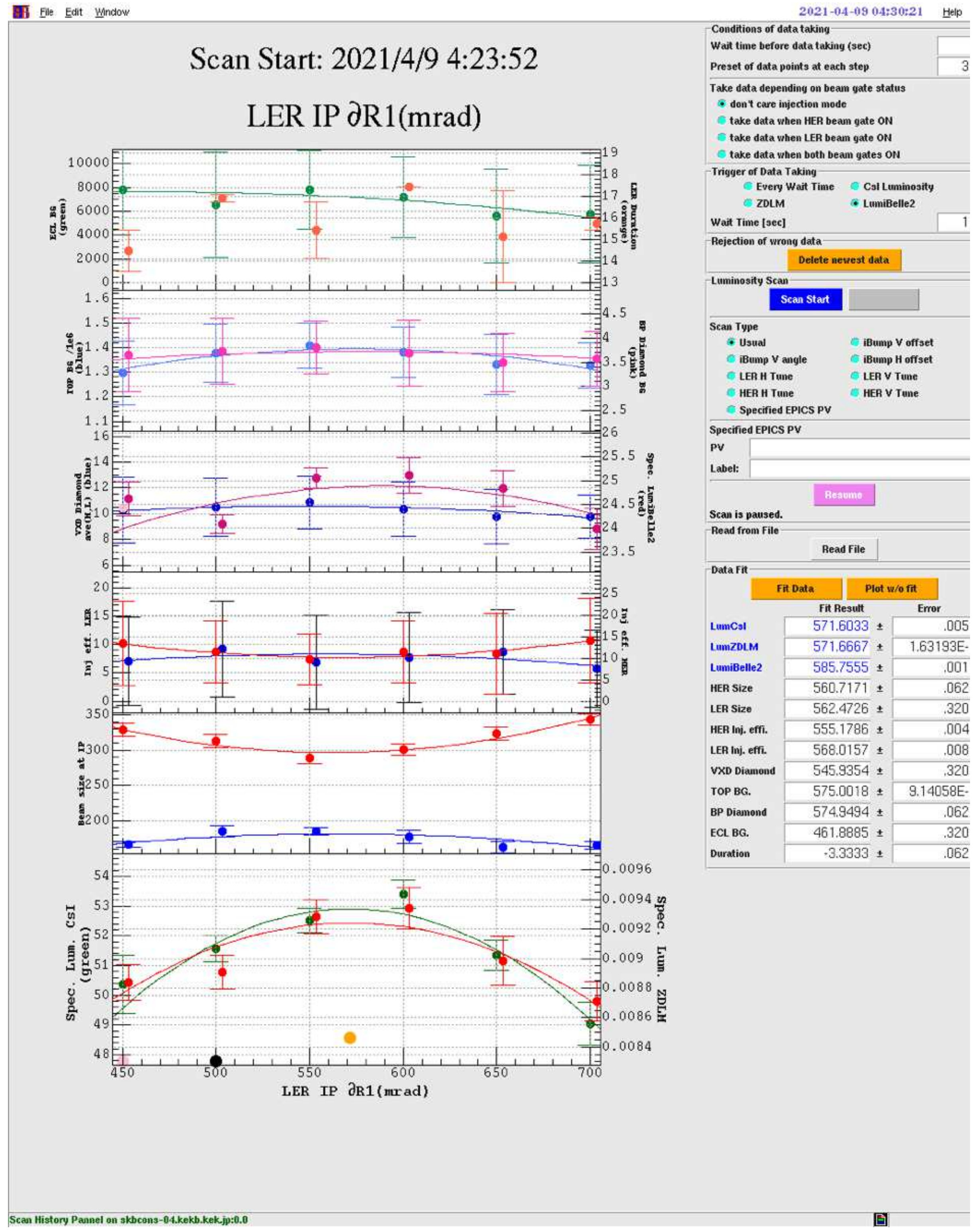
IP Knobs for chromatic X-Y couplings



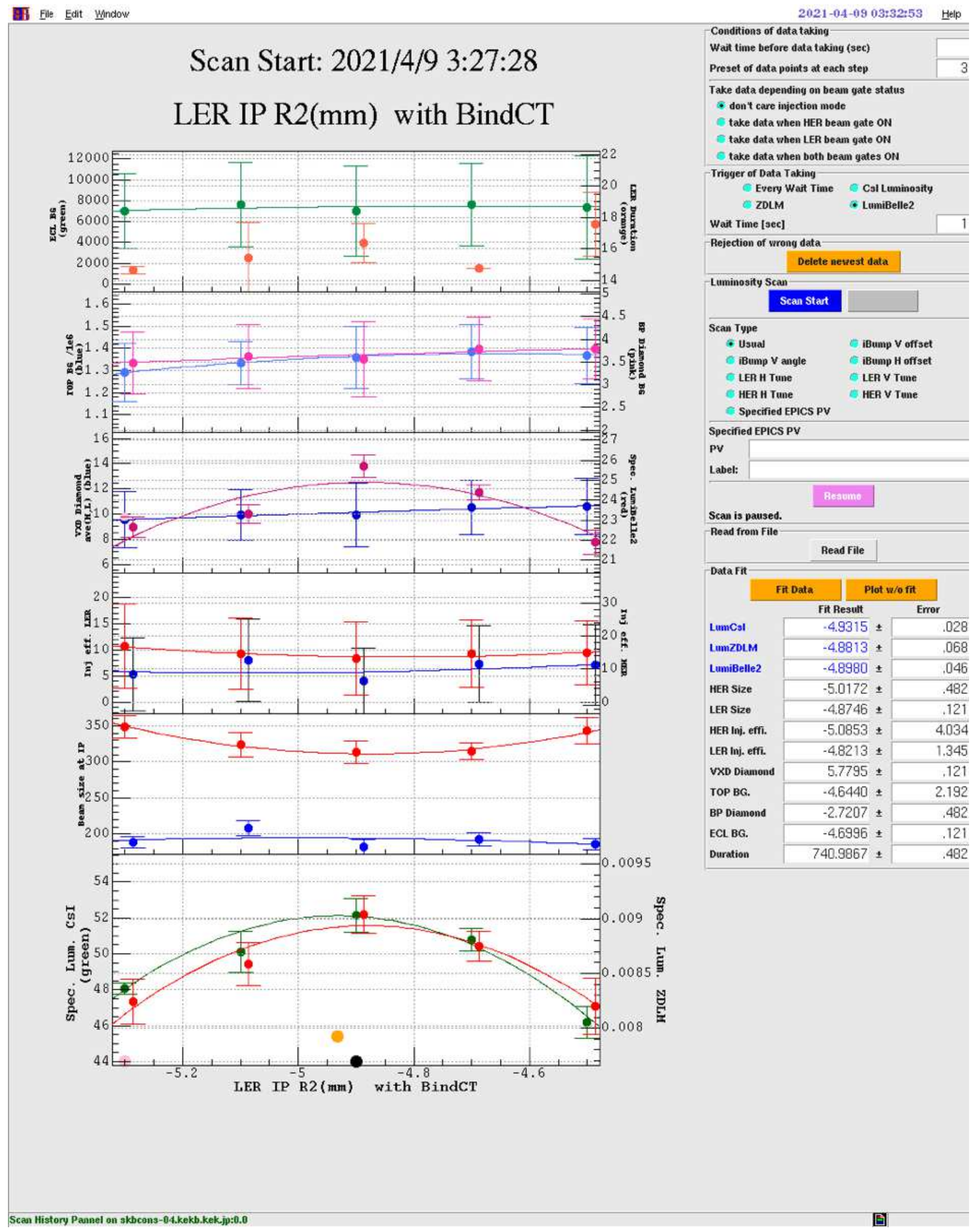


IP Knob Scan for Luminosity Tuning

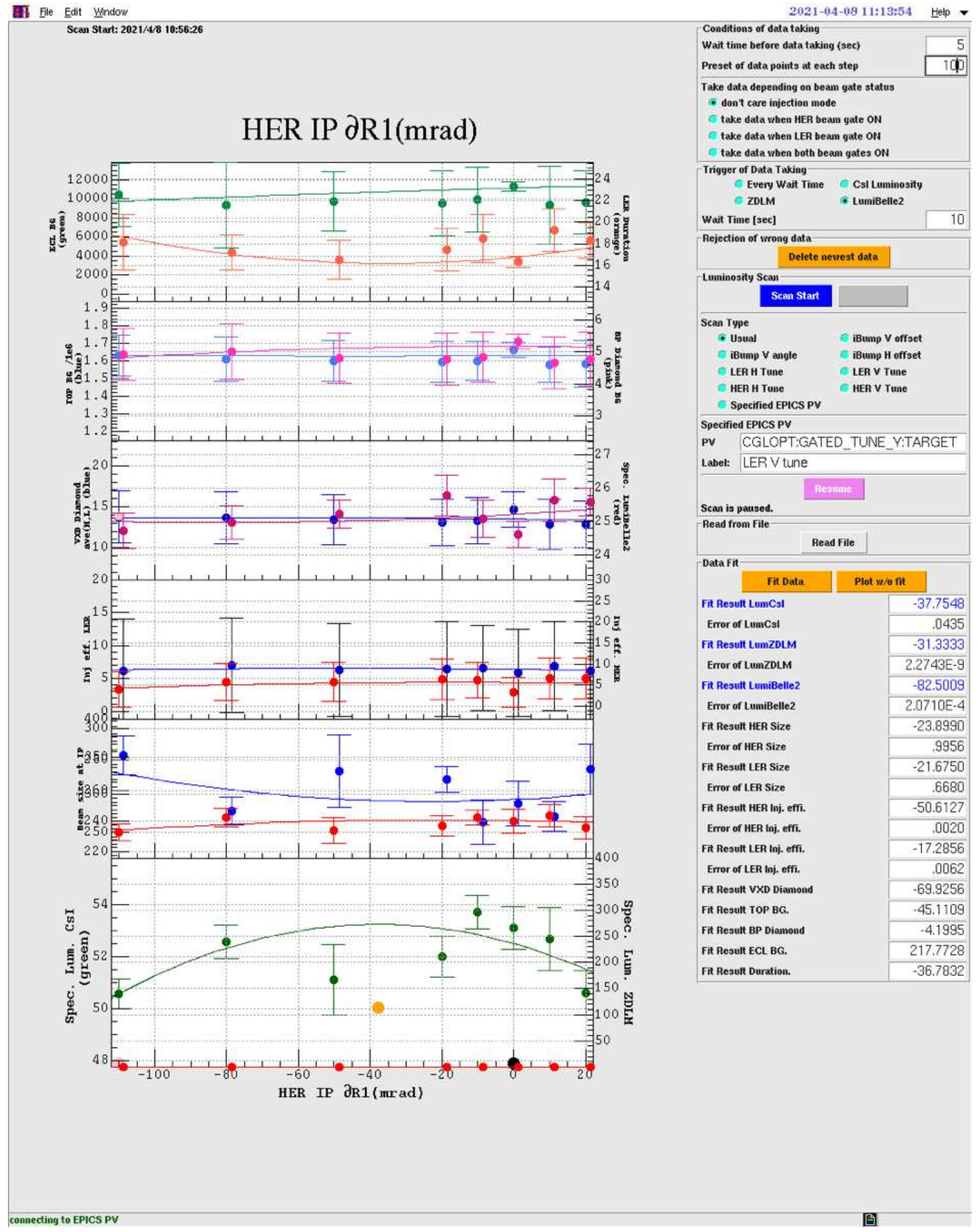
A



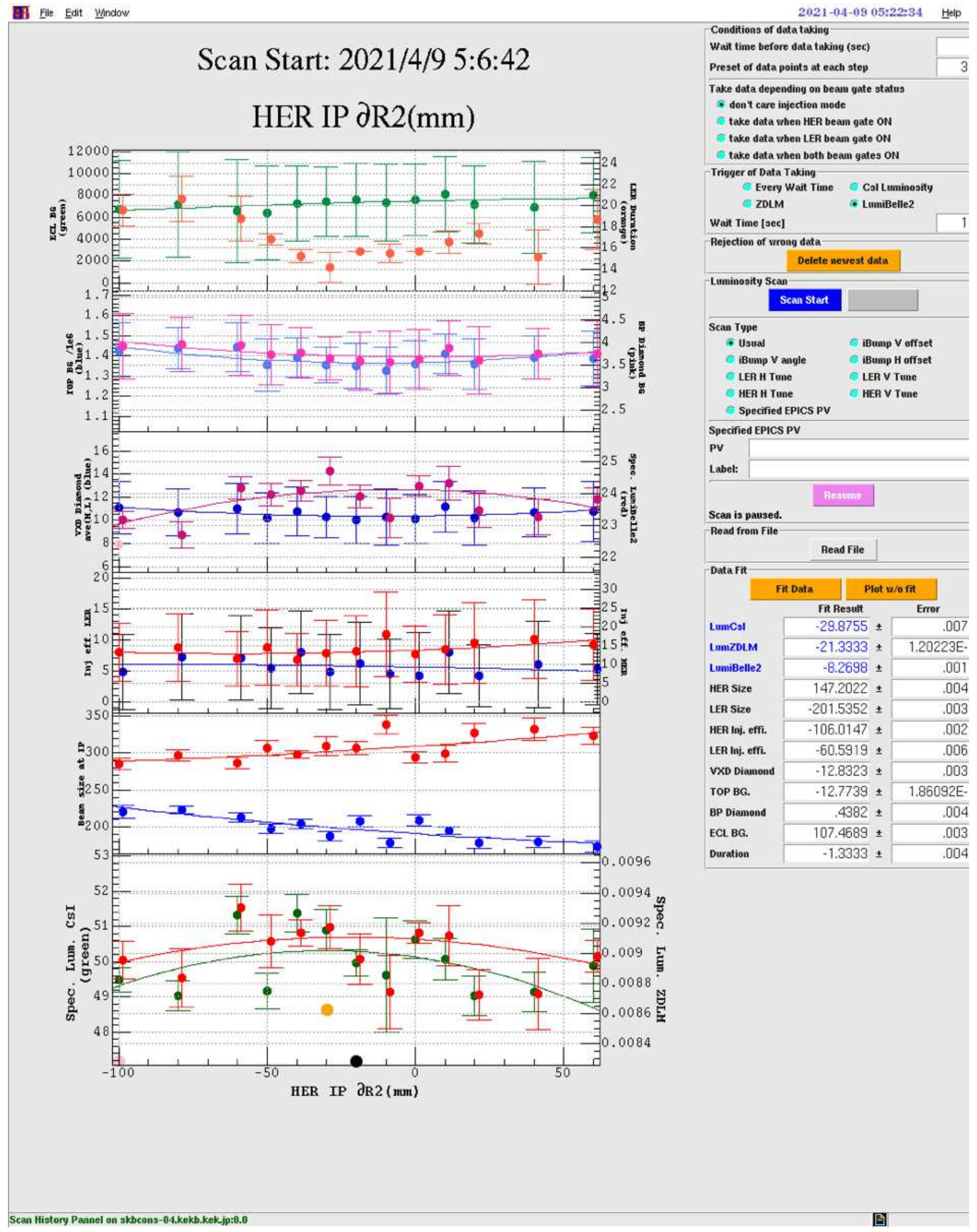
B



C



D

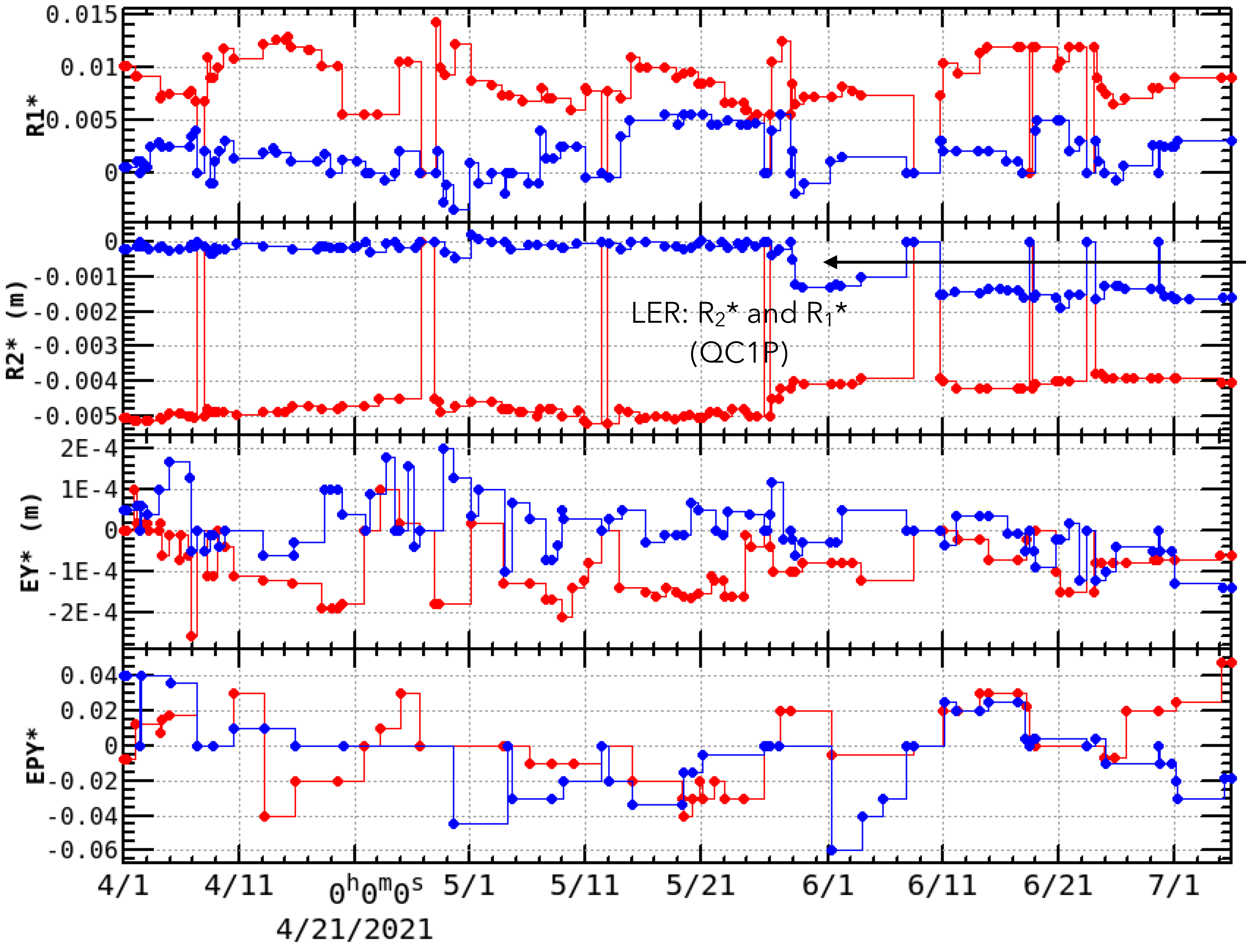


Vertical beam size²

$$\sigma_y^{*2} = \mu^2 \varepsilon_y \left(\beta_y^* + \frac{\Delta s^2}{\beta_y^*} \right) + (\eta_y^* \sigma_\delta)^2 + \varepsilon_x \frac{(R_2^* + R_4^* \Delta s)^2}{\beta_x^*} + \varepsilon_x \beta_x^* (R_1^* + R_3^* \Delta s)^2$$

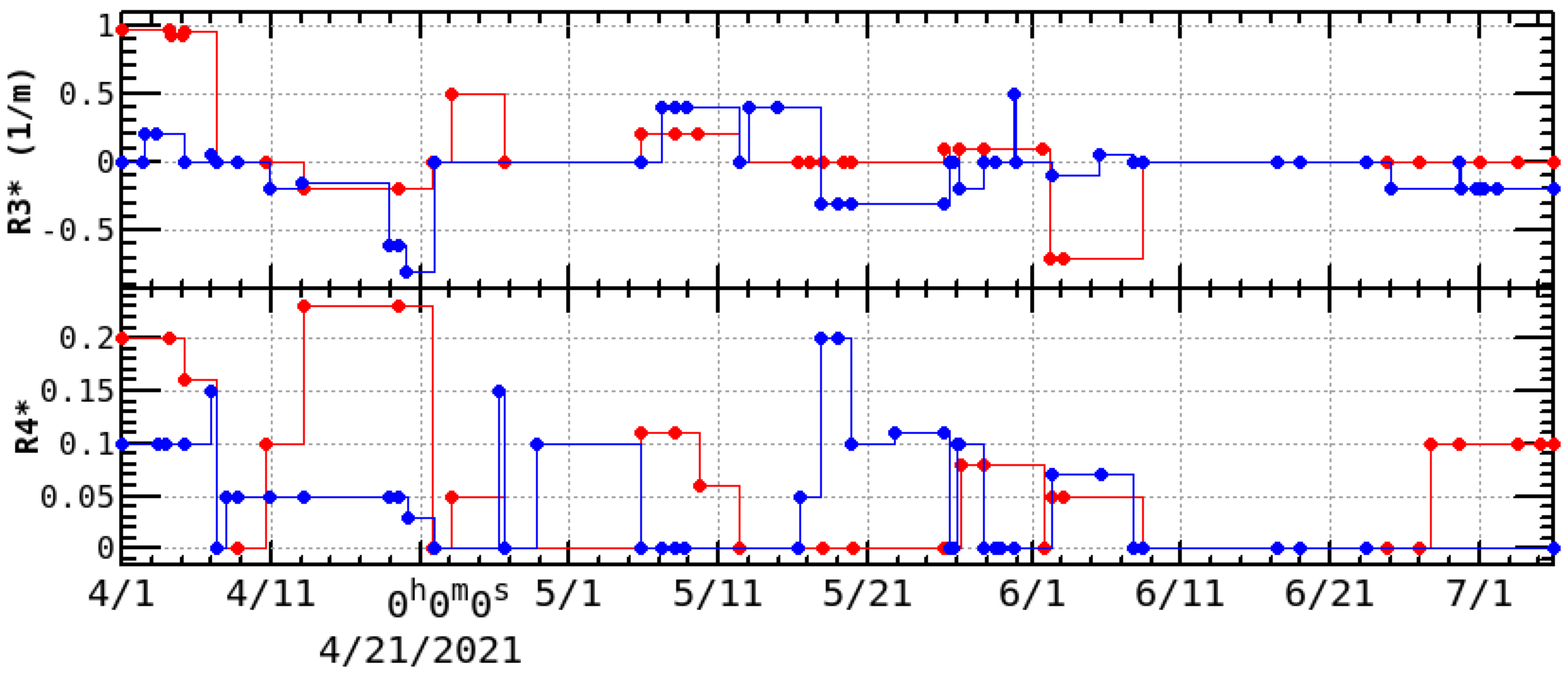
Δs : waist shift If $\Delta s = 0$, R_1^* and R_2^* are elementary parameters to improve the luminosity.

IP X-Y/Dispersion Knobs LER / HER



R₂* in HER changed due to the QC1P skew quadrupole leakage field.

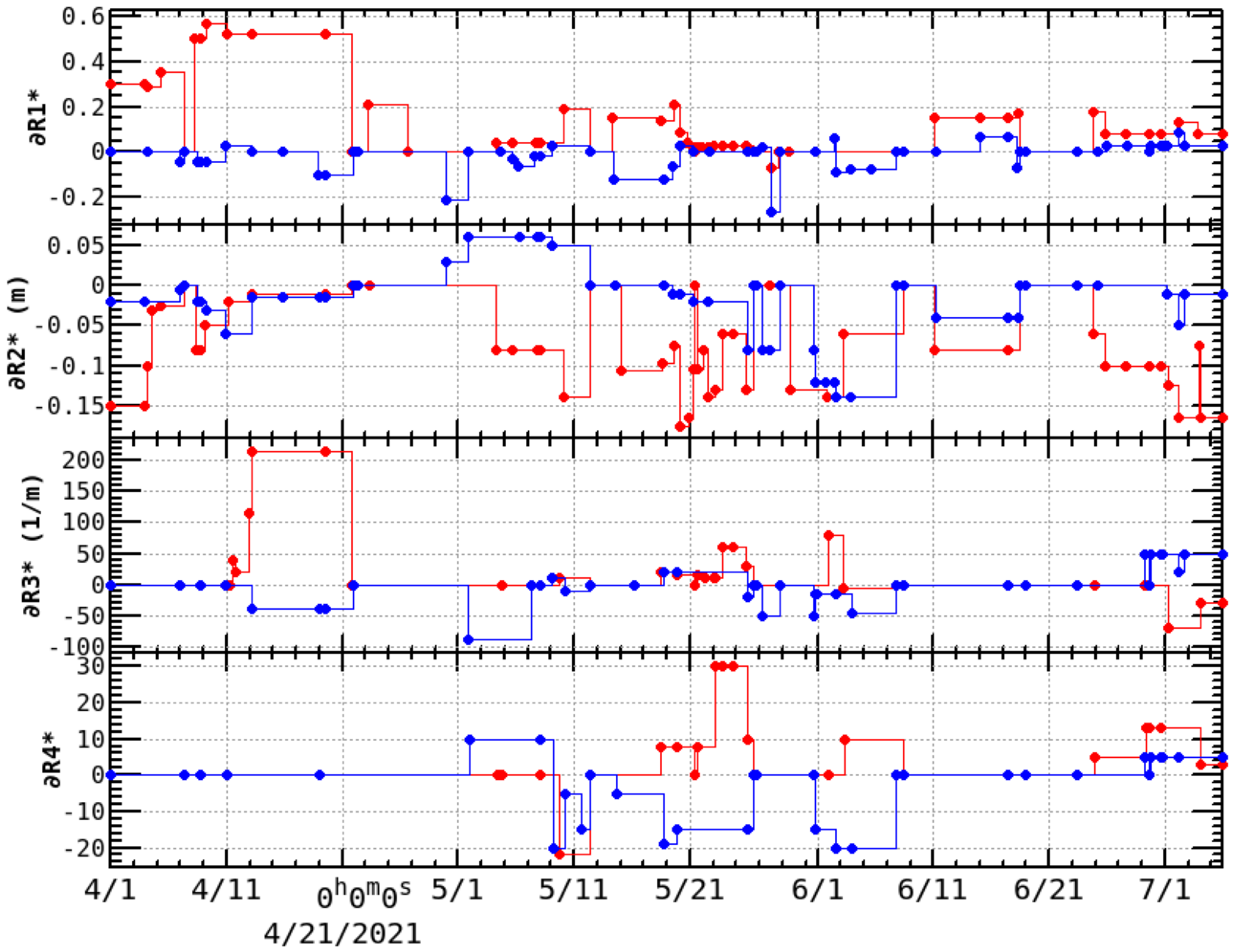
No iron shield on QC1P in LER



R_1^* and R_2^* are almost fixed to optimize luminosity.

R_3^* and R_4^* affect beam background.

IP Chromatic X-Y Coupling Knobs LER / HER



IP knob is separated for X-Y coupling and chromatic knobs. (new knobs)

A. Morita

- Sextupole magnet mounted on rotating table is utilized since March 11 to suppress chromatic X-Y at IP(model).
- Corrector strength and/or BG sometime limits the knob.
- Reduction of Beam-Beam blowup is not clear so far.

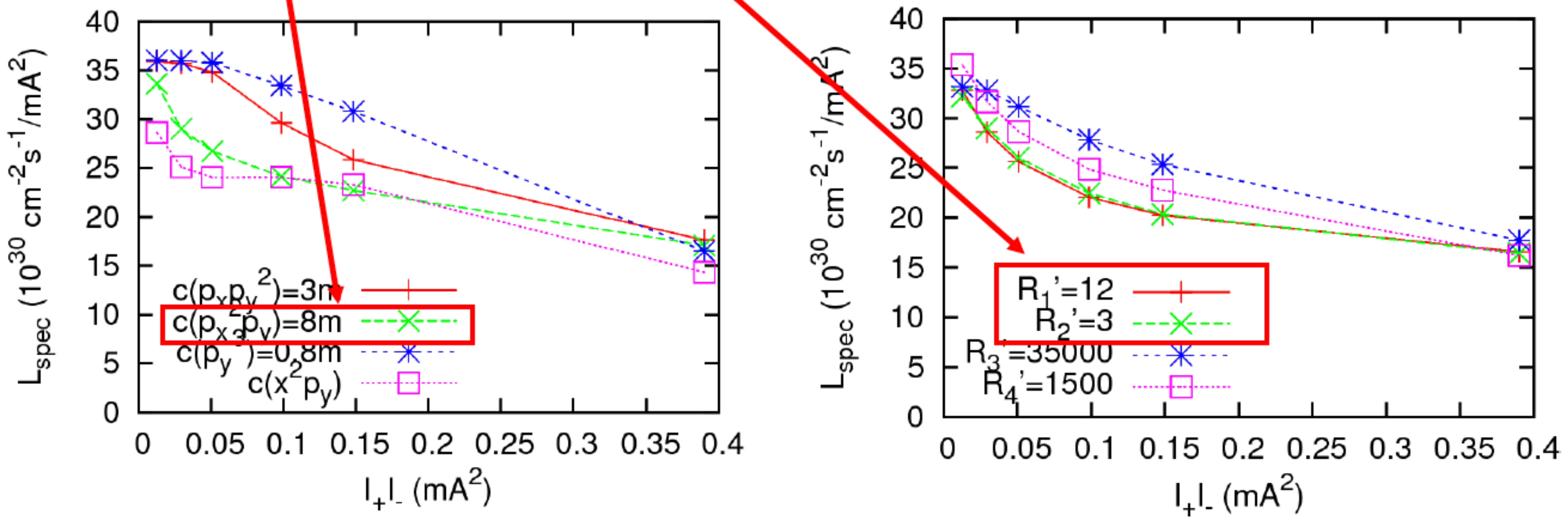
K. Ohmi, KEKB Review 2018

Chromatic, nonlinear aberrations

- Possible errors to explain measured luminosity
- R1'=12rad
- R2'=3m
- $C(p_x^2 p_y)$=8m

100 times larger for the early estimation (page 22)

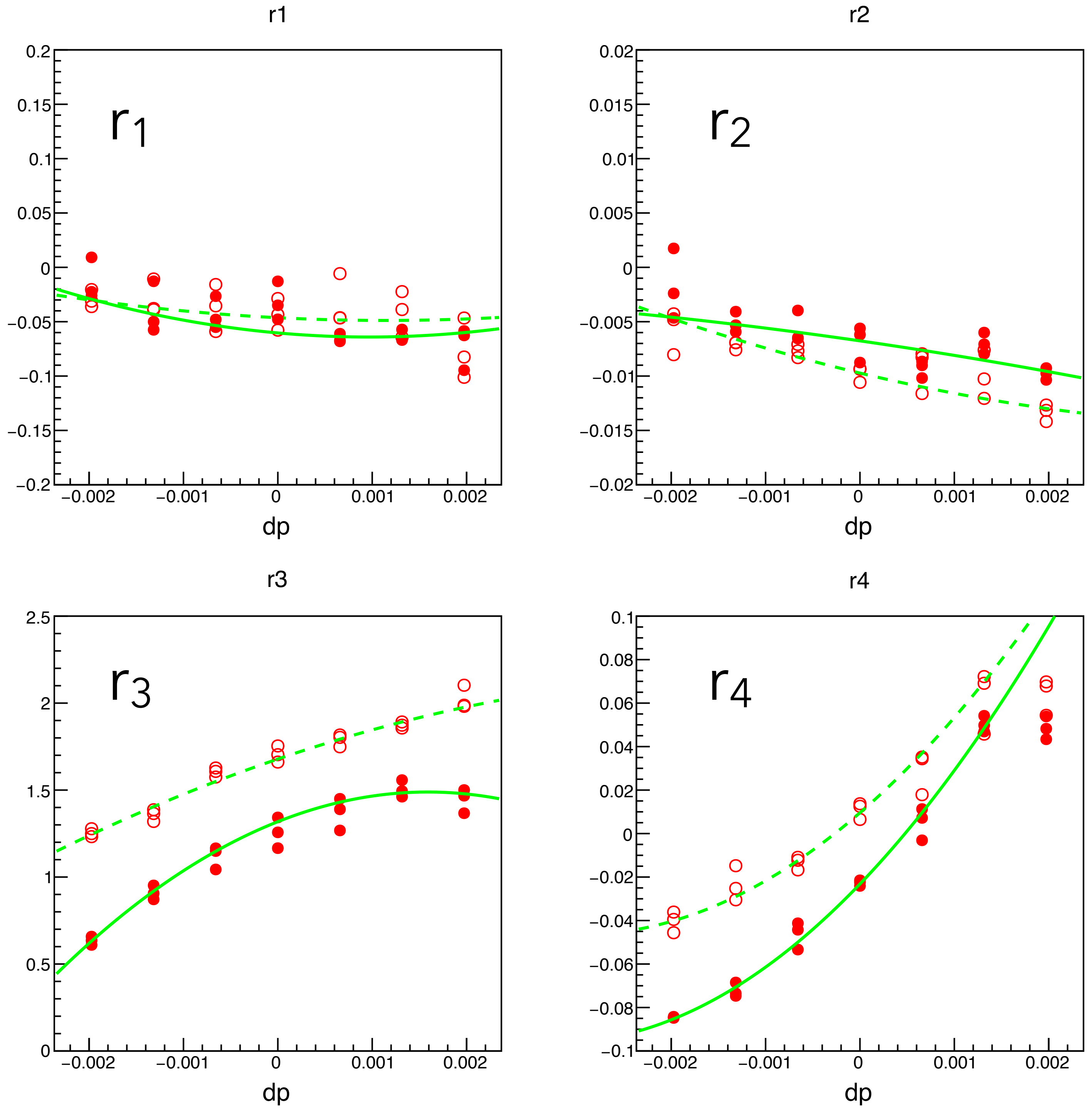
Weak strong simulation with nonlinear IP aberrations



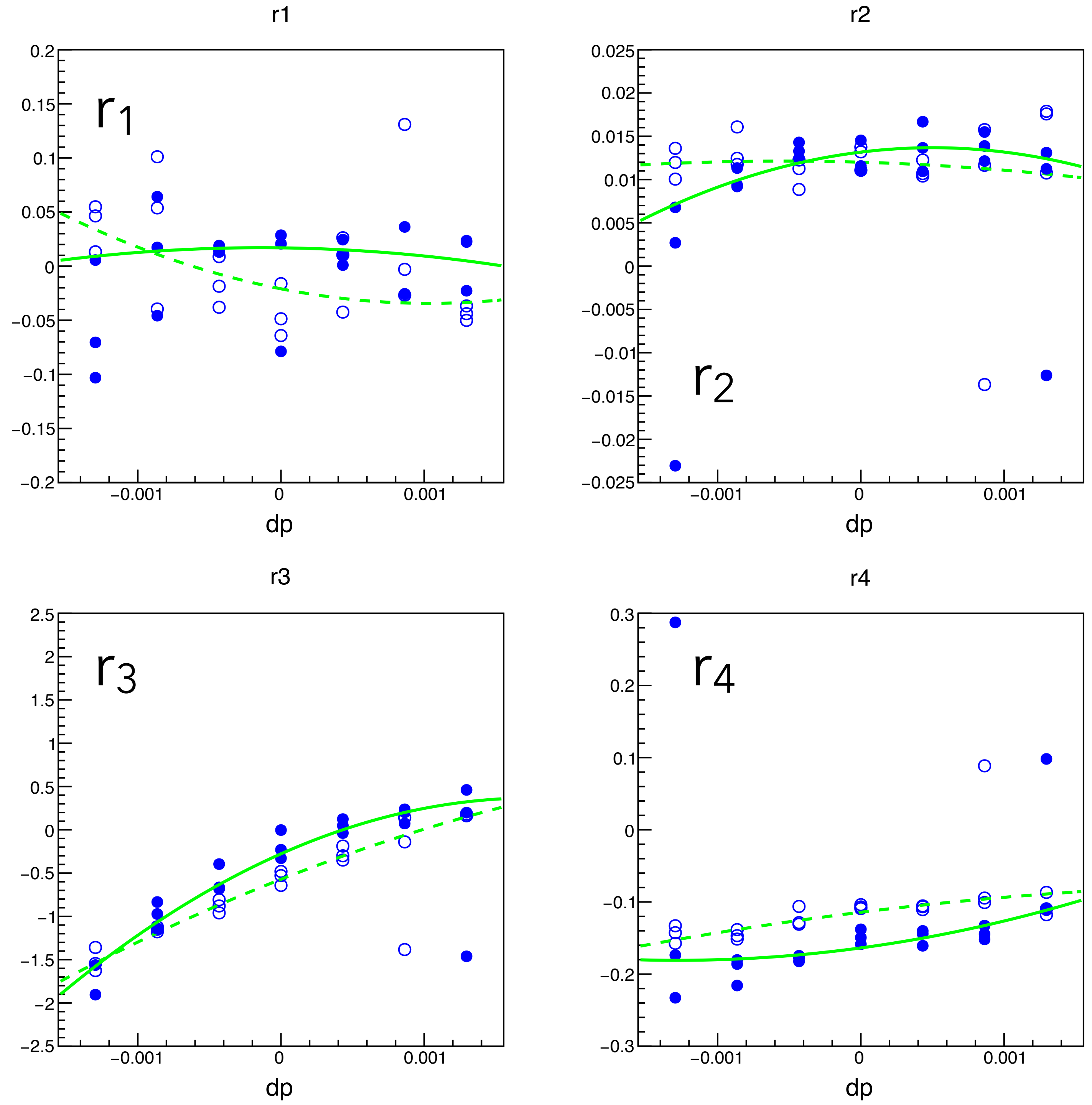
Chromatic X-Y couplings at the IP measured by using TBT BPMs

G. Mitsuka

LER



HER



Accuracy of measurement is under consideration.

LER

IP chromatic knob on

	r	dr/dδ
r_1	-6.034×10^{-2}	-7.764
r_2	-6.763×10^{-3}	-1.254
r_3	1.318	214.6
r_4	-2.319×10^{-2}	45.24

IP chromatic knob off

r_1	-4.634×10^{-2}	-4.379
r_2	-9.726×10^{-3}	-2.079
r_3	1.678	185.0
r_4	9.563×10^{-3}	37.54

HER

IP chromatic knob on

	r	dr/dδ
r_1	1.69×10^{-2}	-1.644
r_2	1.317×10^{-2}	2.028
r_3	-0.2772	733.0
r_4	-0.1637	26.81

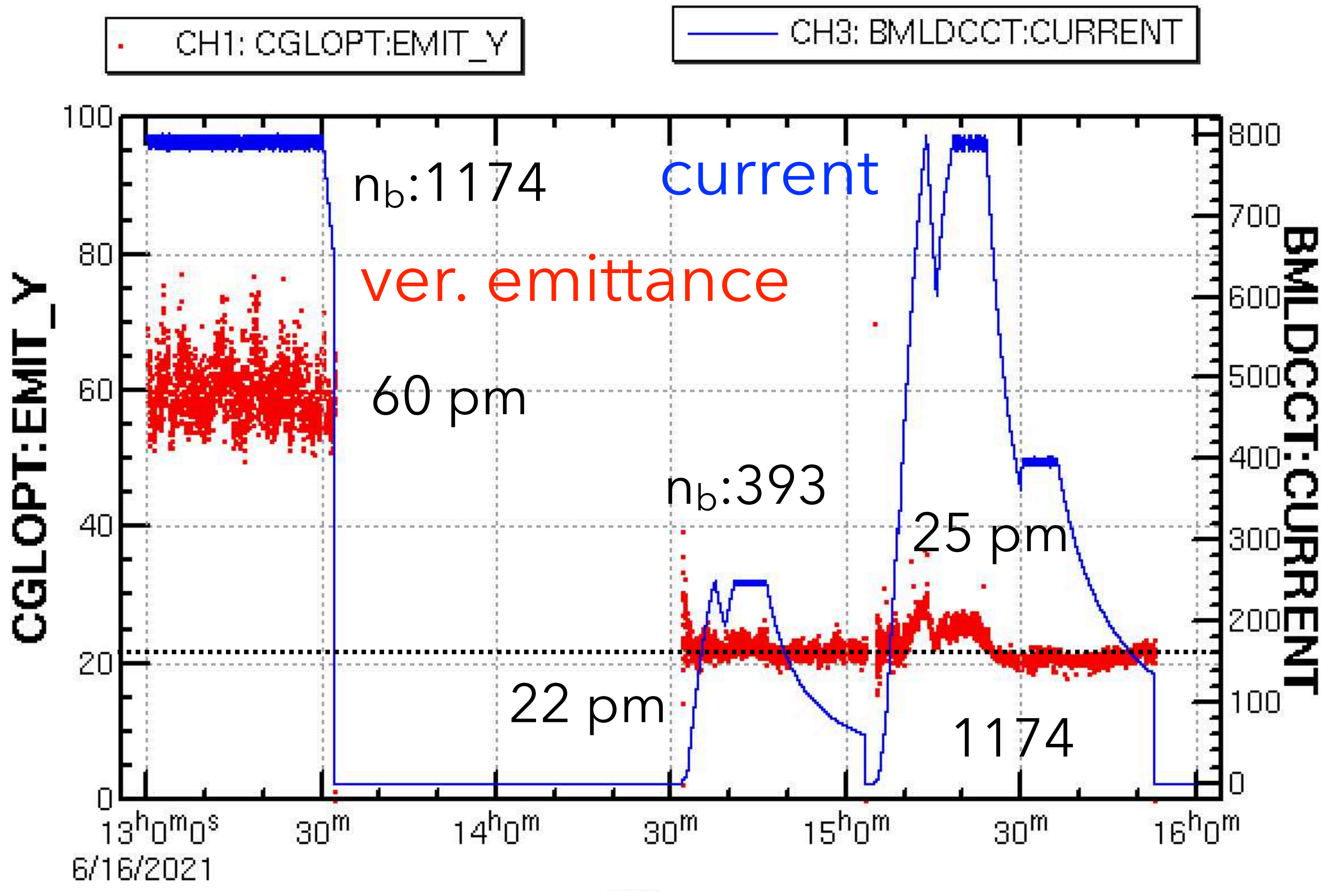
IP chromatic knob off

r_1	-2.095×10^{-2}	-25.99
r_2	1.2×10^{-2}	-0.4769
r_3	-0.5715	652.4
r_4	-0.1142	24.53

Lifetime

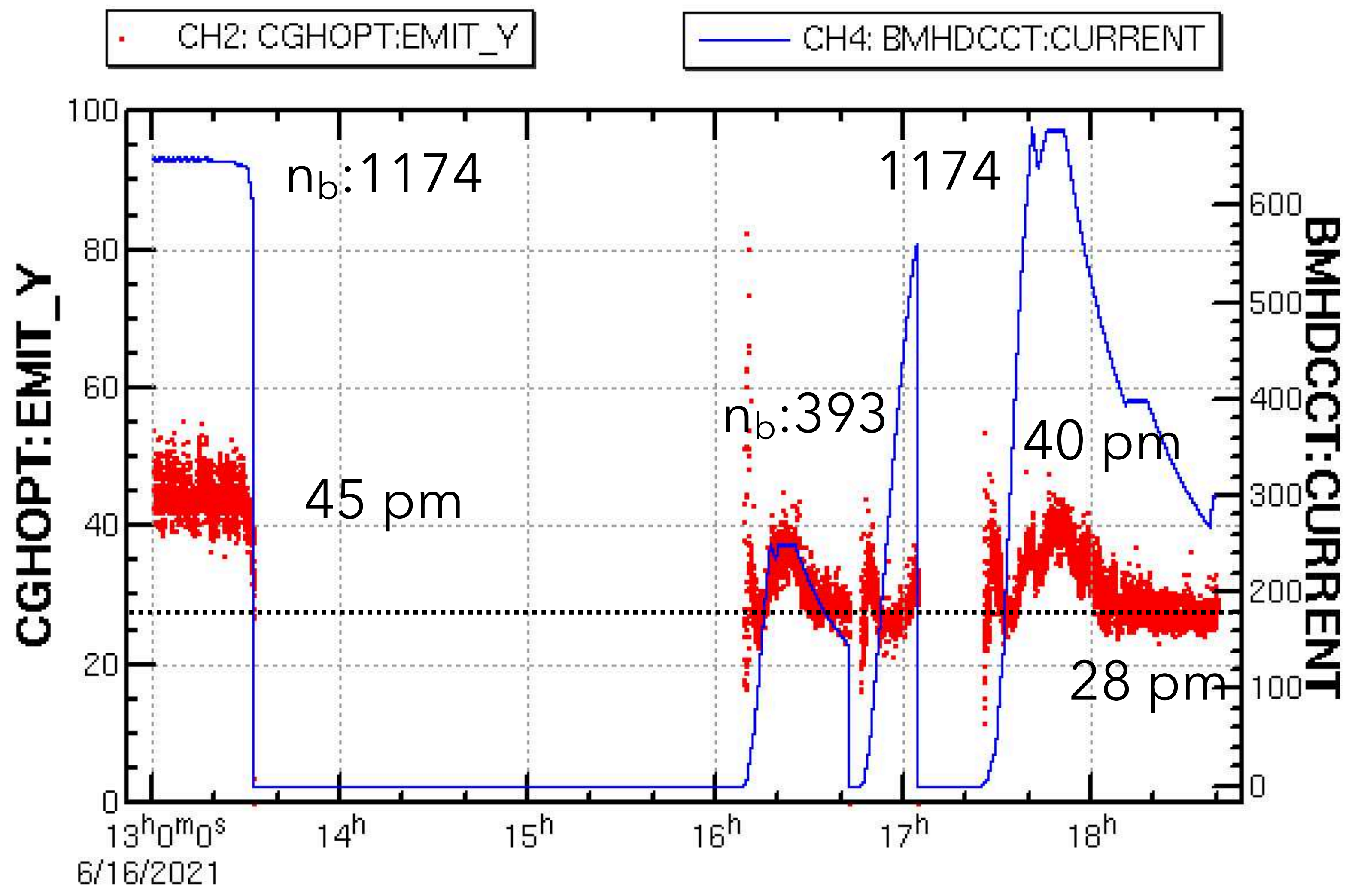
Beam Lifetime and Vertical Emittance

LER



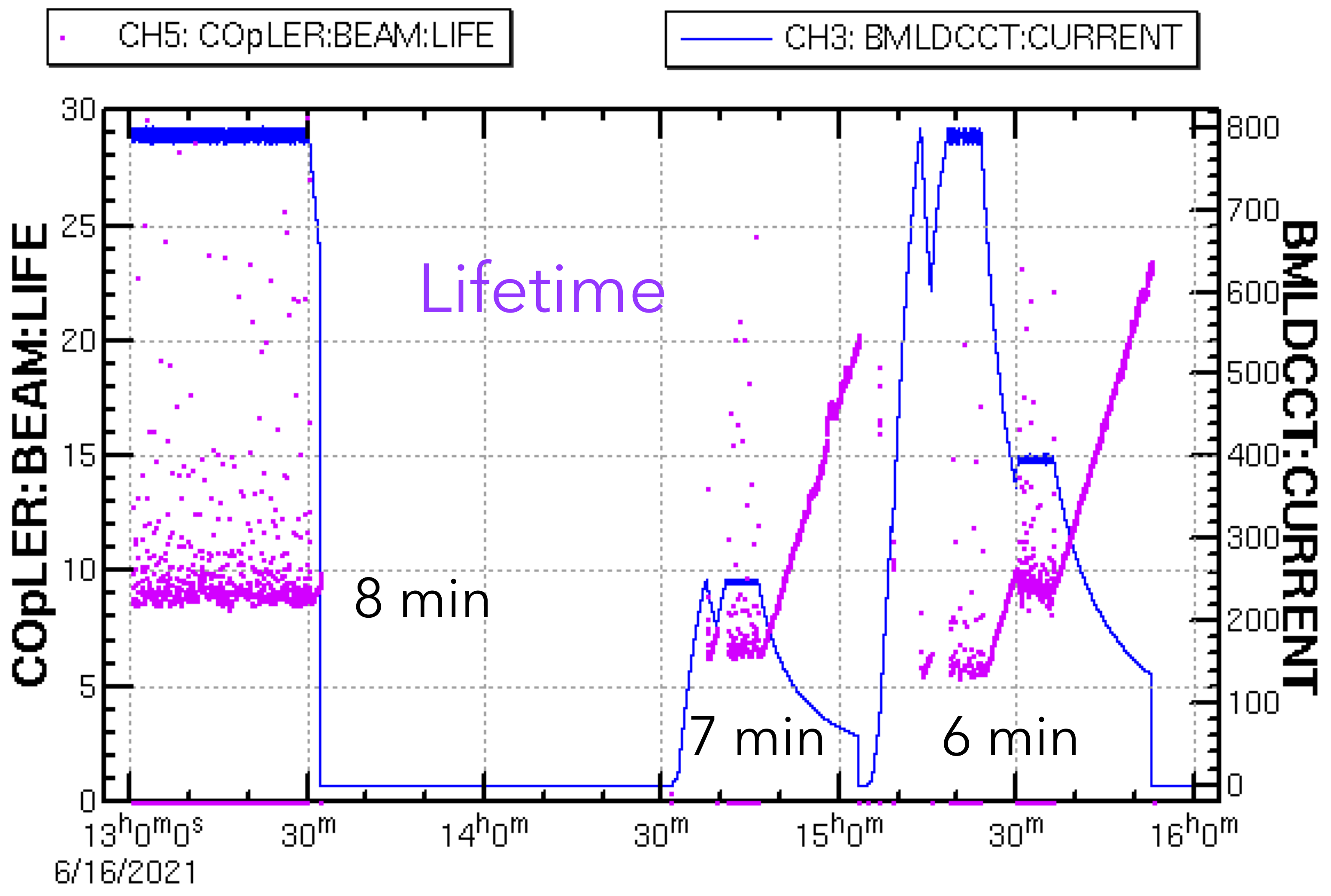
collision single beam

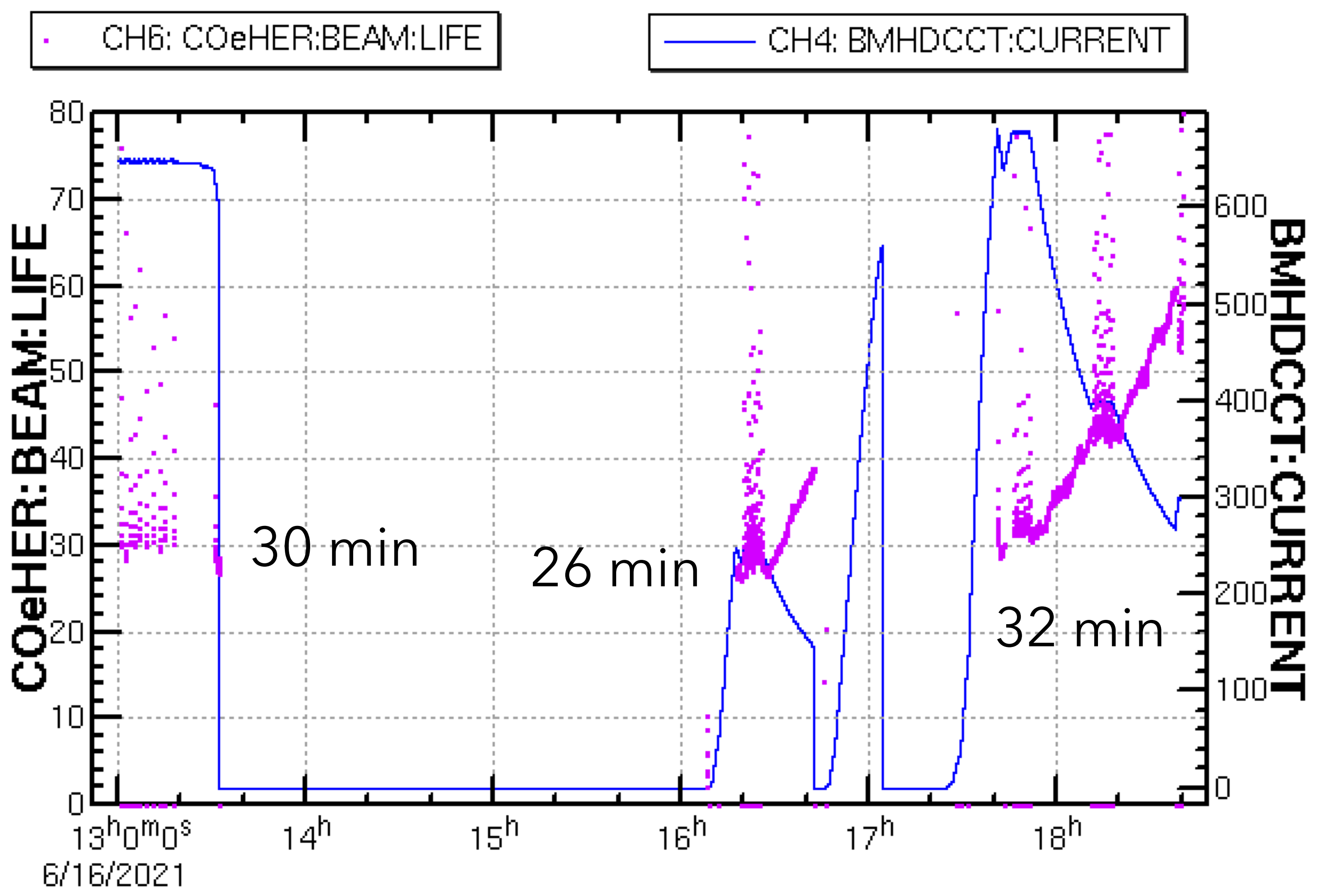
HER



collision single beam

ε_y depends on bunch current.



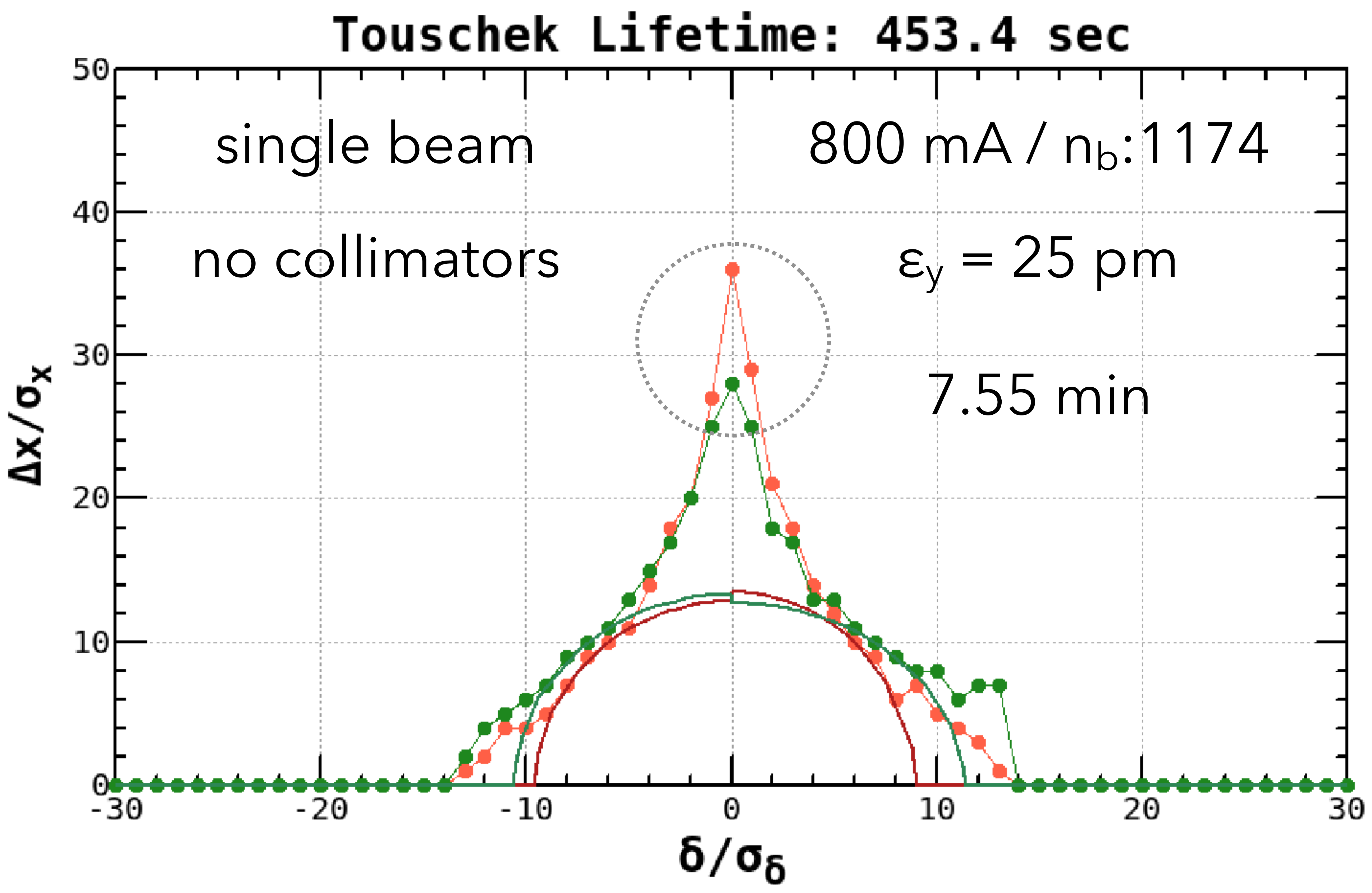


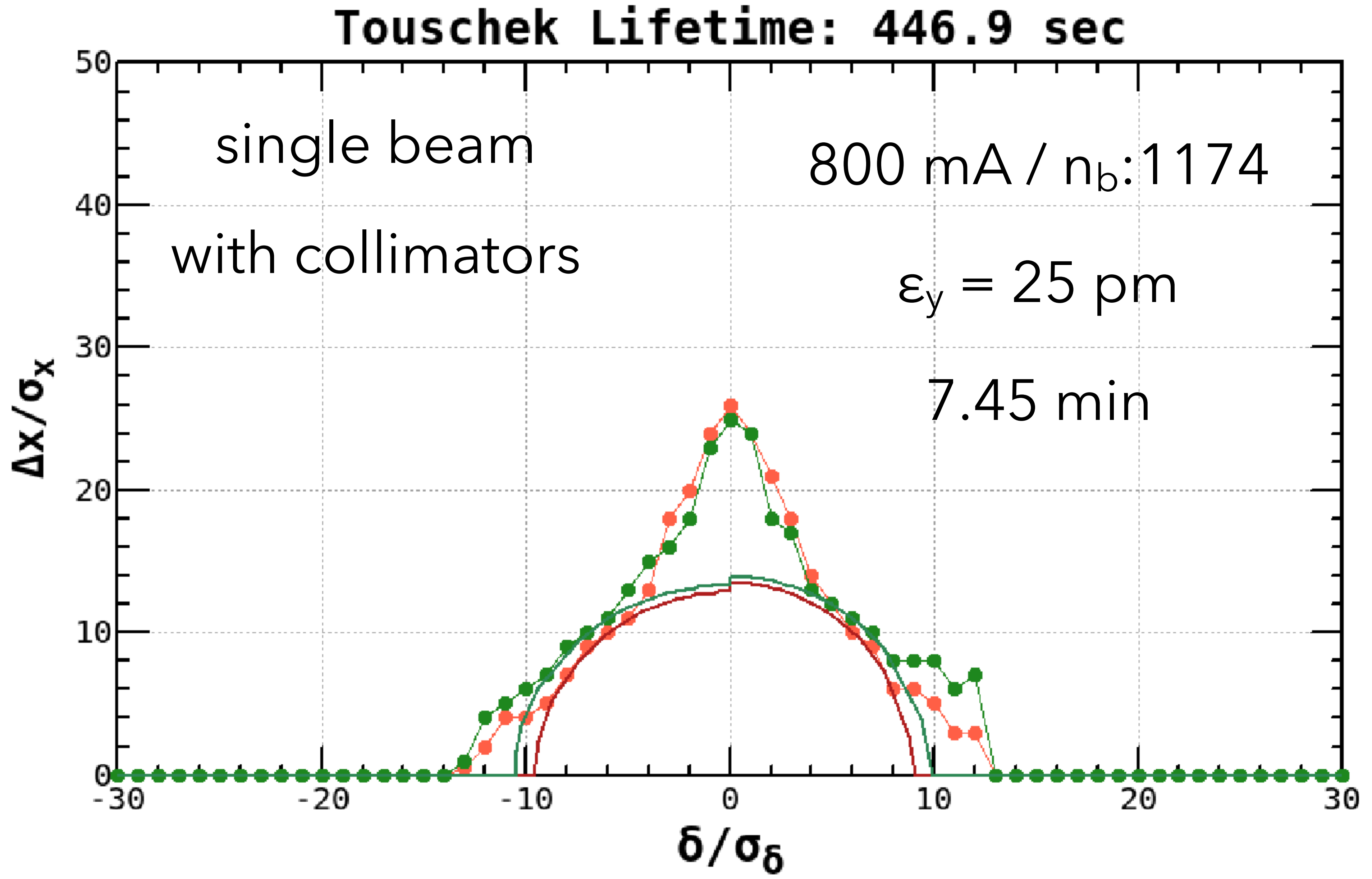
	LER	HER
β_x^*	80 mm	60 mm
β_y^*	1 mm	1 mm
I	800 mA	650 mA
n_b	1174	1174
I_b	0.681 mA	0.545 mA
ε_y collision	60 pm	45 pm
ε_y single	25 pm	40 pm
life collision	8 min	30 min
life single	6 min	32 min

e^+_{inj}: 2.3 nC x 2 x 12.5 Hz x 80 %
I_{max}= 1.5 A for lifetime: 8 min
(TMCI limit : 1.4 A with n_b:1565)

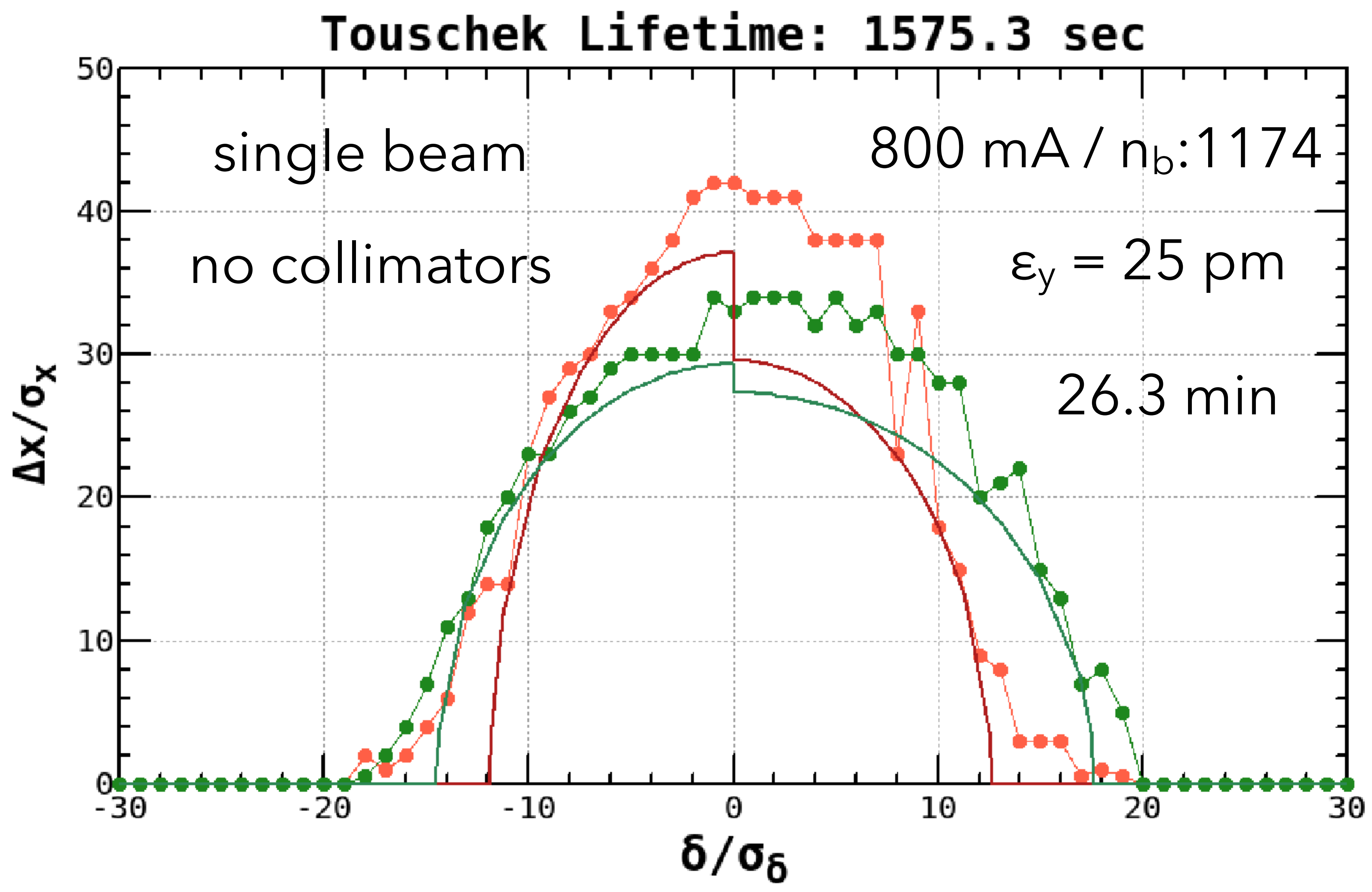
Tracking Simulation
No Machine Error

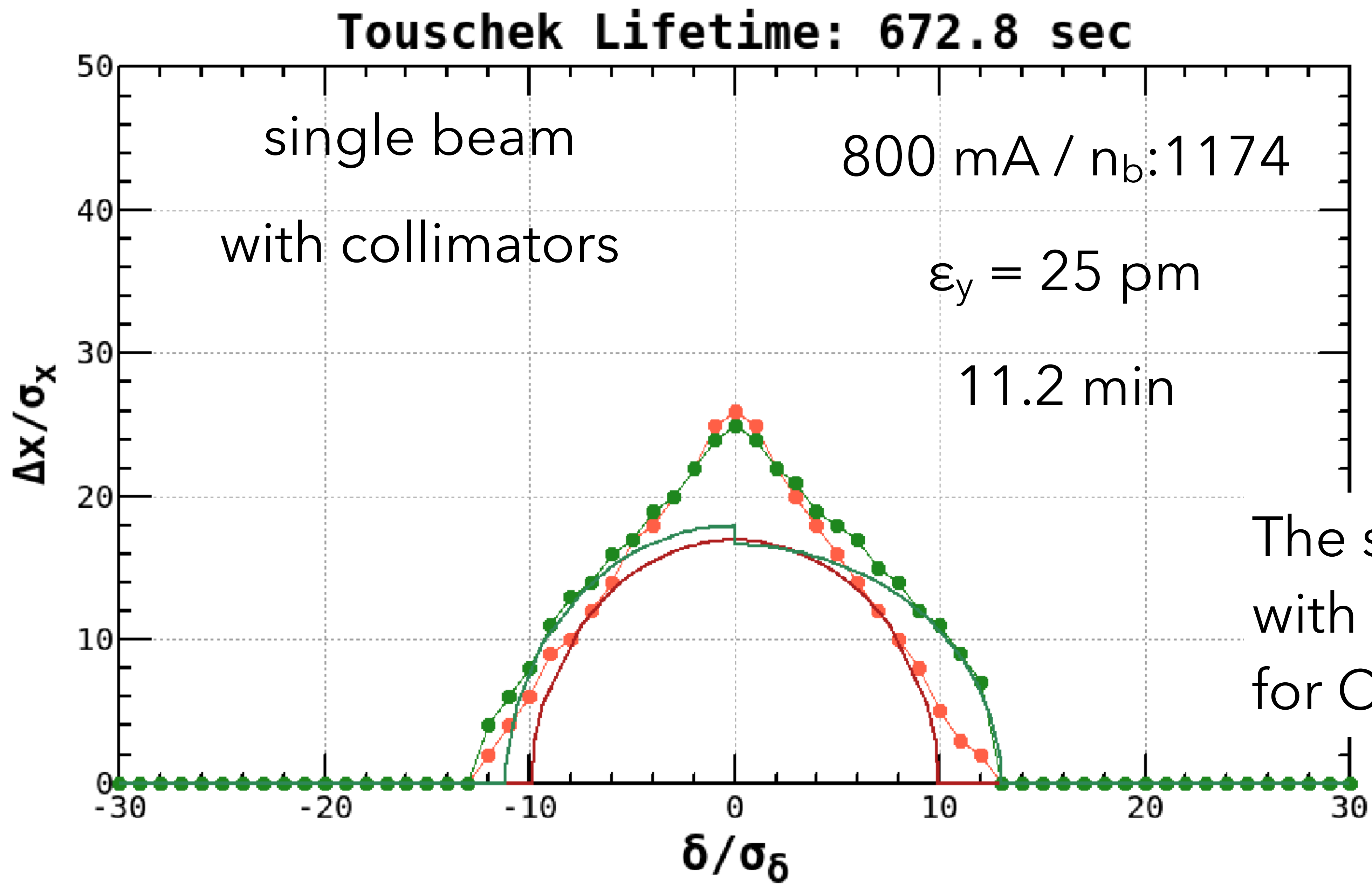
LER : CW 80 %





LER : CW 0 %



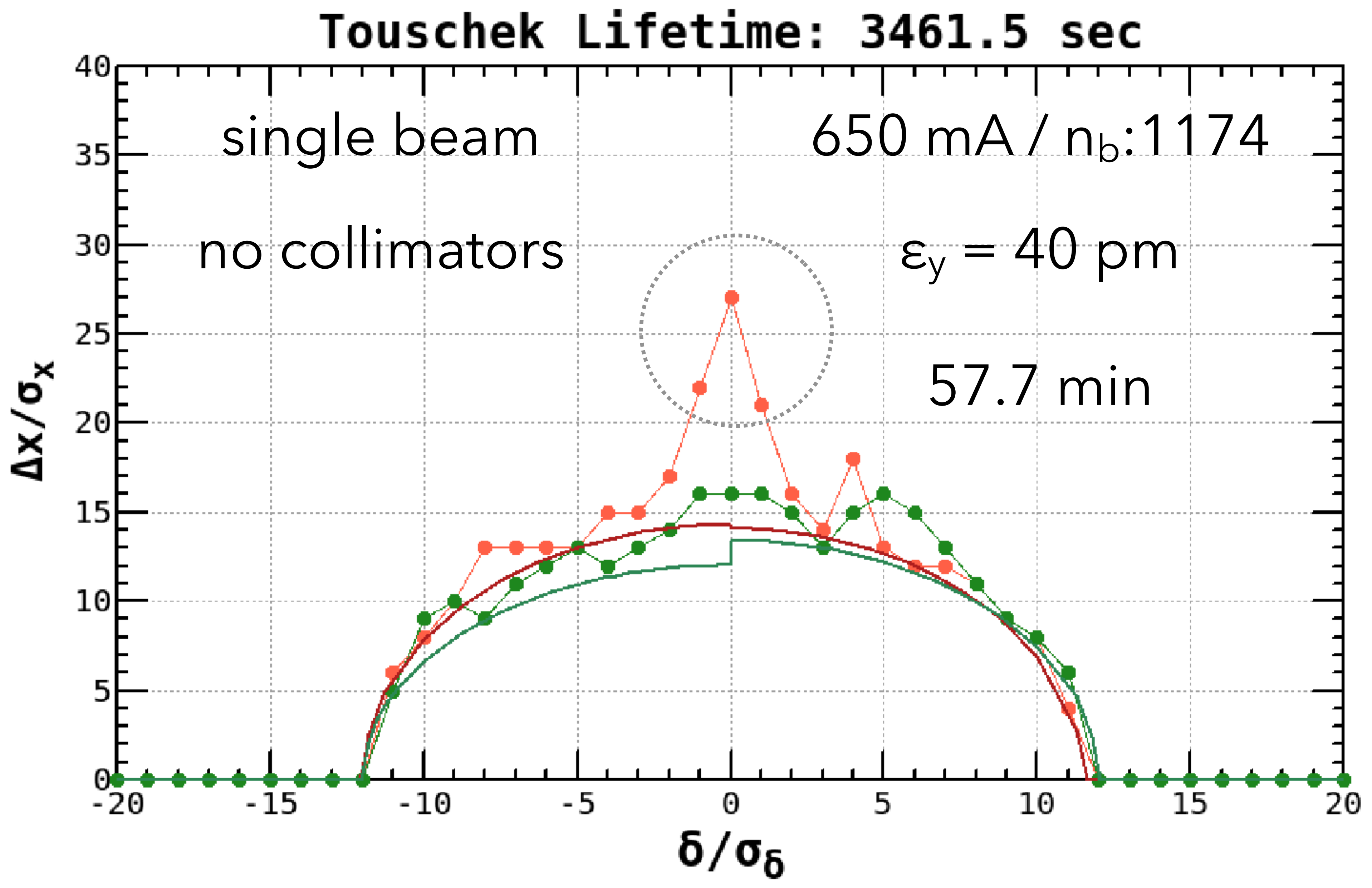


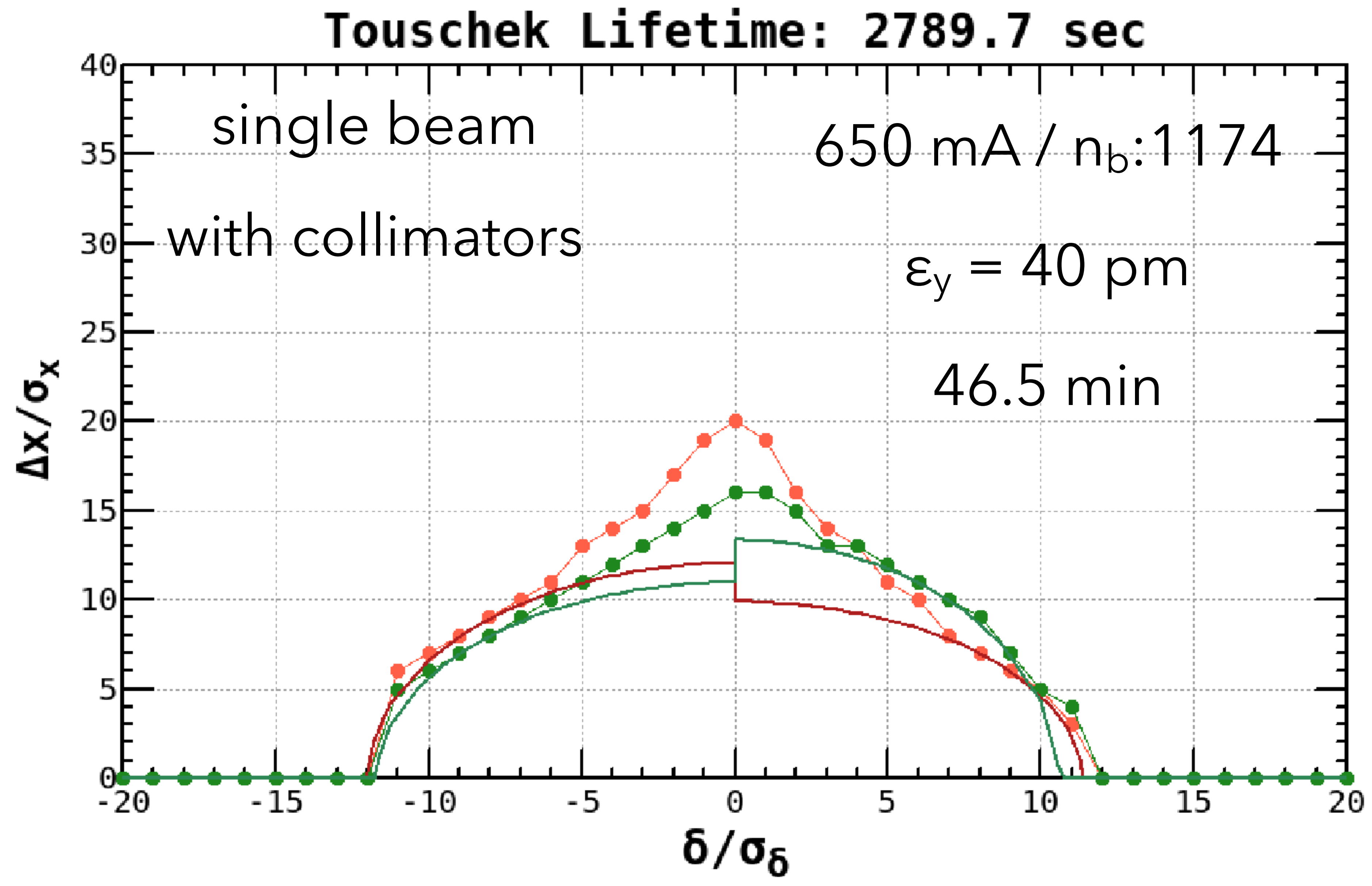
Touschek lifetime is similar to CW 80% with collimators.

The simulation is consistent with the measured lifetime for CW 80 %.

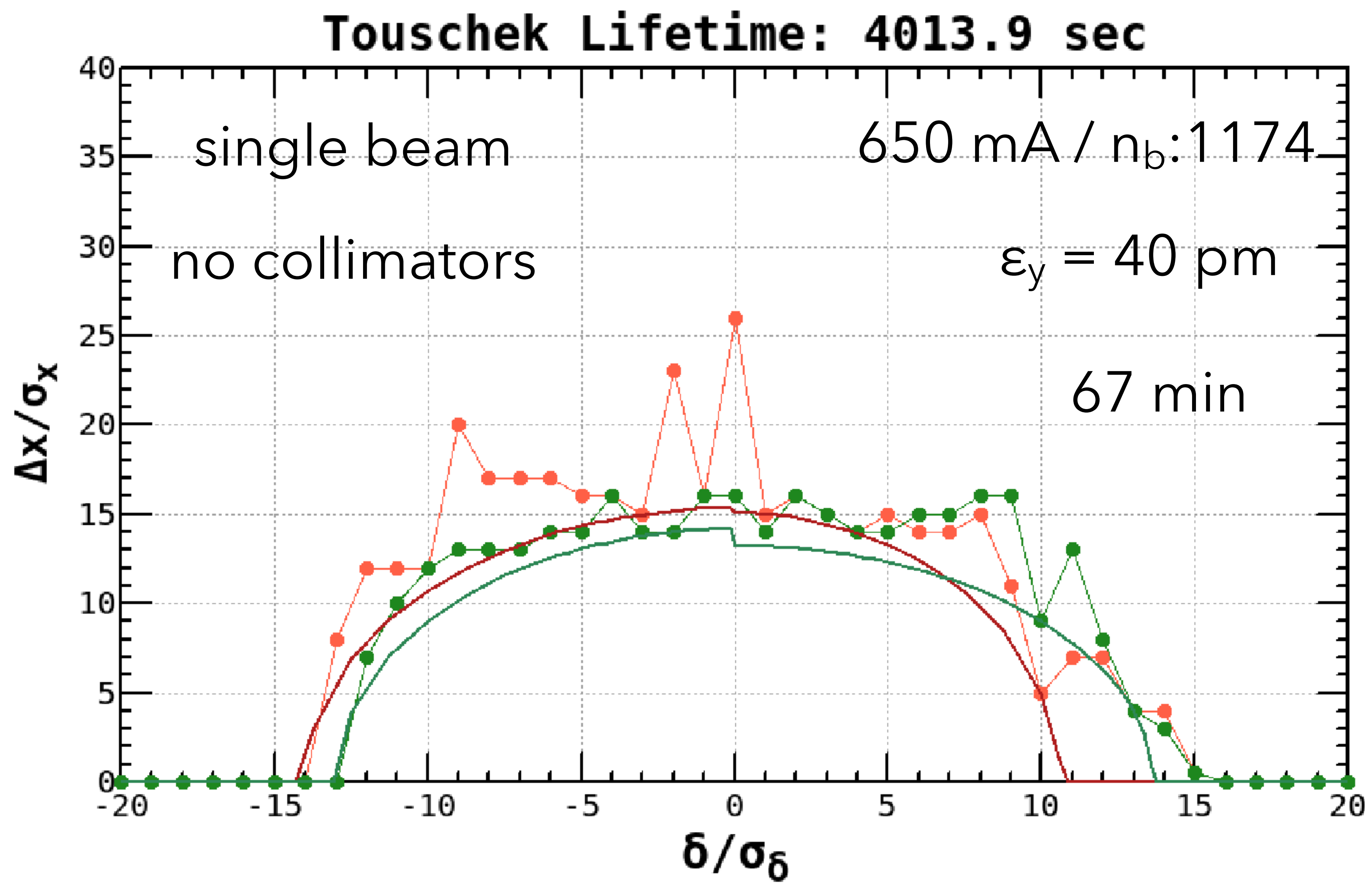
Tracking Simulation
No Machine Error

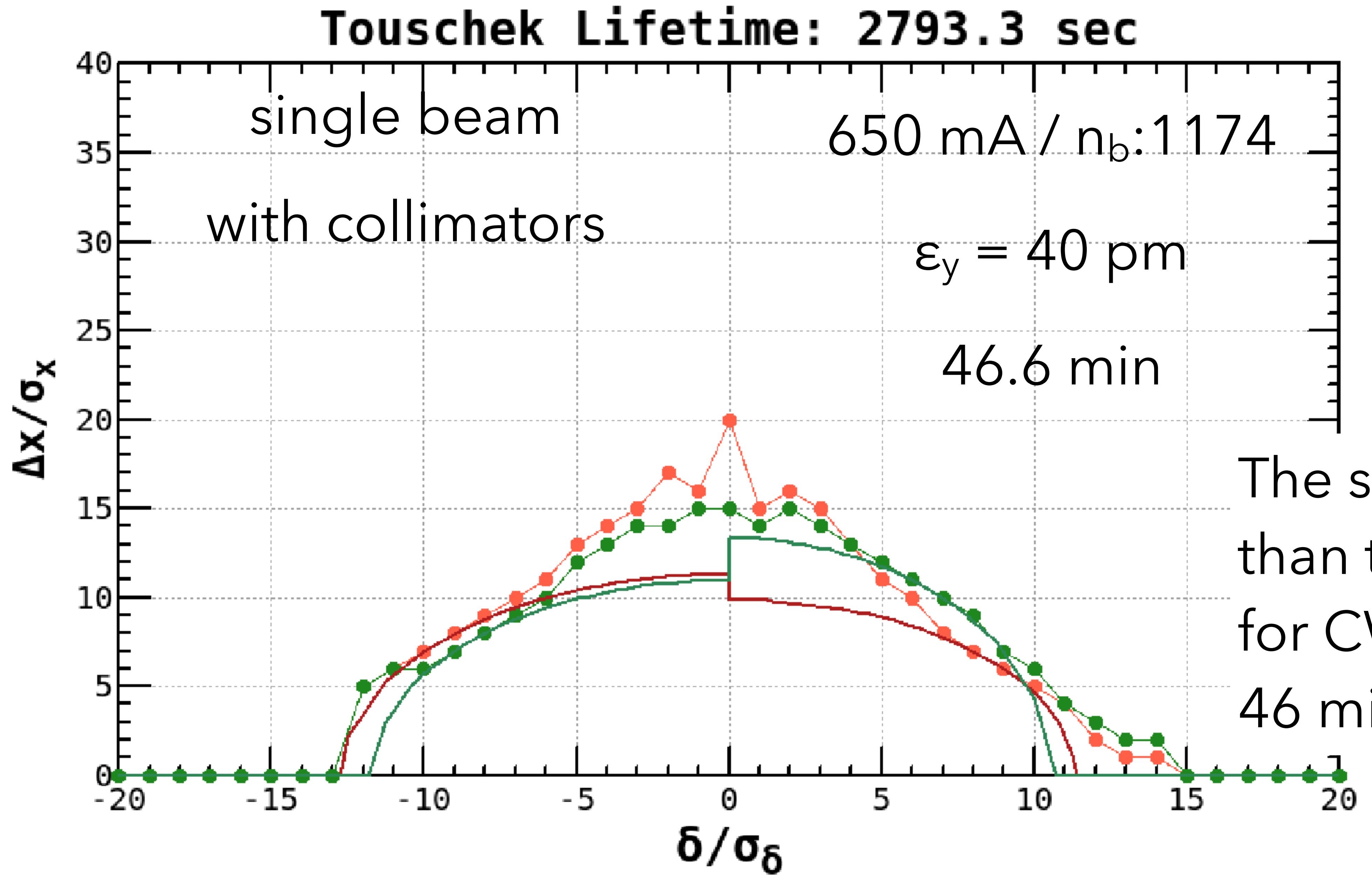
HER : CW 40 %





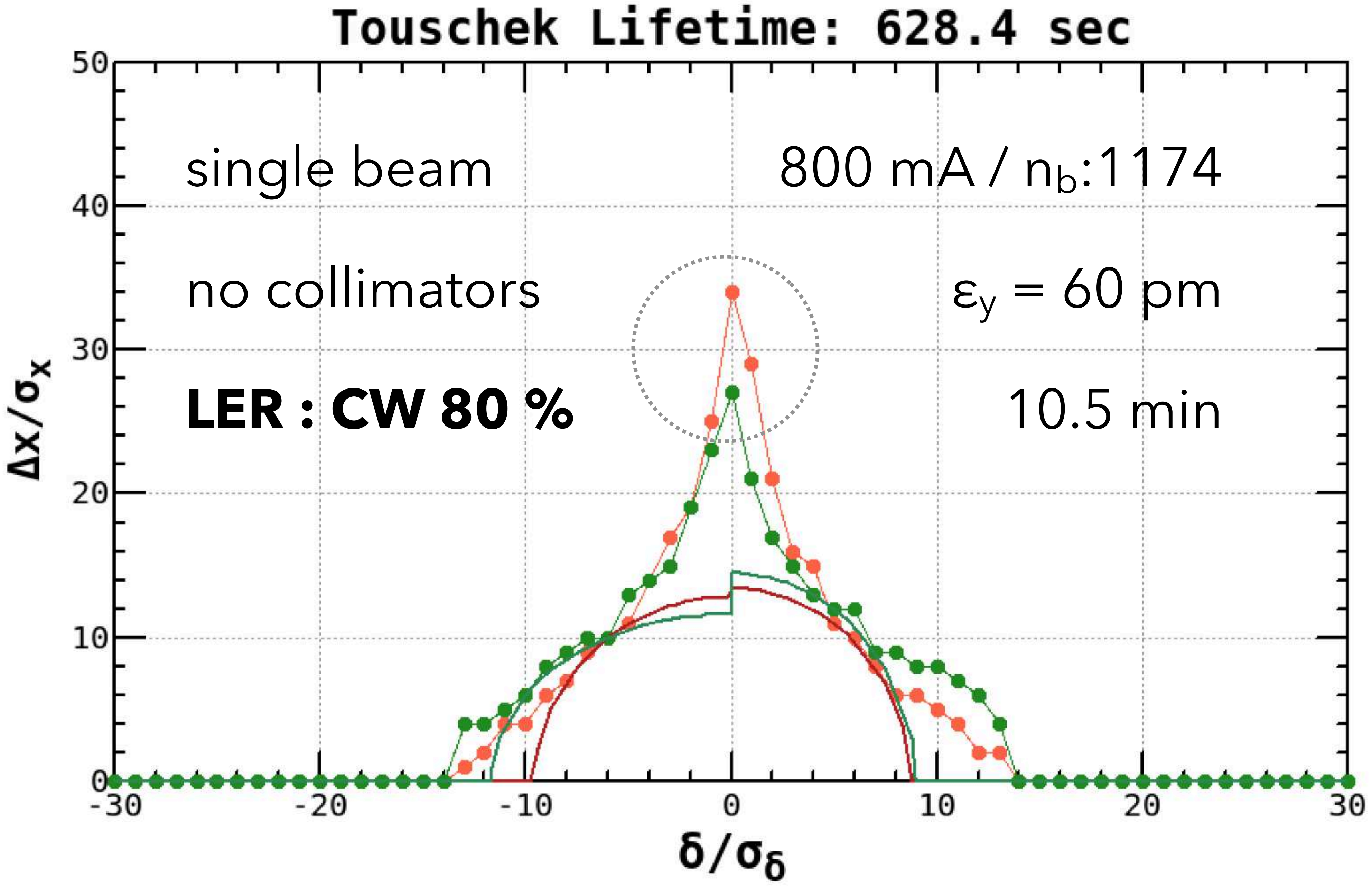
HER : CW 0 %



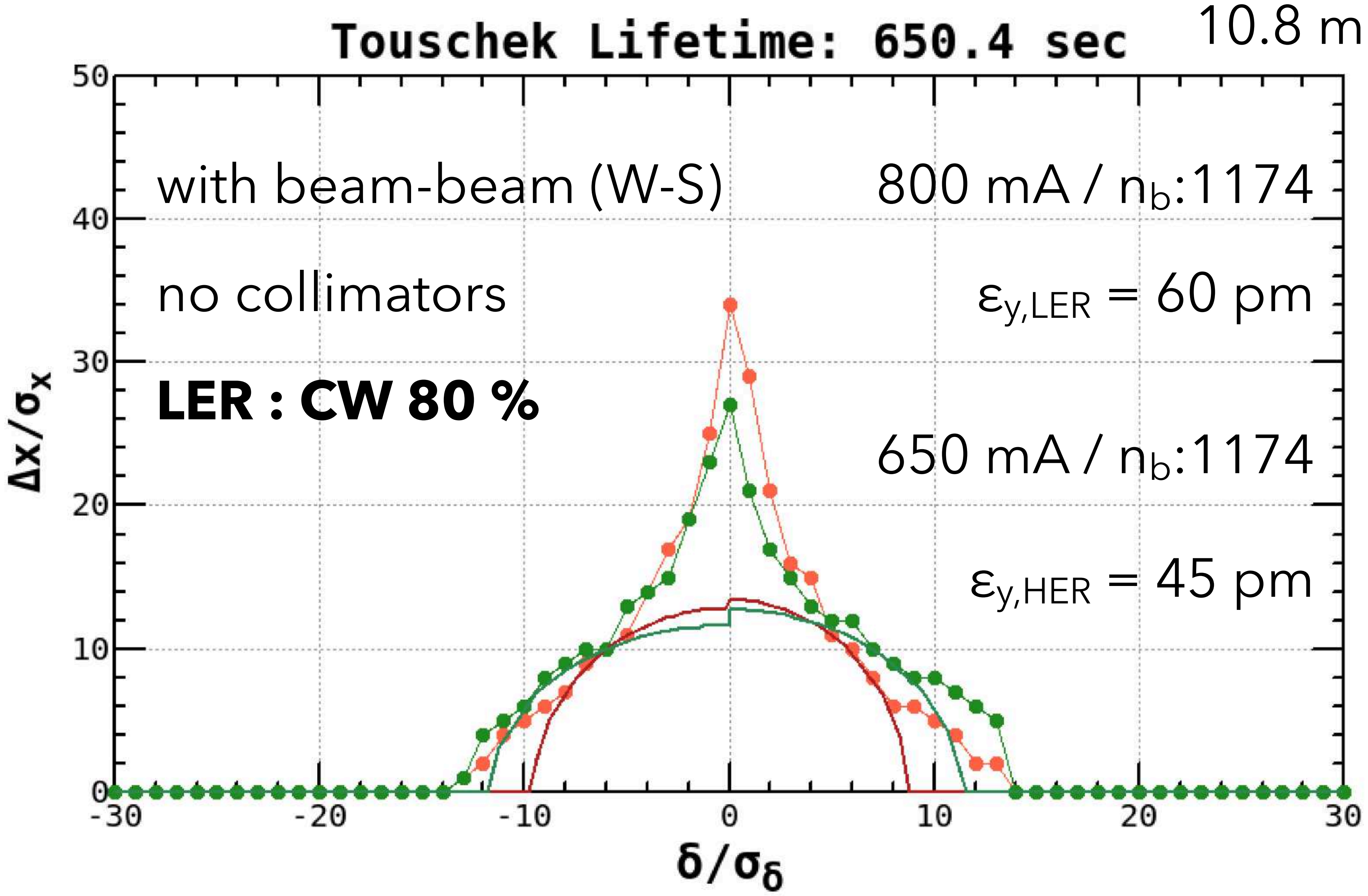


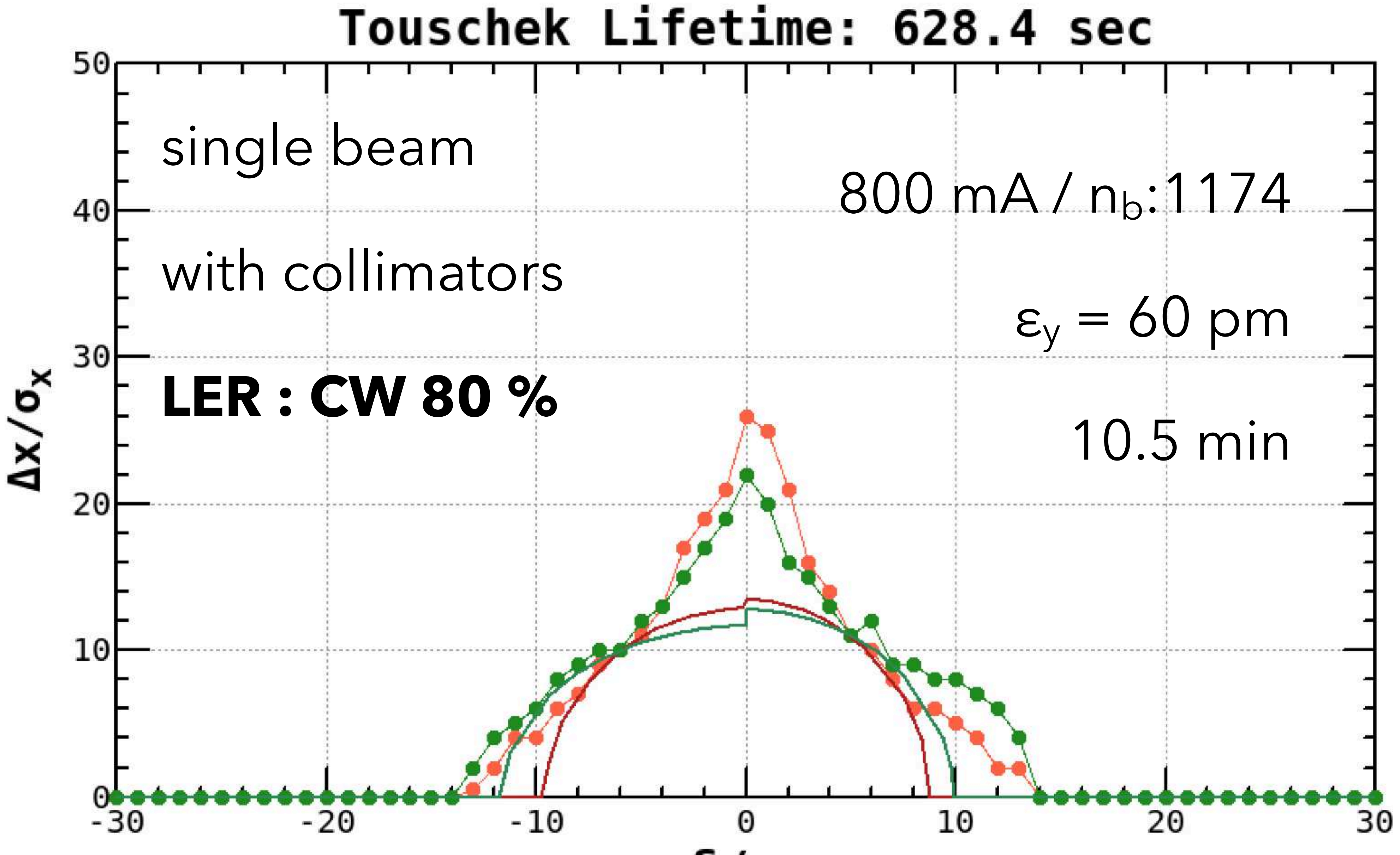
Touschek lifetime is similar to CW 40% with collimators.

The simulation is longer than the measured lifetime for CW 40 %.
46 min > 32 min



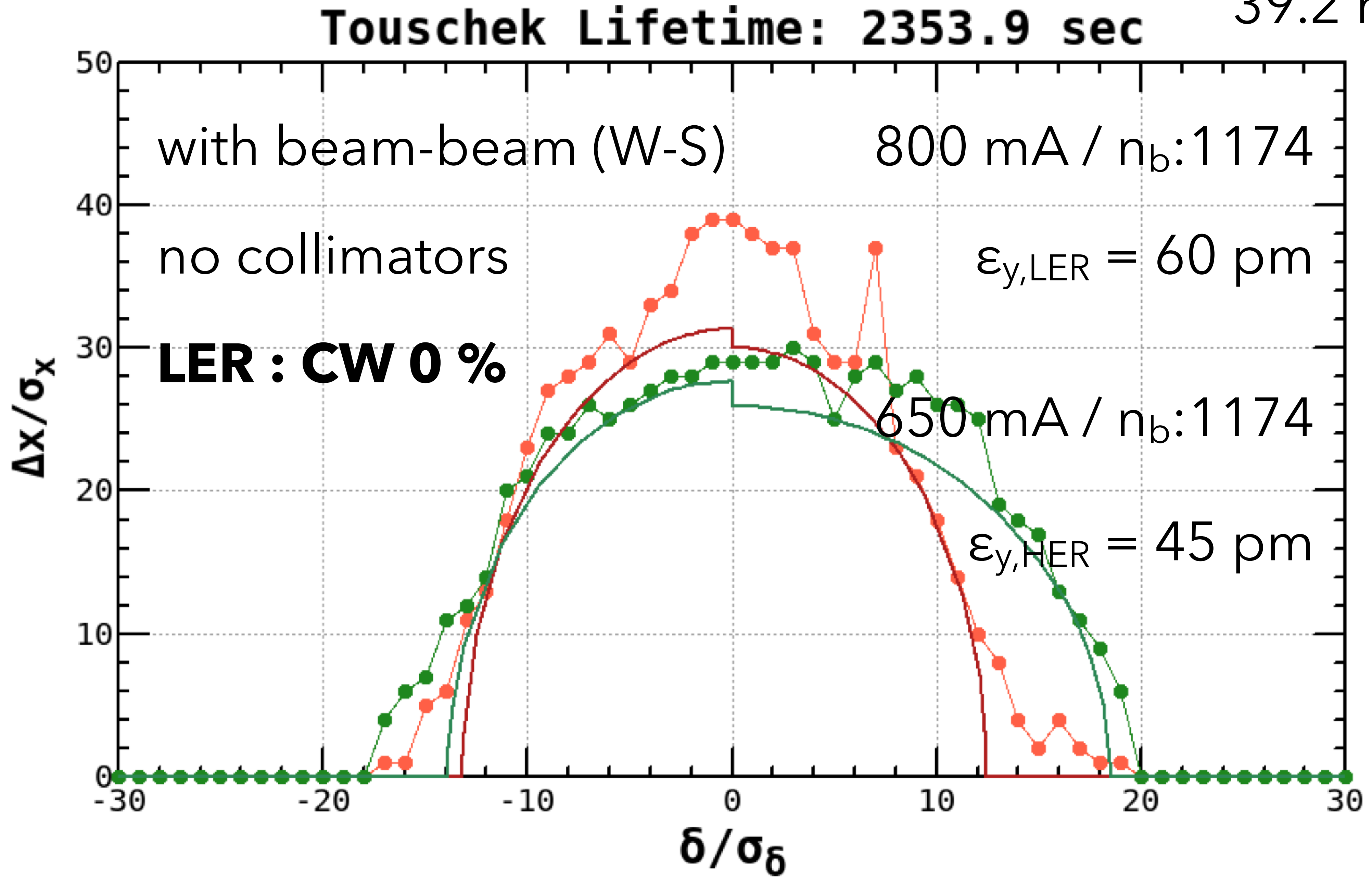
10.8 min





10.5 min (sim.) > 8 min (meas.)

39.2 min



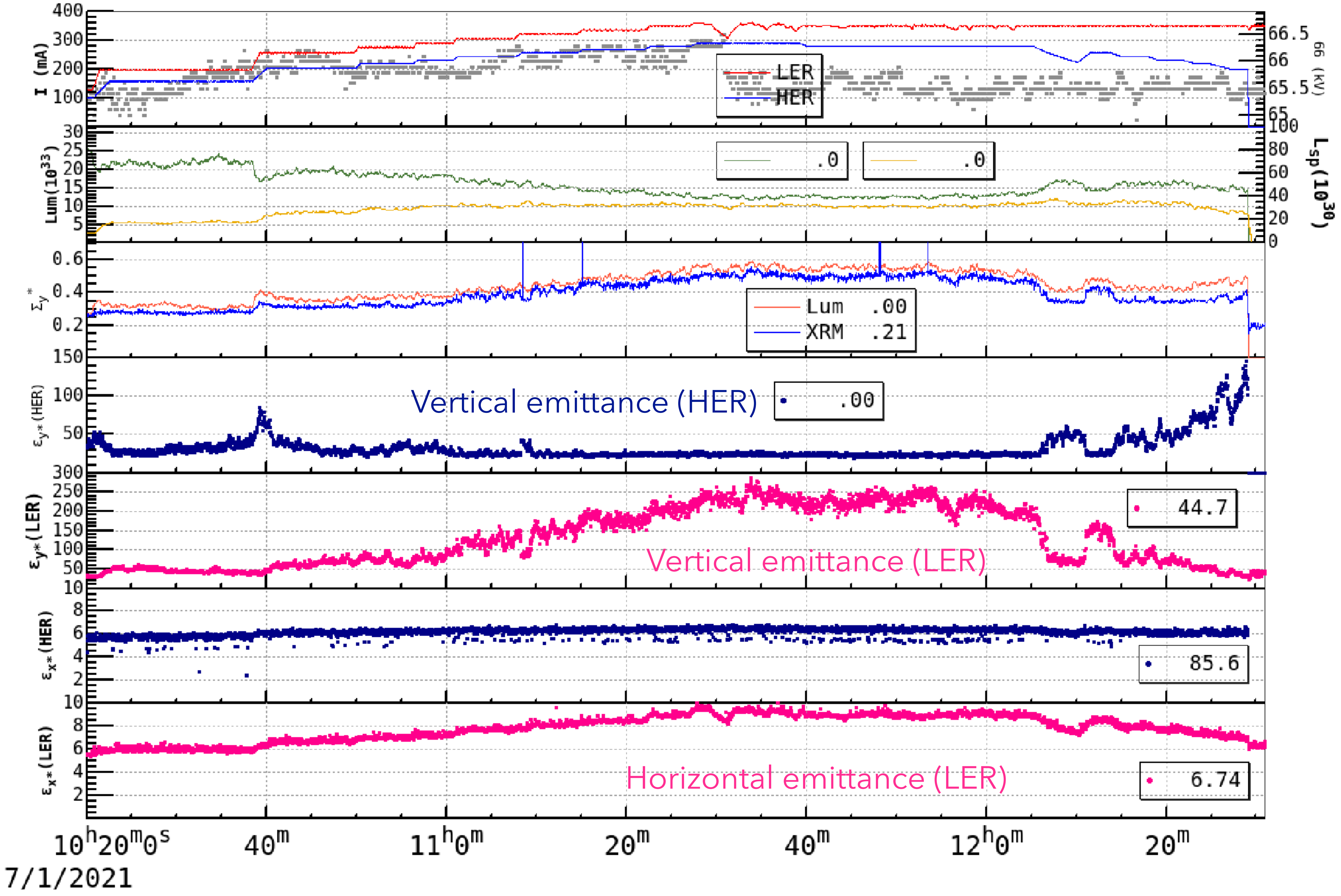
Lifetime and Vertical Emittance

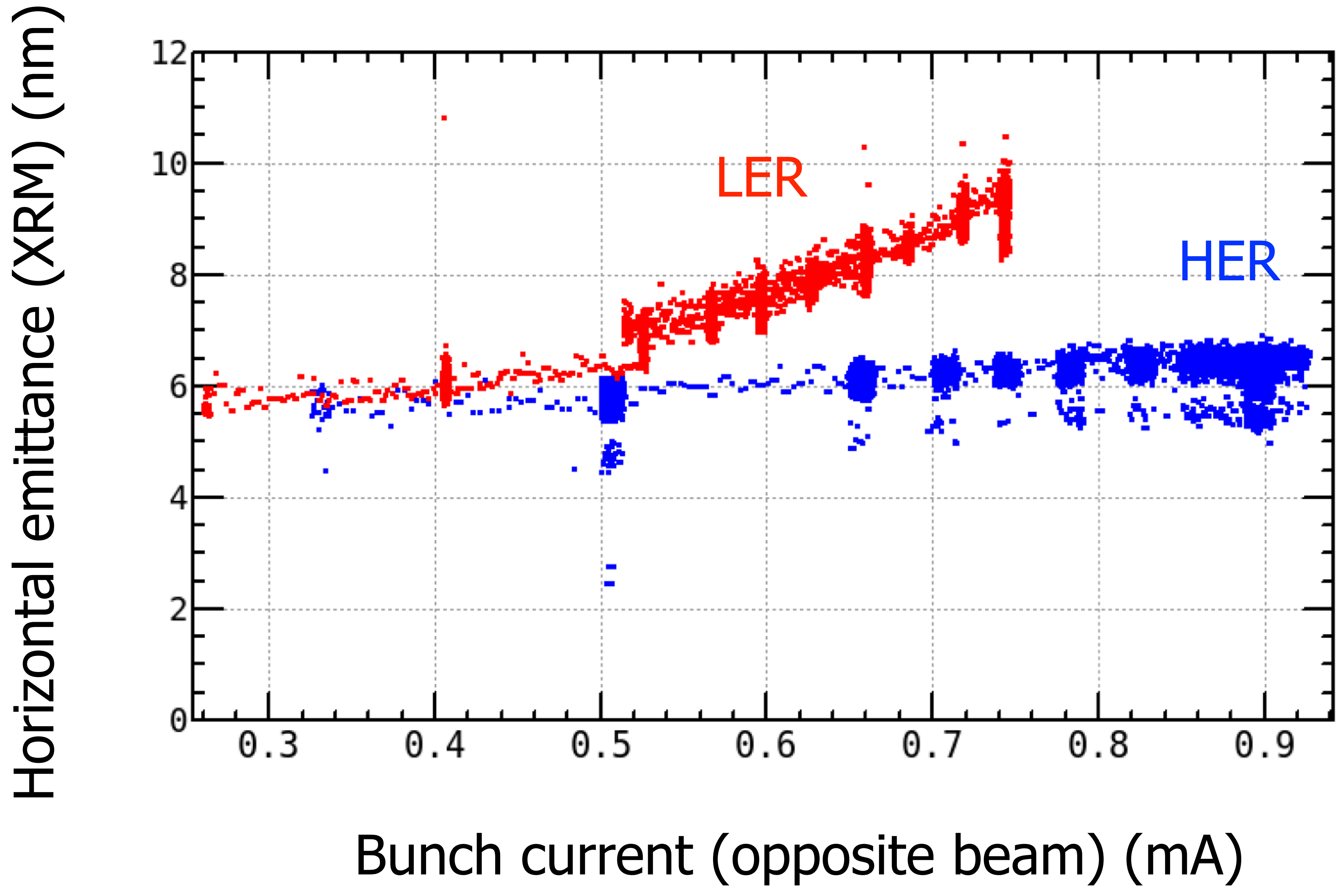
- LER
  - ε_y is 22 pm - 25 pm for the single beam.
  - ε_y increases up to 60 pm due to beam-beam blowup at 800 mA(0.68 mA/bunch).
  - The luminosity reduction is 65 %.
  - The DA can almost explain the measured lifetime.
  - The crab waist reduces the DA. But the tight collimators reduce the PA significantly. The collimators make small difference between CW 0 % and CW 80 %.
  - The lifetime is about 8 min for collision at 800 mA. It is quit shorter than what we expected.
  - In the case of no CW and no Collimators, Touschek lifetime depends on ε_y in the tracking simulation.
- HER
  - ε_y is 28 - 40 pm which depends on the bunch current.
  - Beam-beam blowup is mild. It is from 40 pm to 45 pm at 650 mA(0.55 mA/bunch).
  - The collimators reduce the PA significantly. It is same as the LER.
  - The measured lifetime is shorter than the simulation. (32 min < 46 min; vacuum lifetime not included)

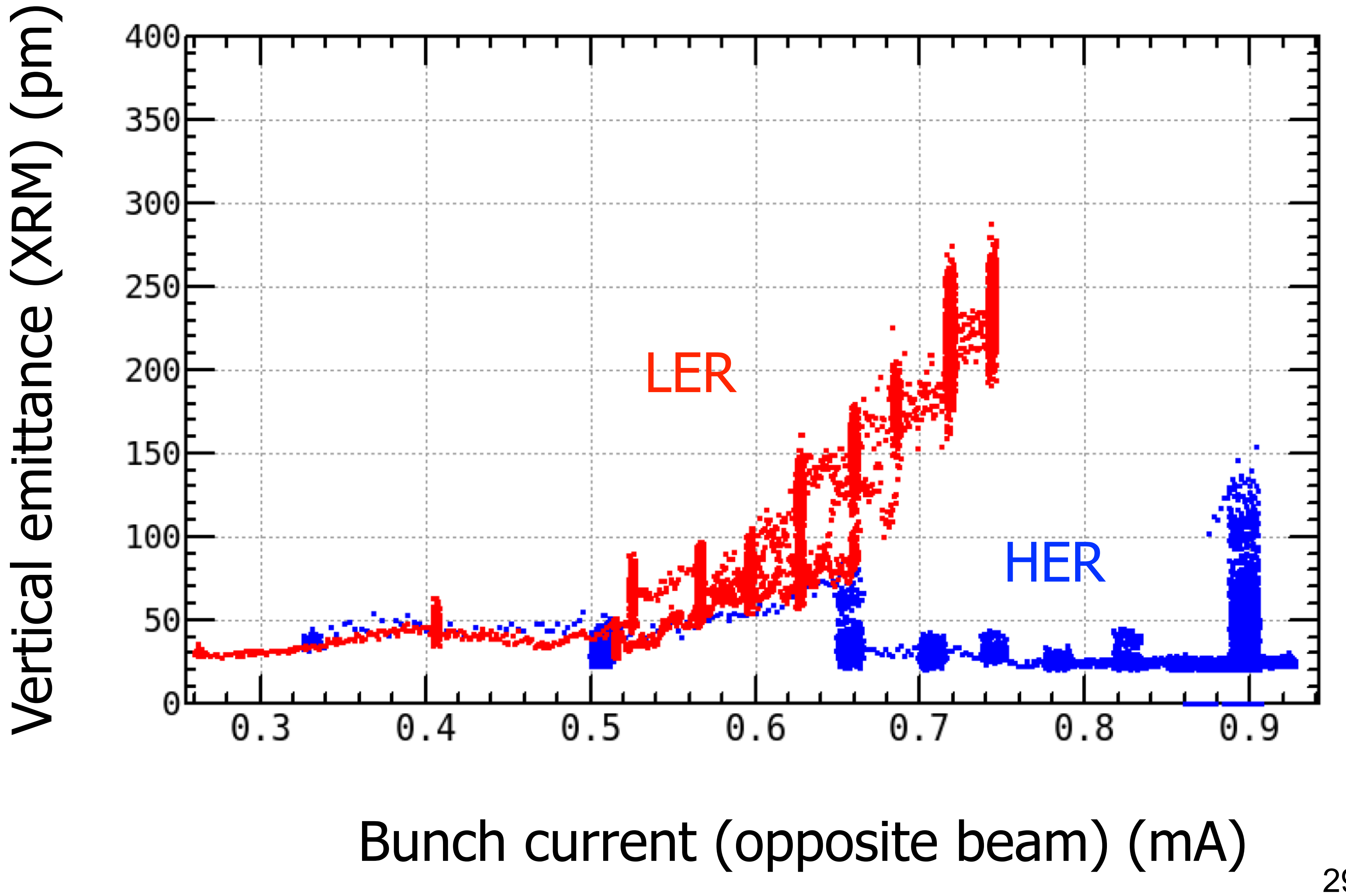
Beam-Beam Blowup

High Bunch Current Collision

small number of bunches n_b : 393 (12.25 spacing)

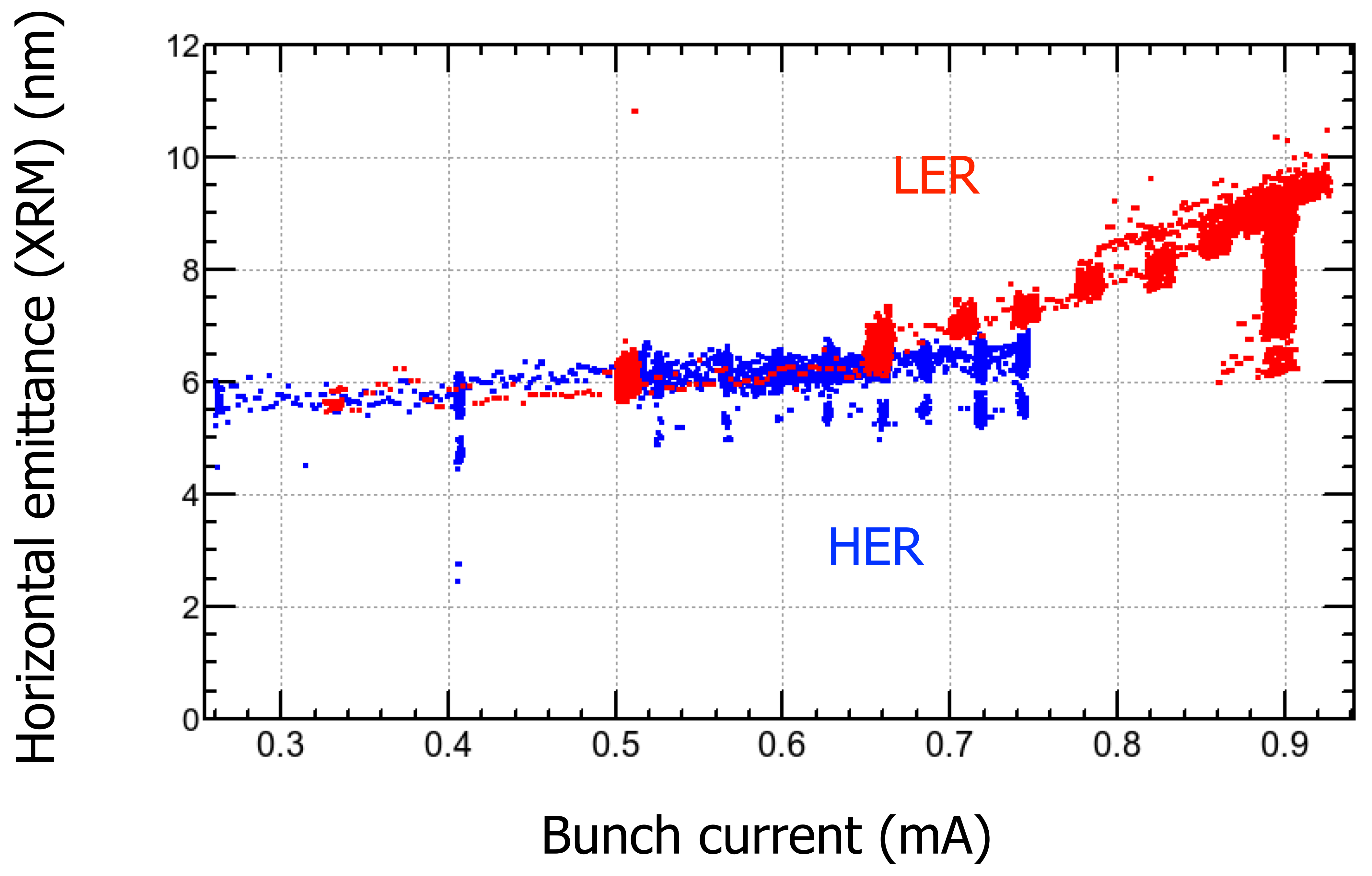


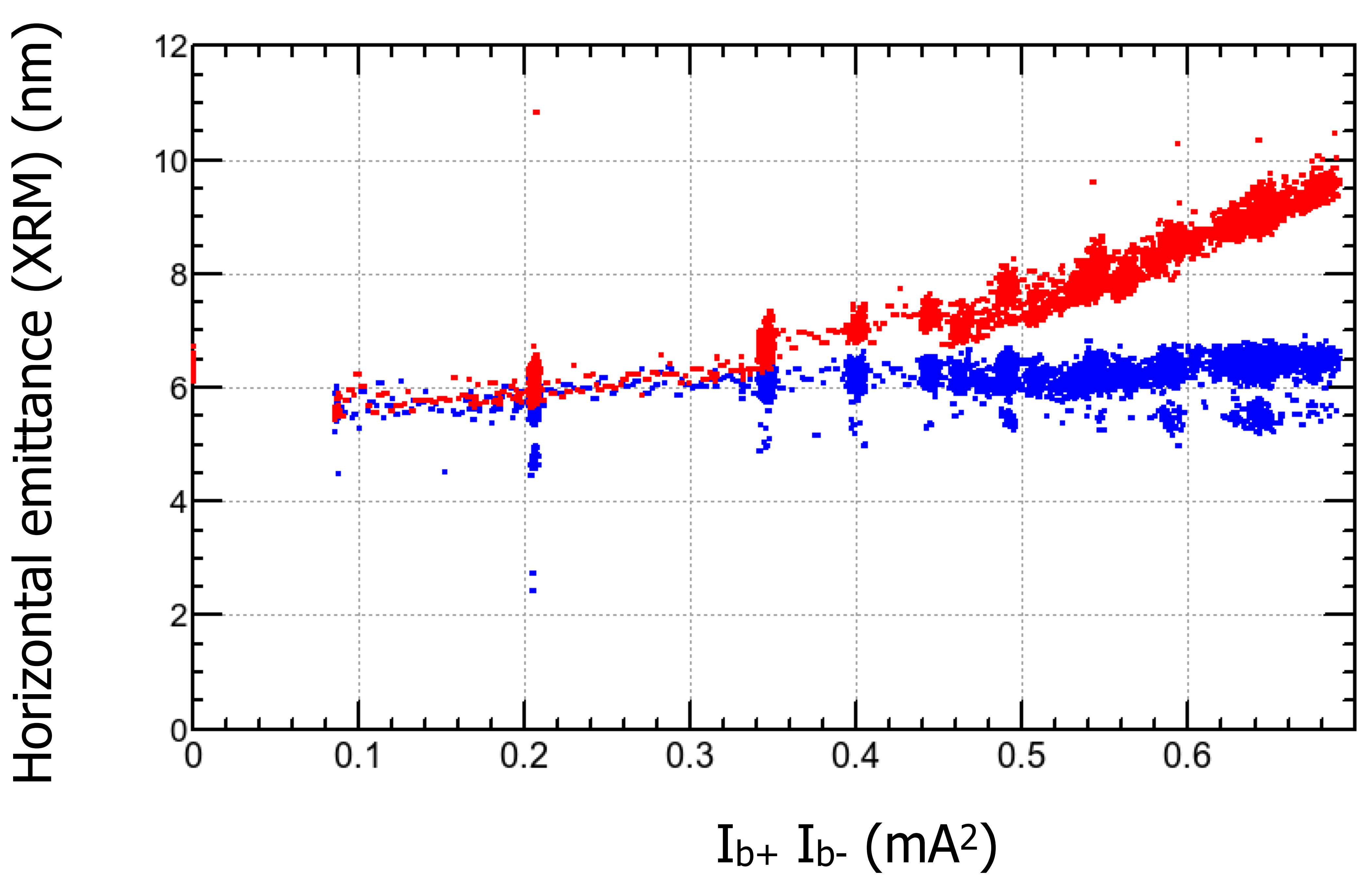


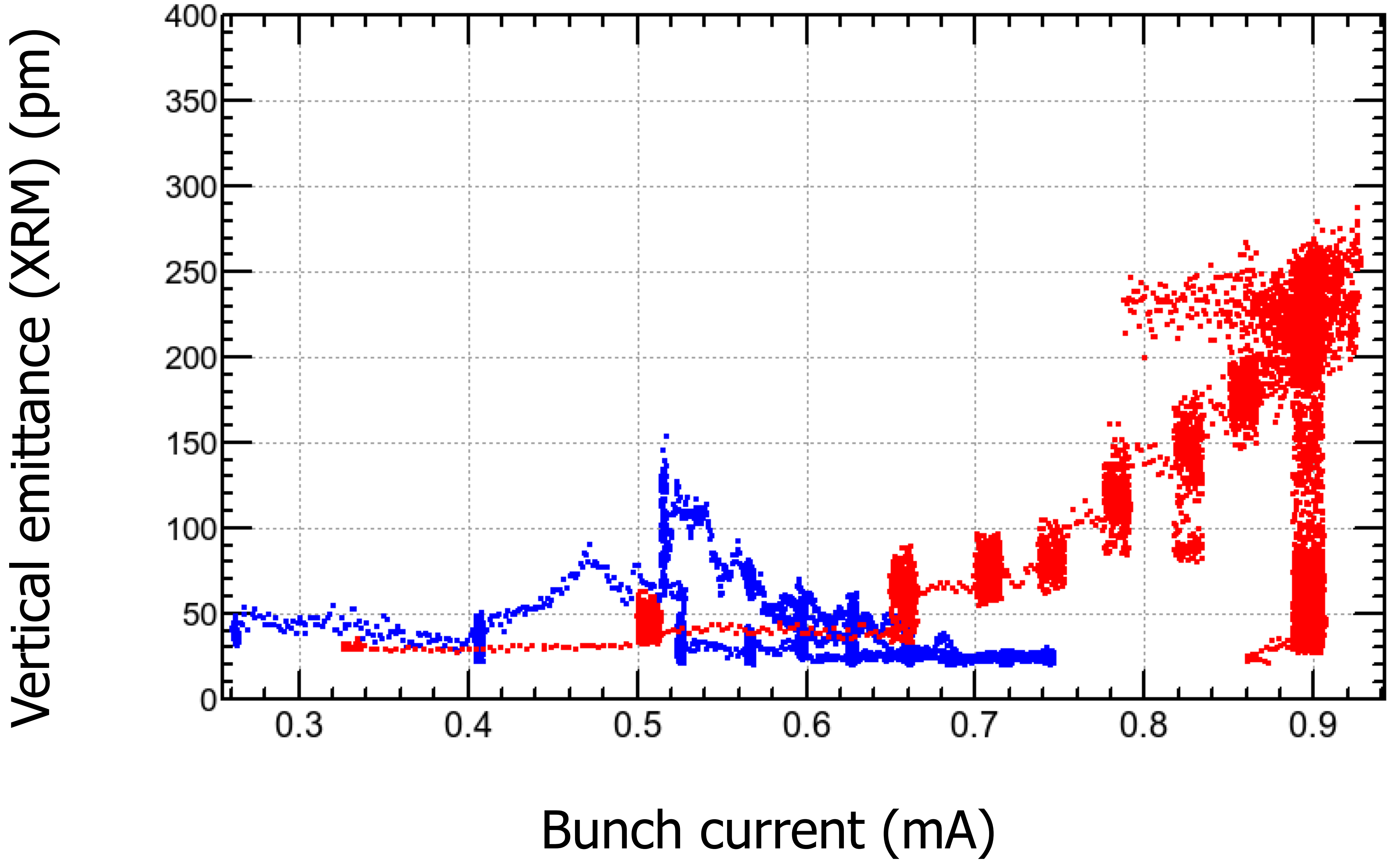


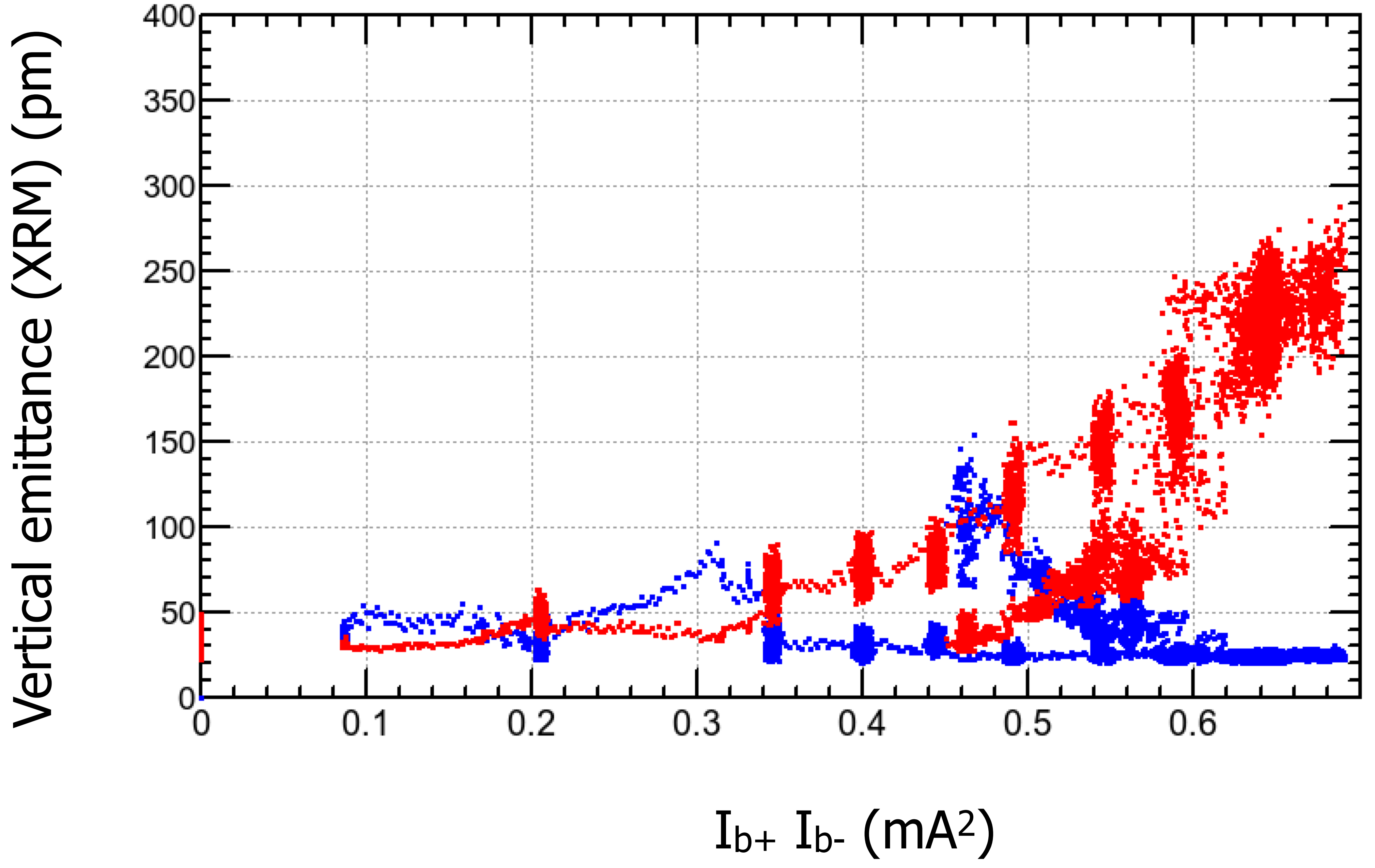
- We observed large beam-beam blowup in the LER from 40 pm to 250 pm.
- It depends on the HER beam current.
- Horizontal emittance also increases in LER.

We consider coherent beam-beam head-tail instability (BBHT(XZ)) and/or dynamic beta/emittance effect.


Horizontal emittance (XRM) (nm)
Bunch current (mA)
LER
HER

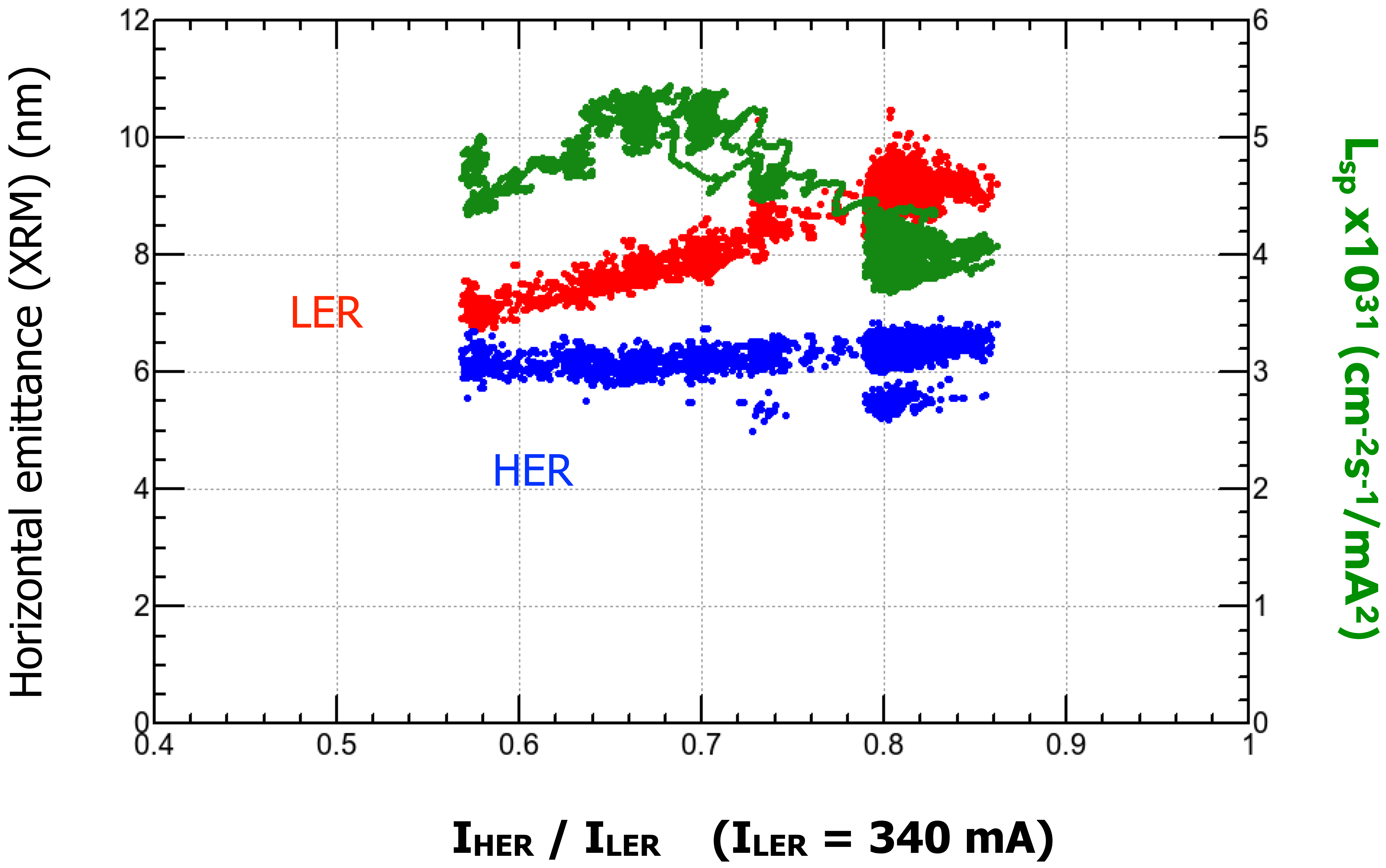

Horizontal emittance (XRM) (nm)
$I_{b+} I_{b-}$ (mA^2)


Vertical emittance (XRM) (pm)
Bunch current (mA)

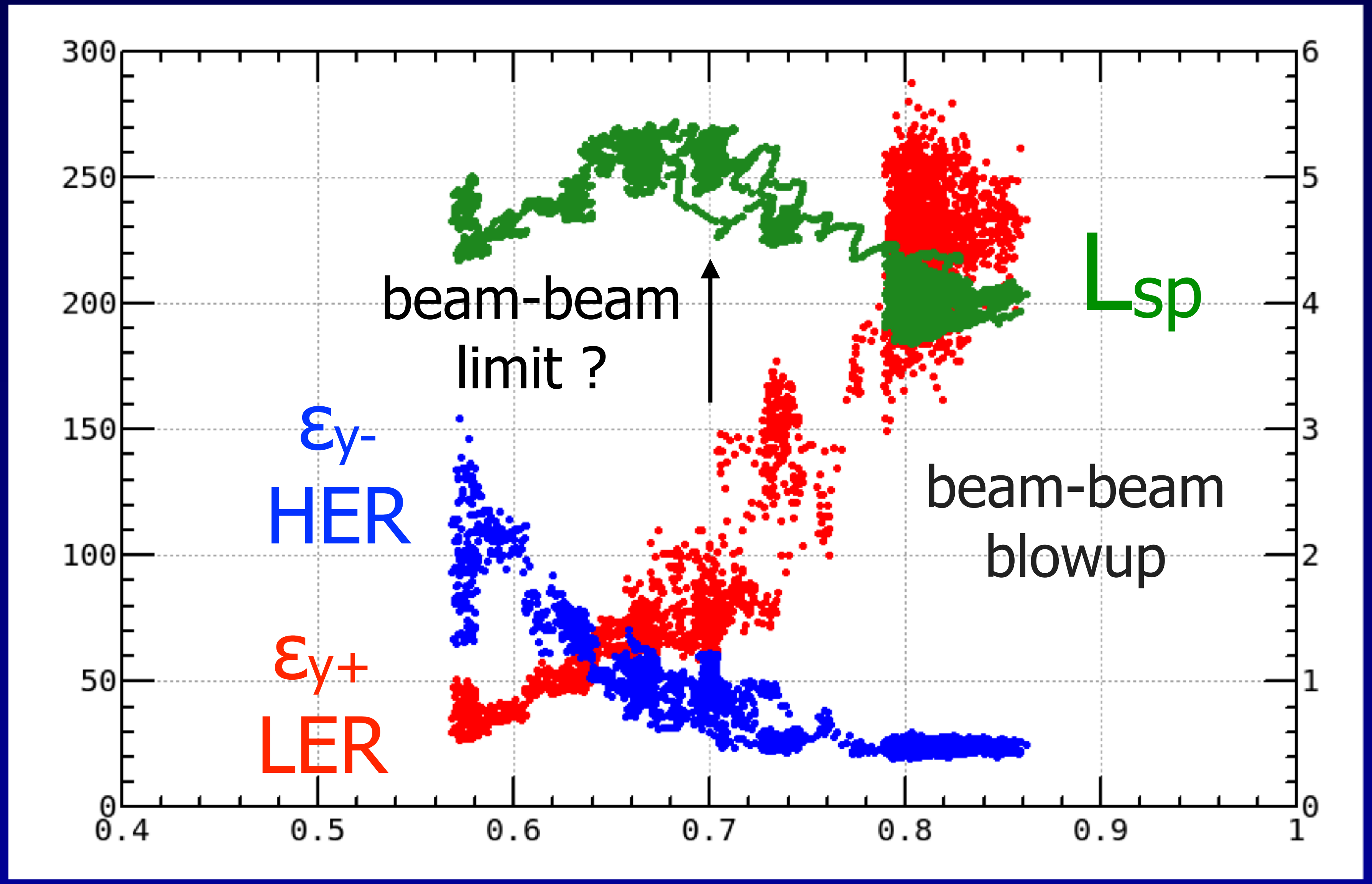

Vertical emittance (XRM) (pm)
$I_{b+} I_{b-}$ (mA^2)

The horizontal emittance in the LER depends on HER beam current.

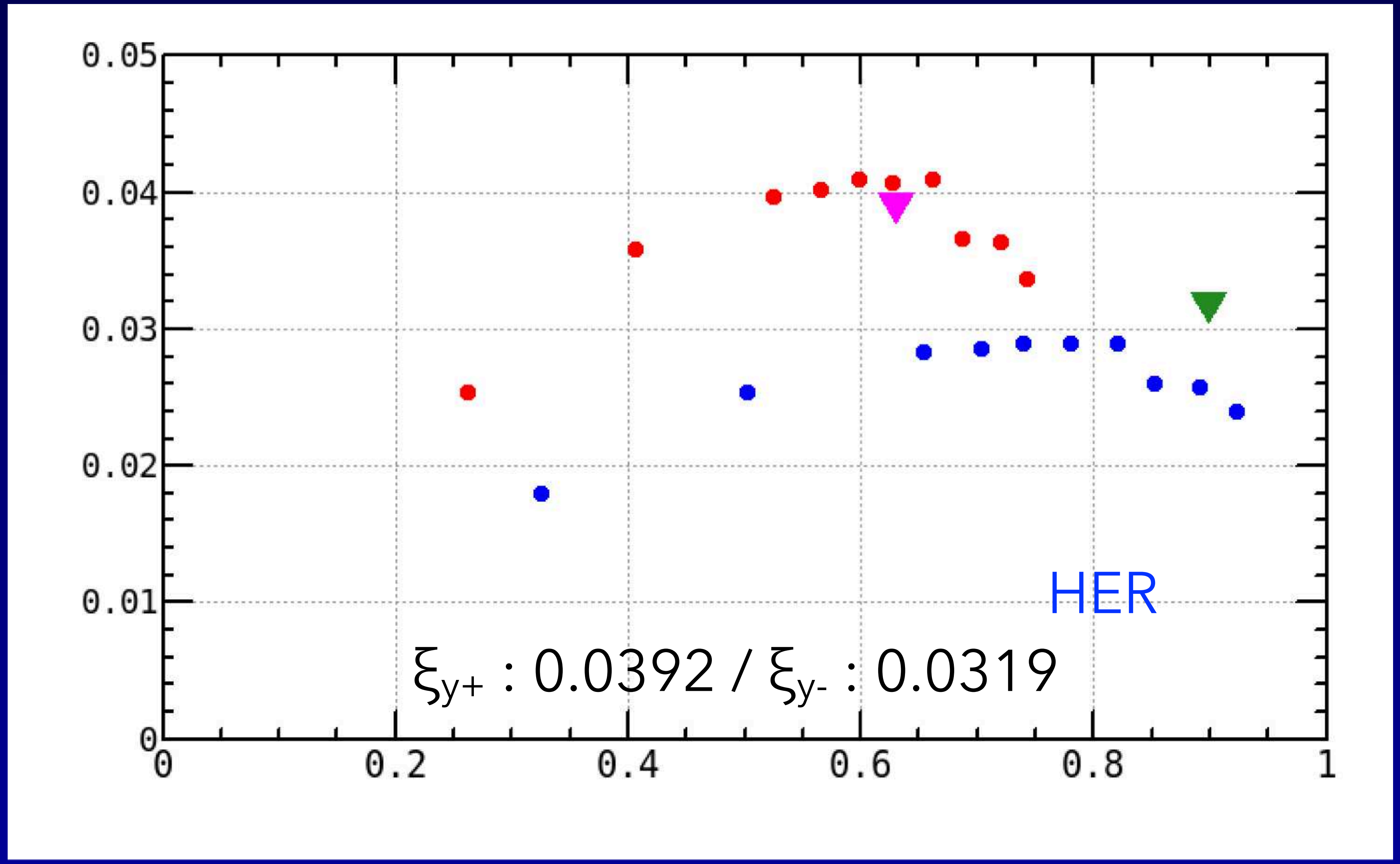
HER beam current changes with
fixed LER beam current to be 340 mA.

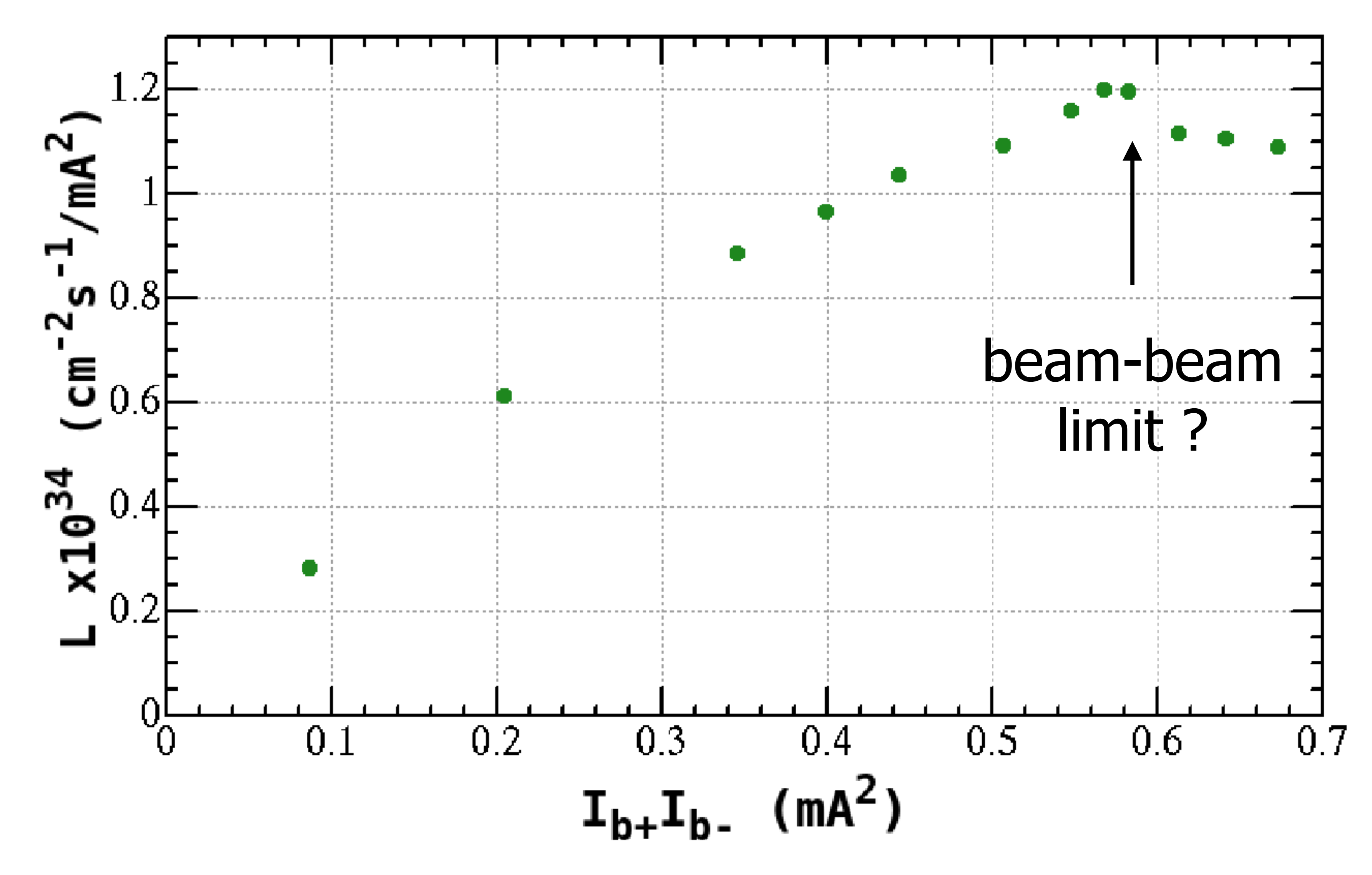


Collision with small number of bunches（393 bunches）



Vertical emittance is measured by X-ray beam size monitor.





- The beam current ratio is kept to be I_{LER} : I_{HER} = 5 : 4 (circle)
- Beam-beam limit was observed at around 0.03 for HER.
- The bunch current ratio can be optimized to improve luminosity.
- The optimized ratio of beam current is 10 : 7 (triangle) at I_{b+} > 0.8 mA.

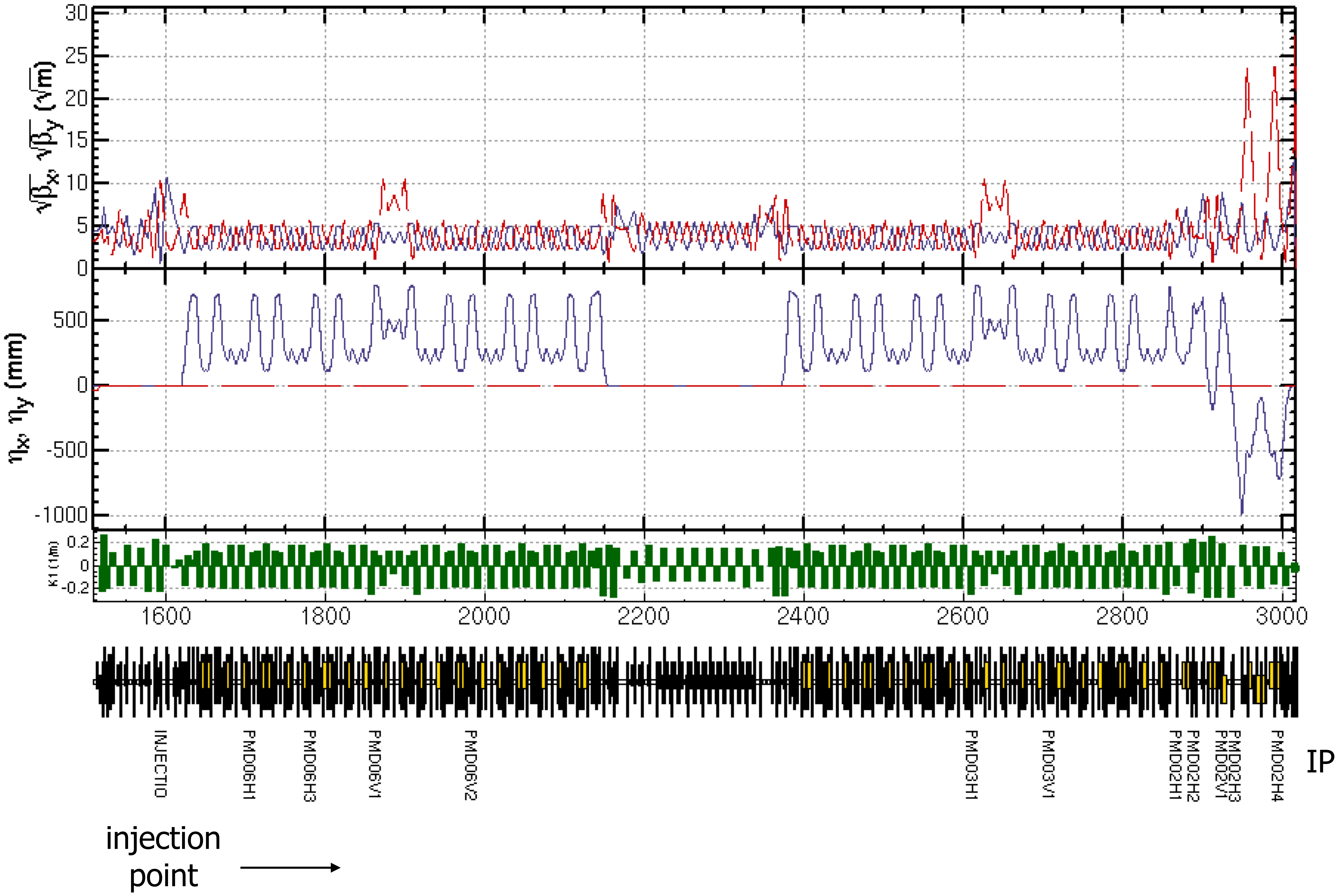
$$\xi_{y\pm} = \frac{2er_e\beta^*_{y\pm}L}{\gamma_\pm I_\pm}$$

1.2 x10^{34} $cm^{-2}s^{-1}$ at 0.57 mA^2 (393 bunches)

4.78 x 10^{34} $cm^{-2}s^{-1}$ is expected for 1565 bunches.
(I_{LER} : 1.4 A / I_{HER} : 1.0 A)

Operation Issues

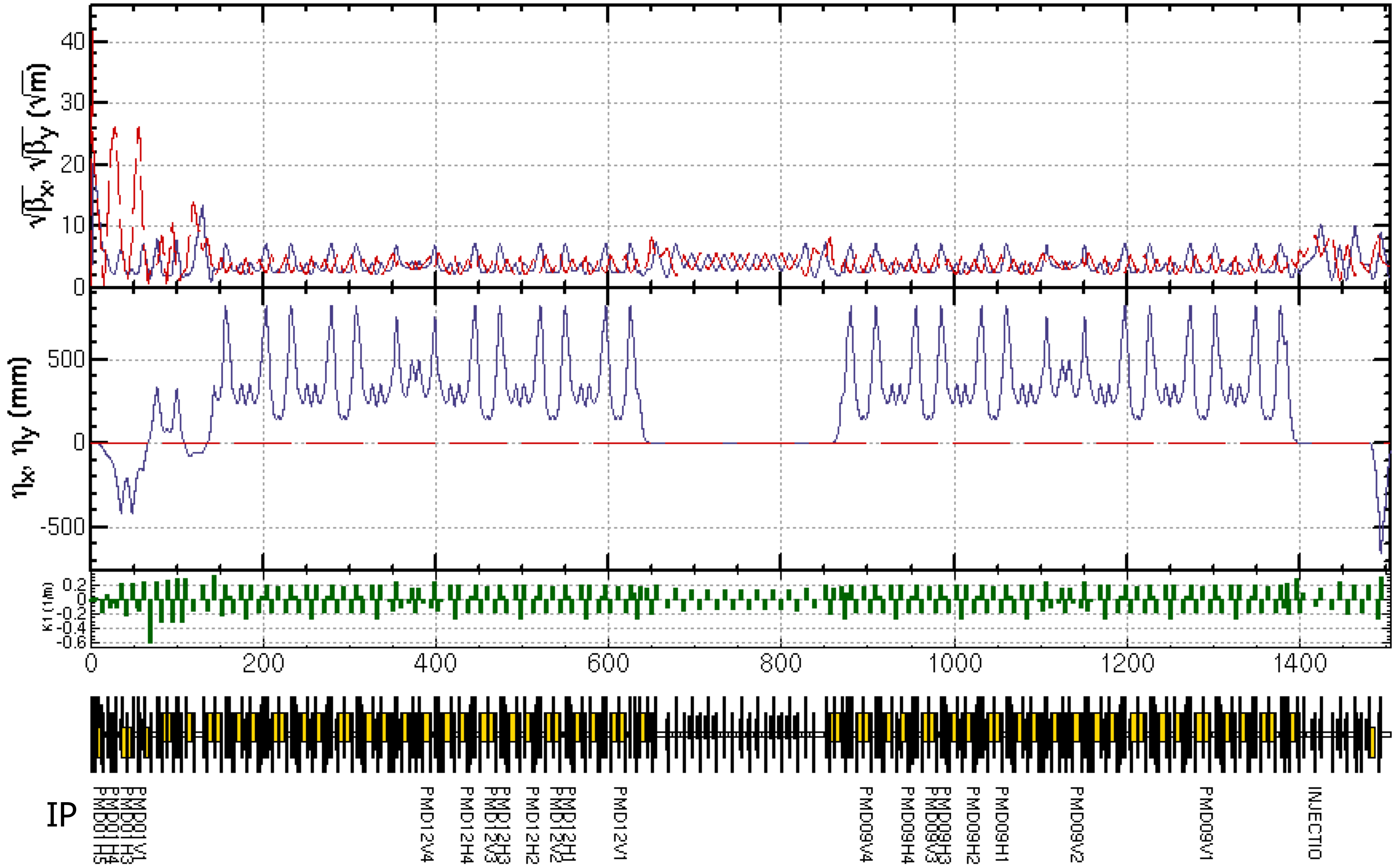
LER Collimator



2021	d_y (mm)	β_y (m)	N_{sig}
June 16			ε_y: 60 pm
D06V1	±2.9	67.3	45.6
D06V2	±2.2	20.6	62.6
D03V1	±8.0	17.0	250.8
D02V1	±1.2	11.9	45.0

$$N_{sig} = \frac{d_y}{\sigma_y}$$

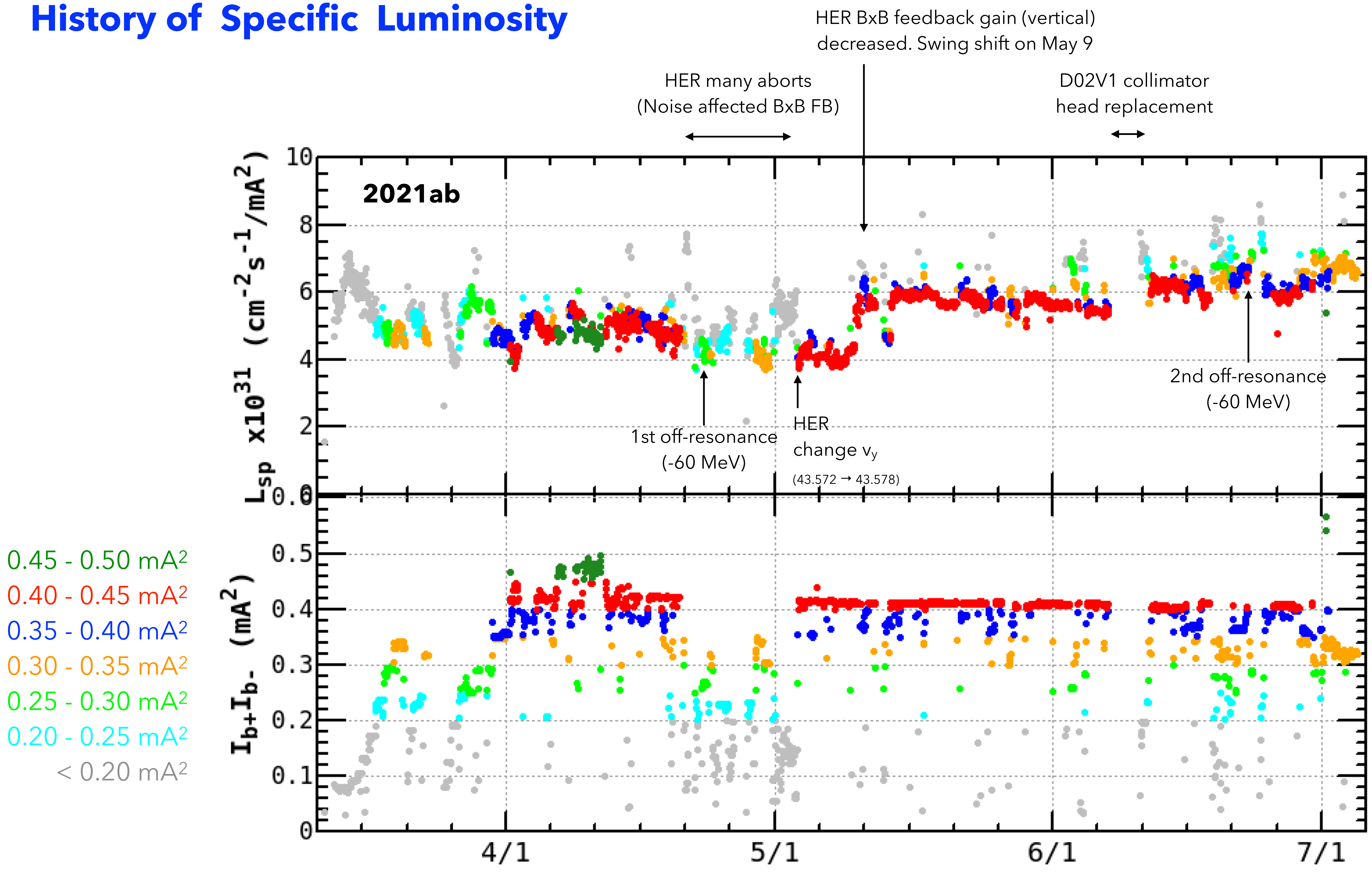
HER Collimator



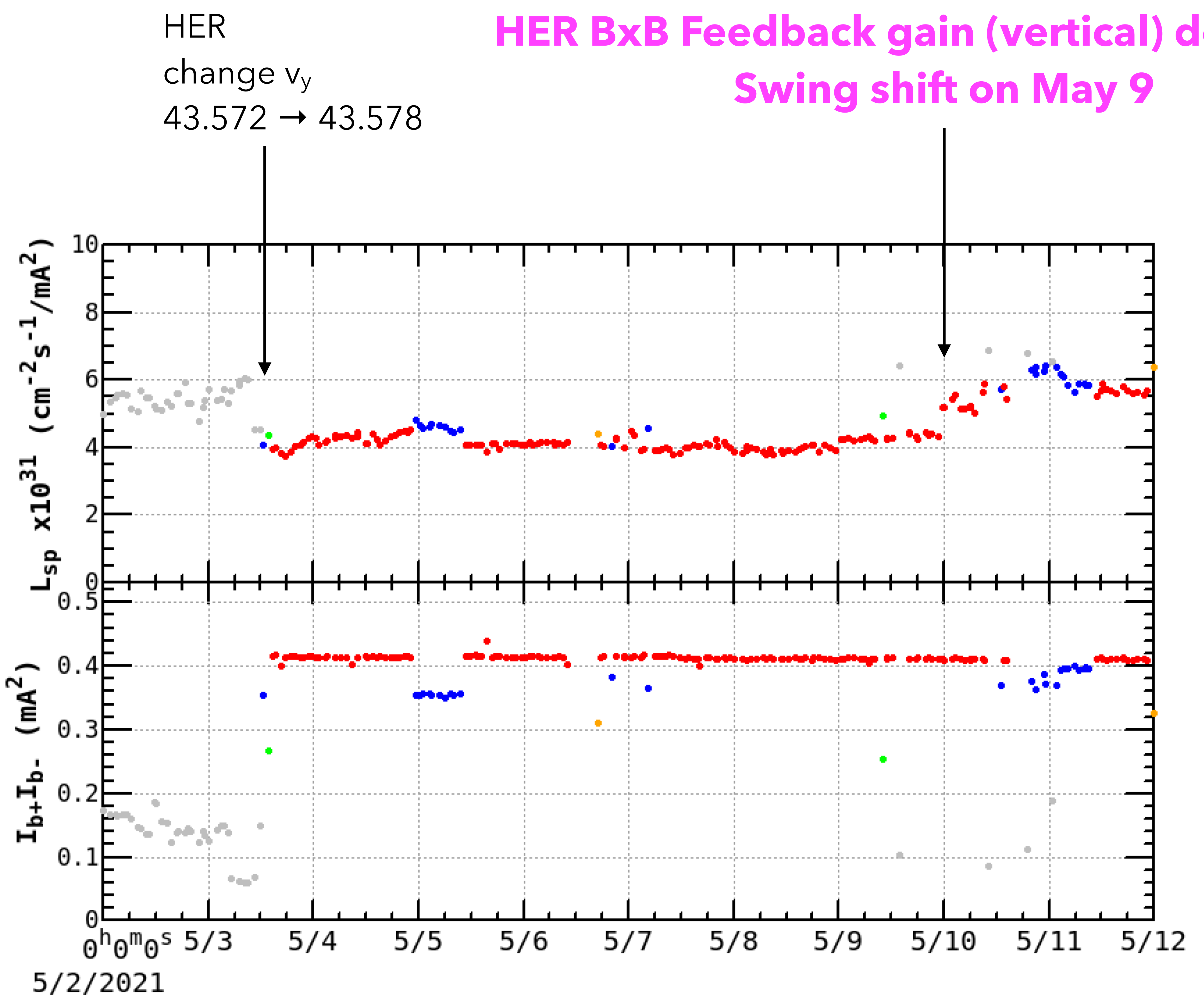
injection point

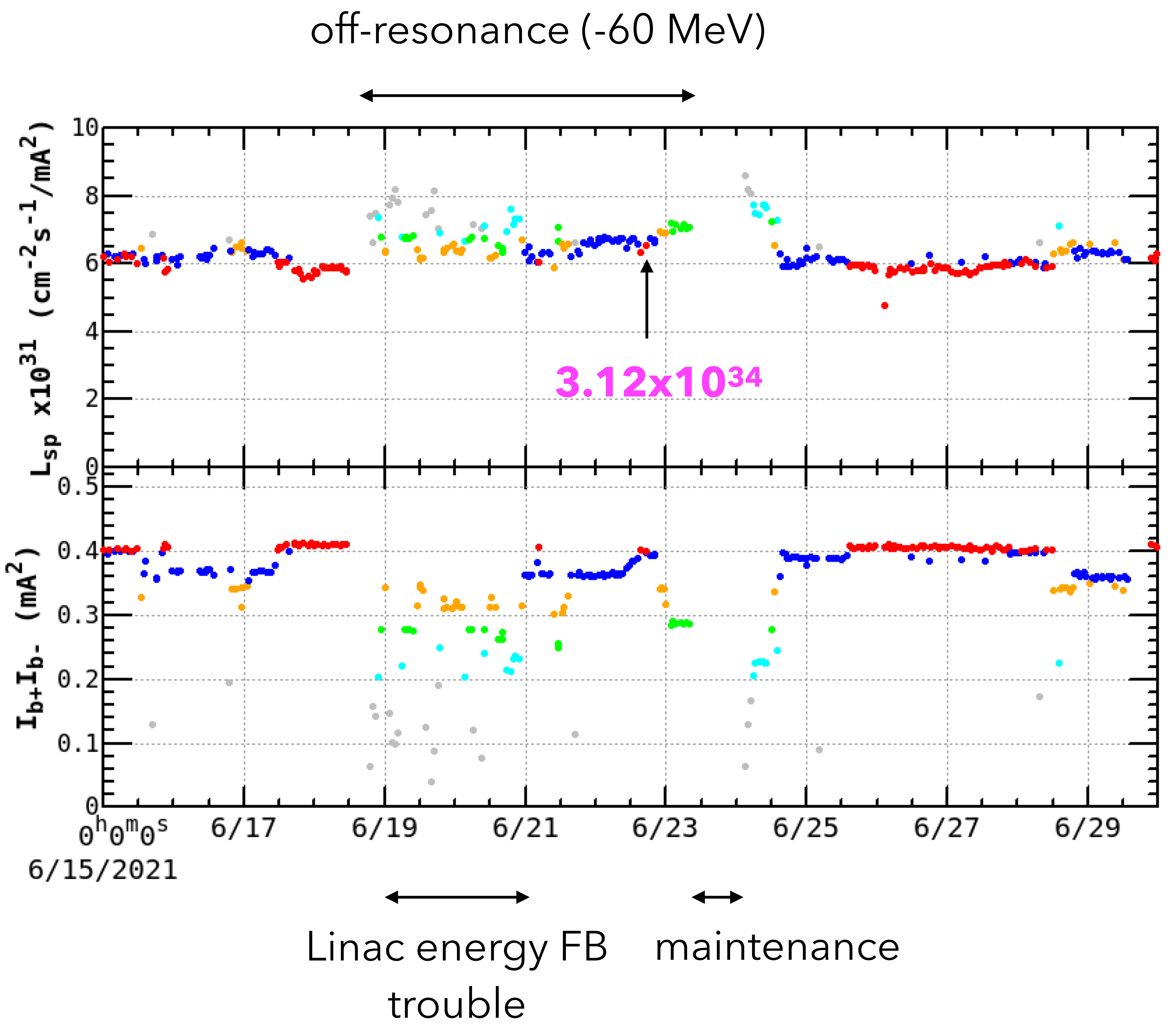
2021 June 16	d_y (mm)	β_y (m)	N_{sig} ε_y: 45 pm
D09V1	-1.7	15.5	64.4
D09V2	-3.1	19.4	104.8
D09V3	-1.5	15.5	56.8
D09V4	-3.4	16.7	123.9
D12V1	3.3	16.7	120.2
D12V2	-1.8	15.5	68.2
D12V3	2.1	15.5	79.6
D12V4	-3.2	19.4	108.2
D01V1	±2.2	46.5	48.1

History of Specific Luminosity



More detail of L_{sp}

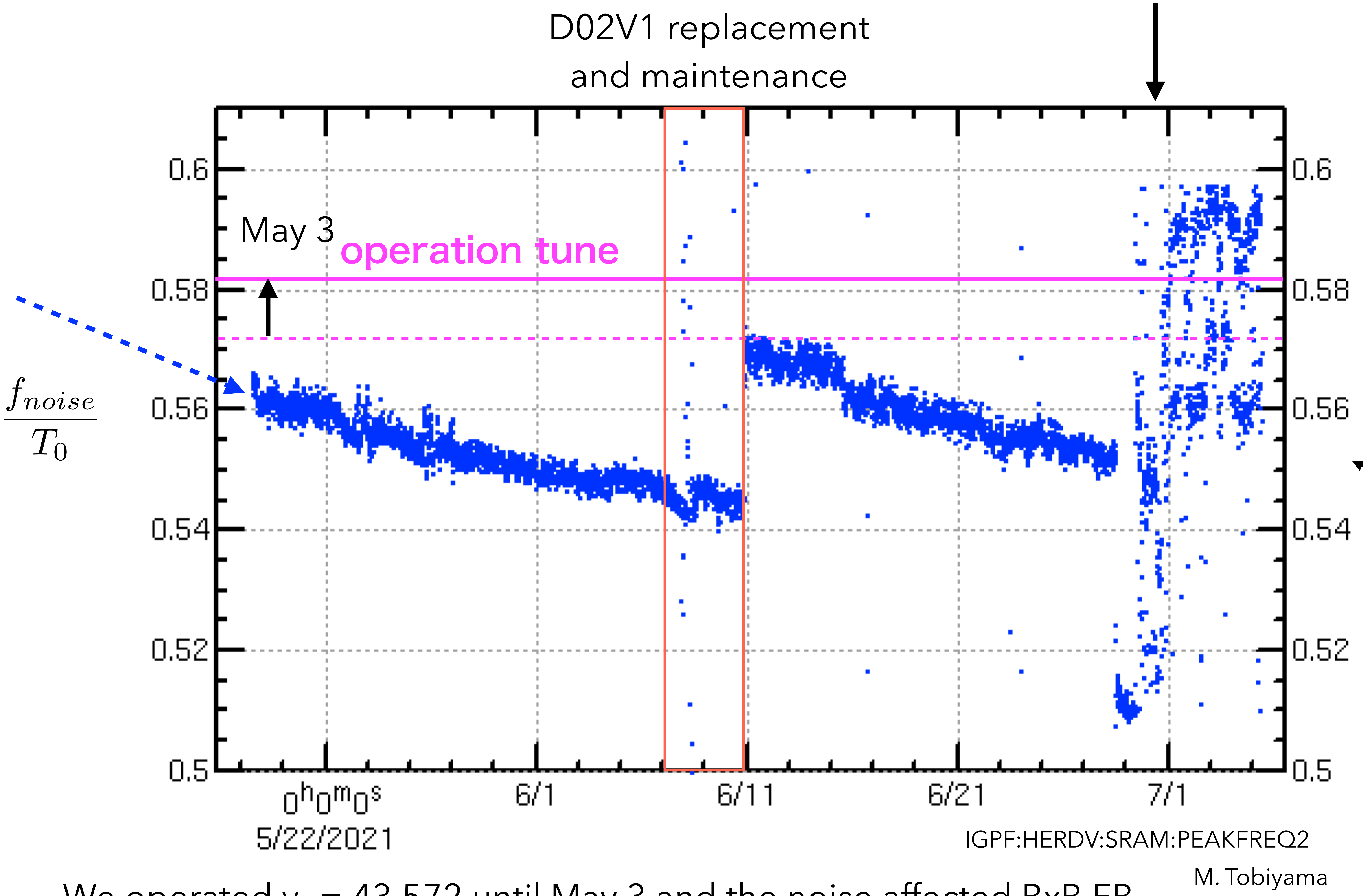


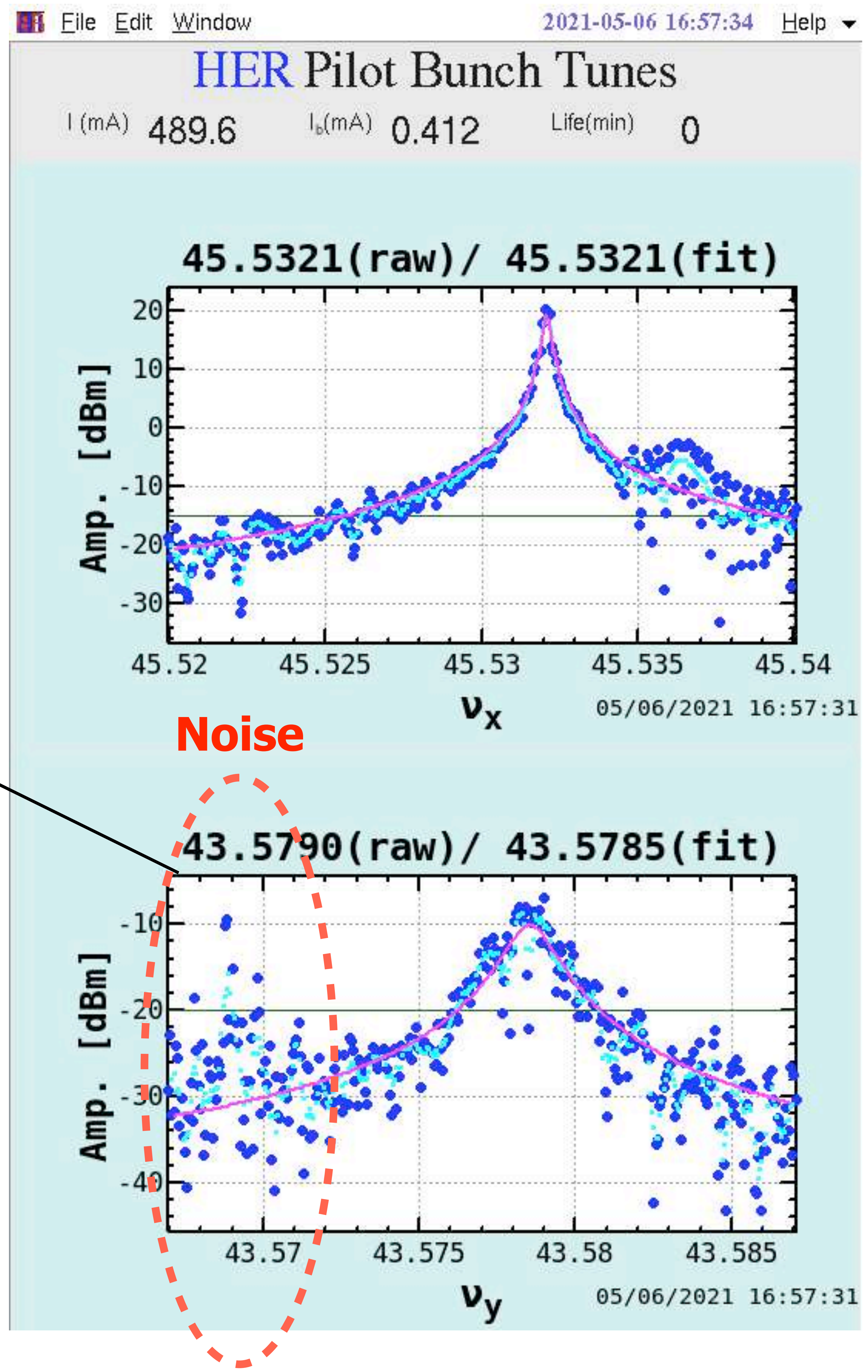


BxB Feedback Noise in HER

May 6, 2021

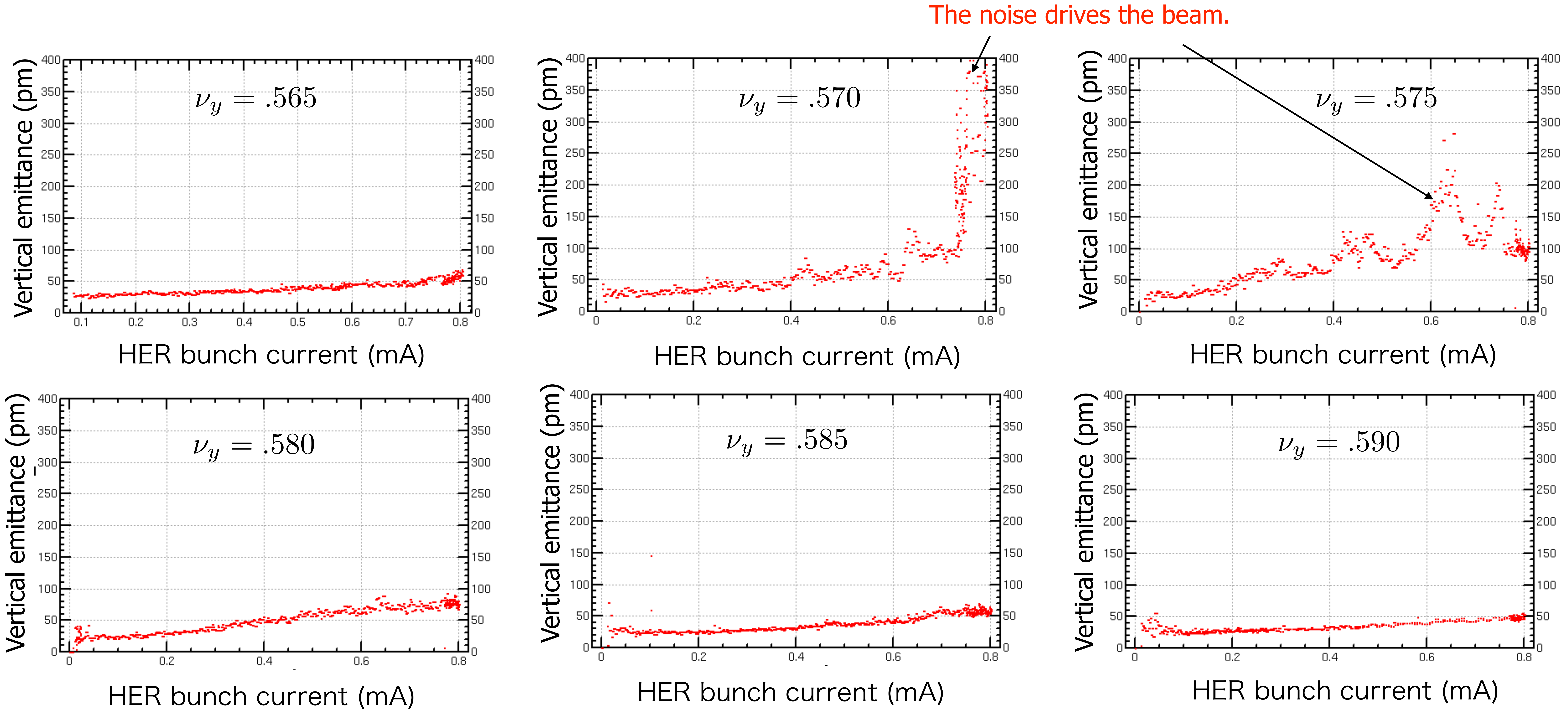
HER BxB FB noise is fixed on June 30
after NIM bin and fanout replacement.



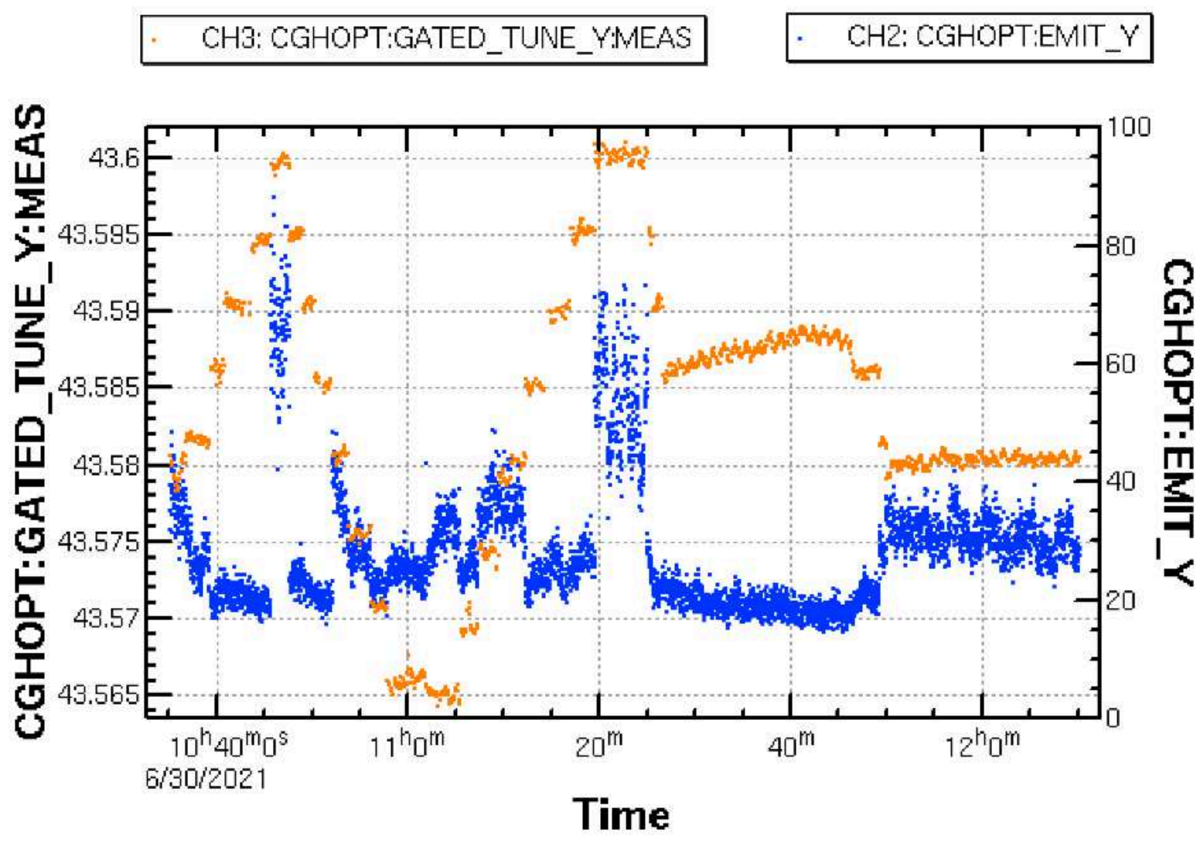


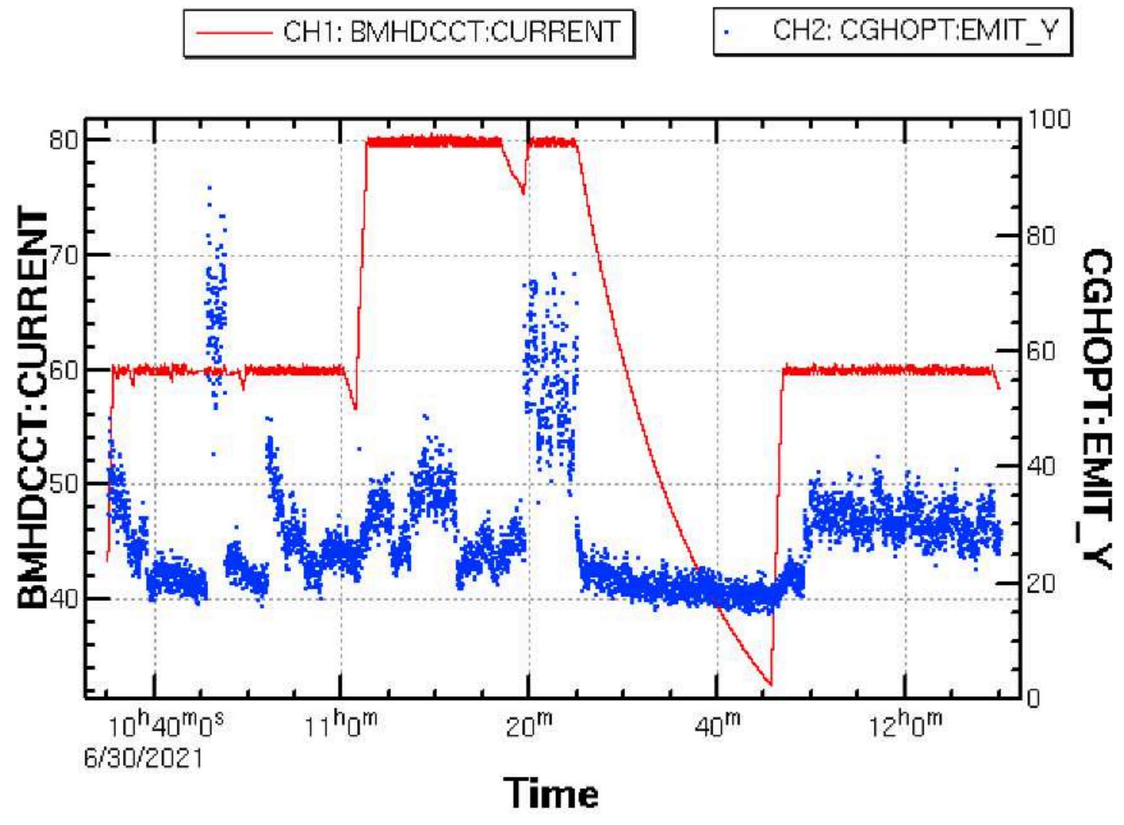
We operated ν_y = 43.572 until May 3 and the noise affected BxB FB,
then we got many aborts when we increased the beam current in HER.
The noise moved away from the working point on May 14.

Vertical Emittance for Single beam in HER on May 6

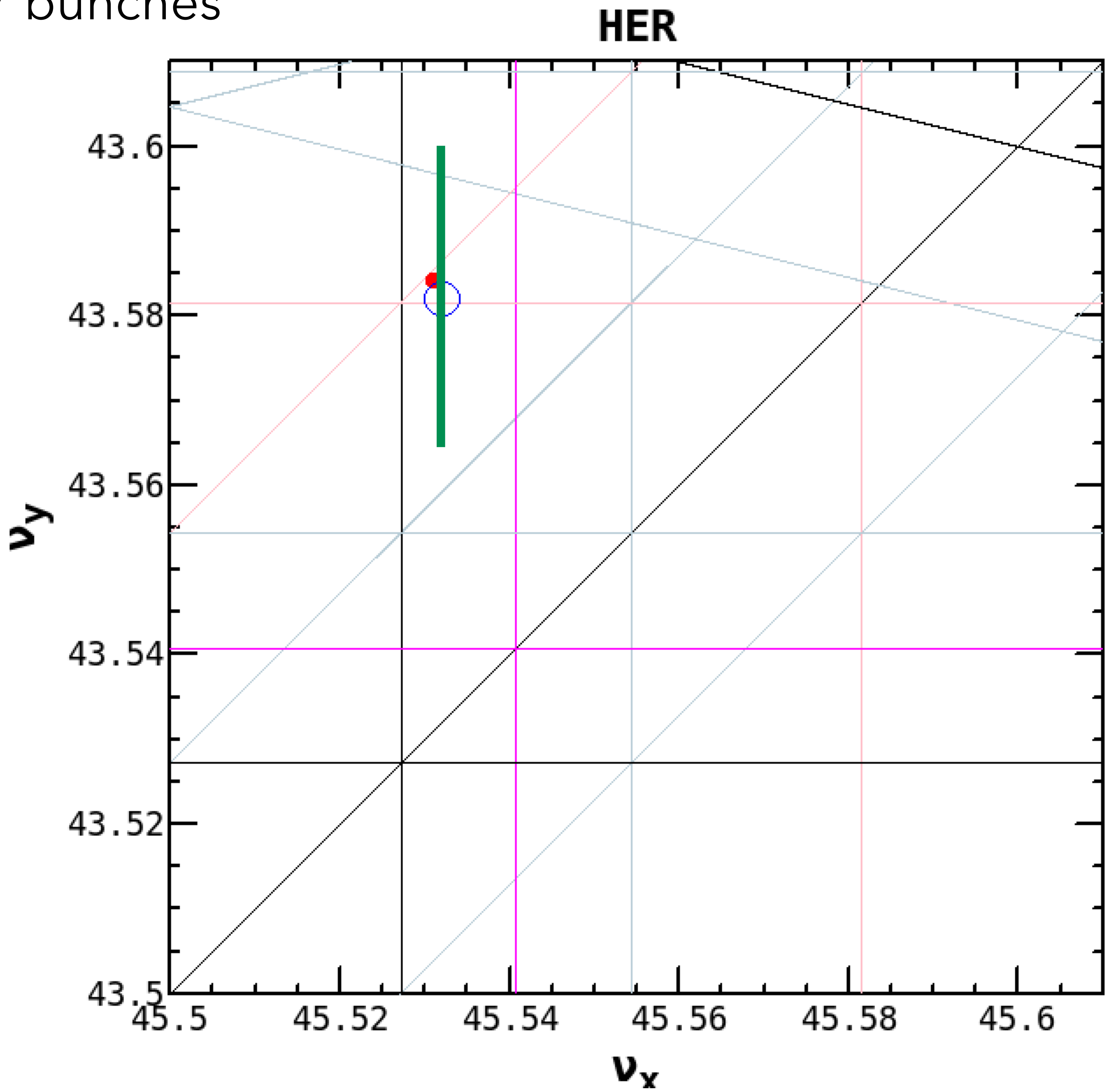


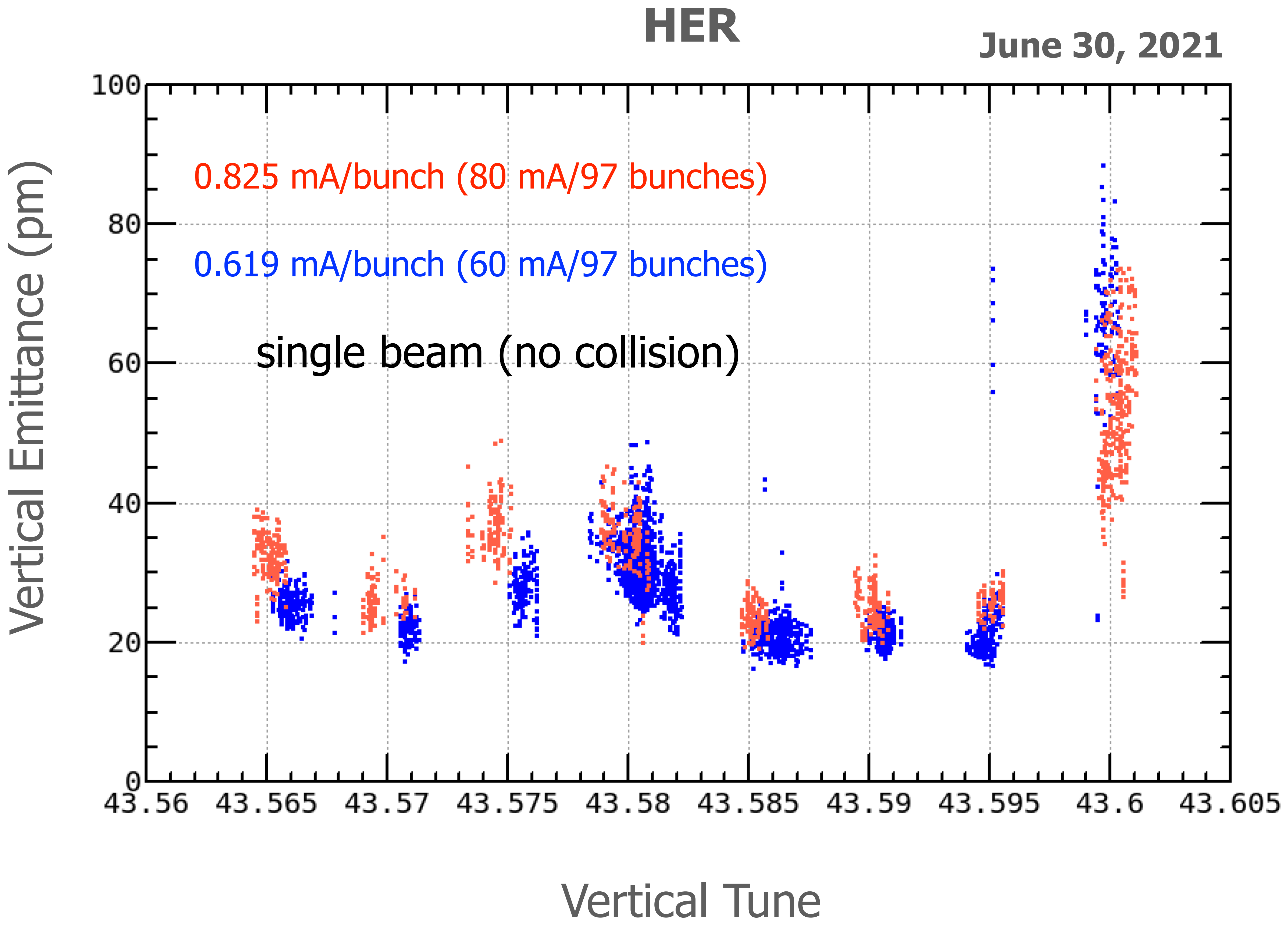
HER Vertical Emittance and Vertical Tune





97 bunches

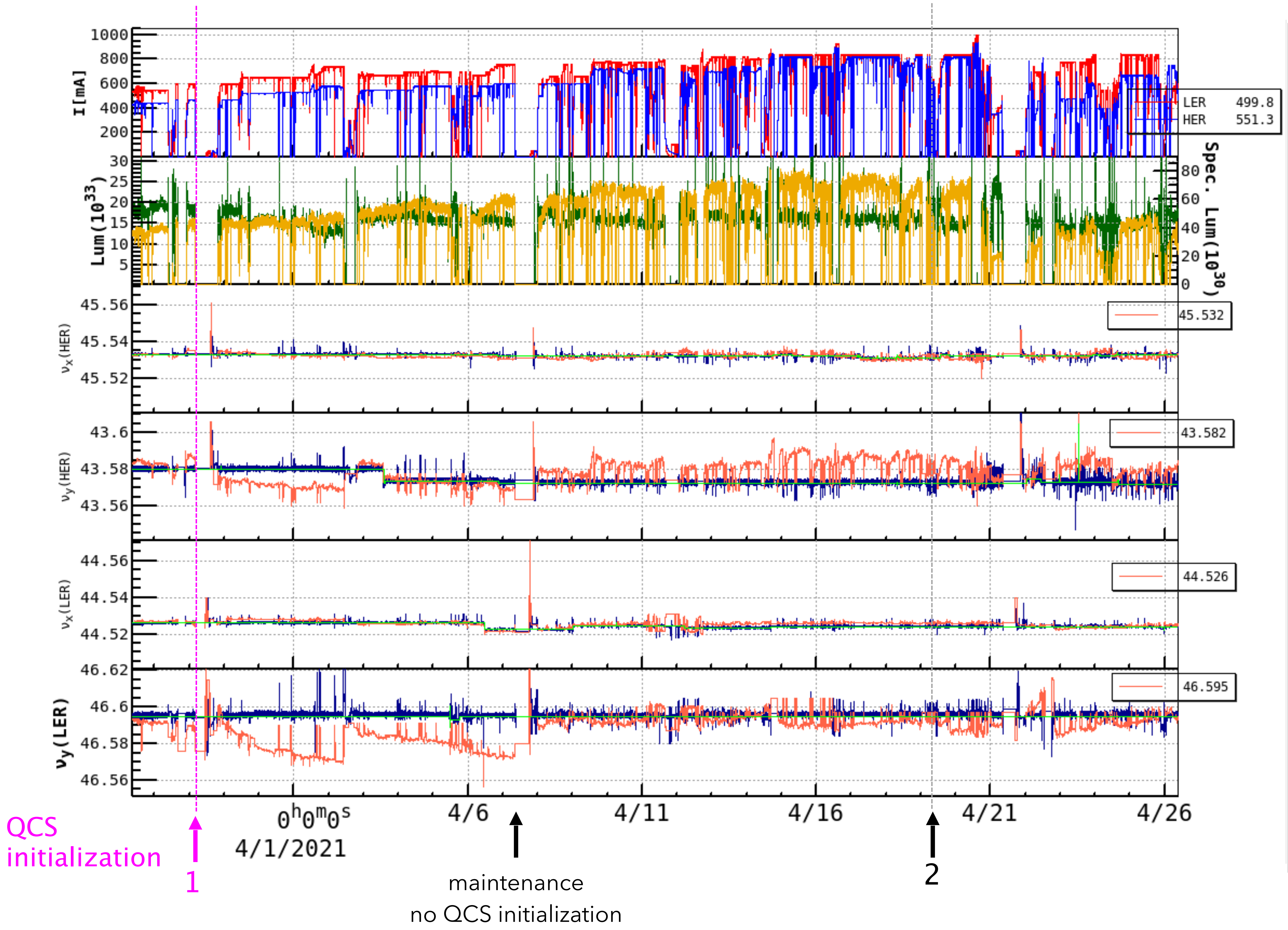


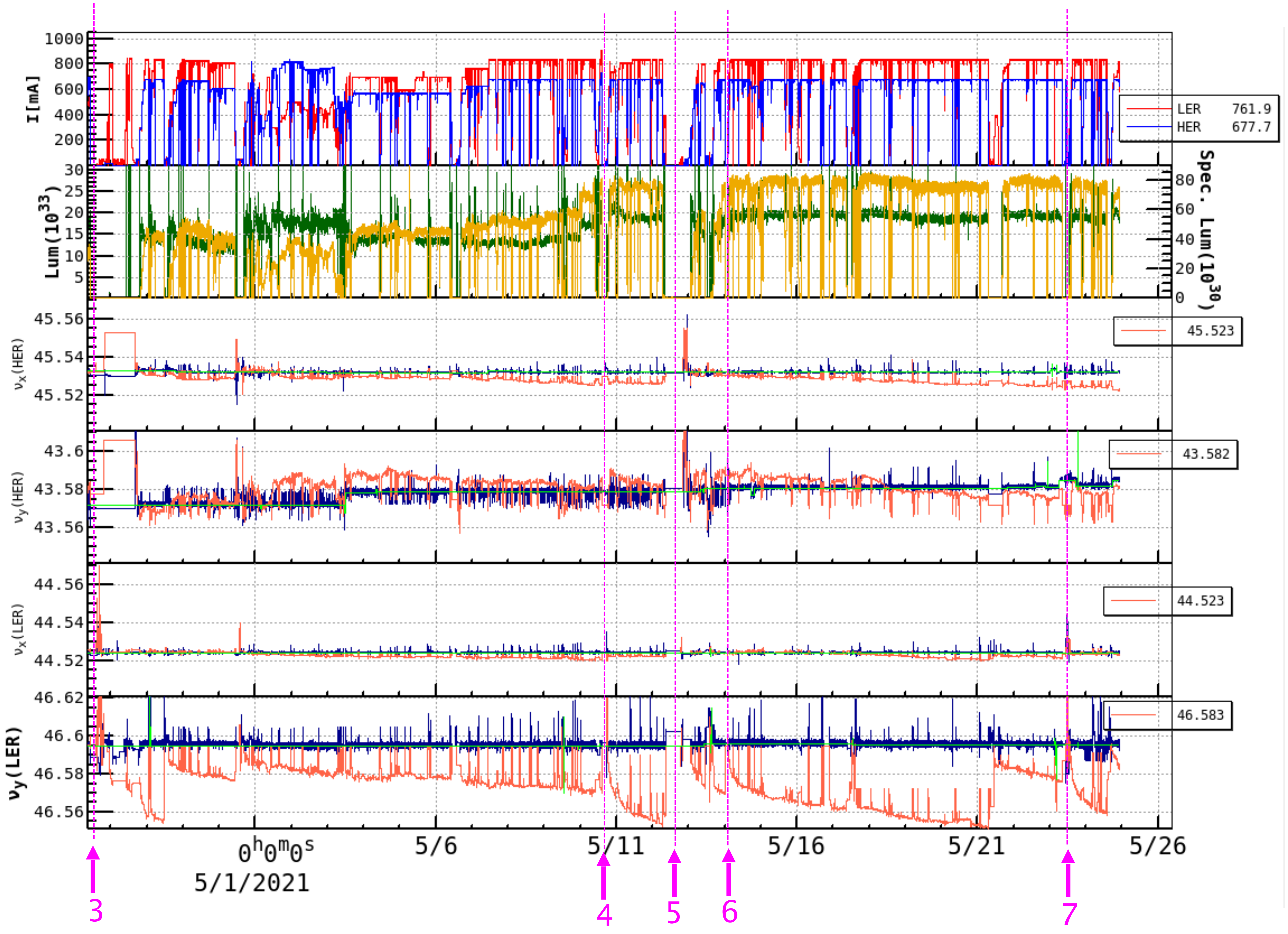


We observed only resonance lines.
There is no strange behavior like May 6
after NIM-bin and fanout module were replaced on June 29.

Tune History: Optics degradation

H. Koiso





1. 3/28 Magnet PS QC1LE Charging Volt I/L Trouble
2. 4/19 QC1LE quench
   (4/21 On -> Off-resonance)

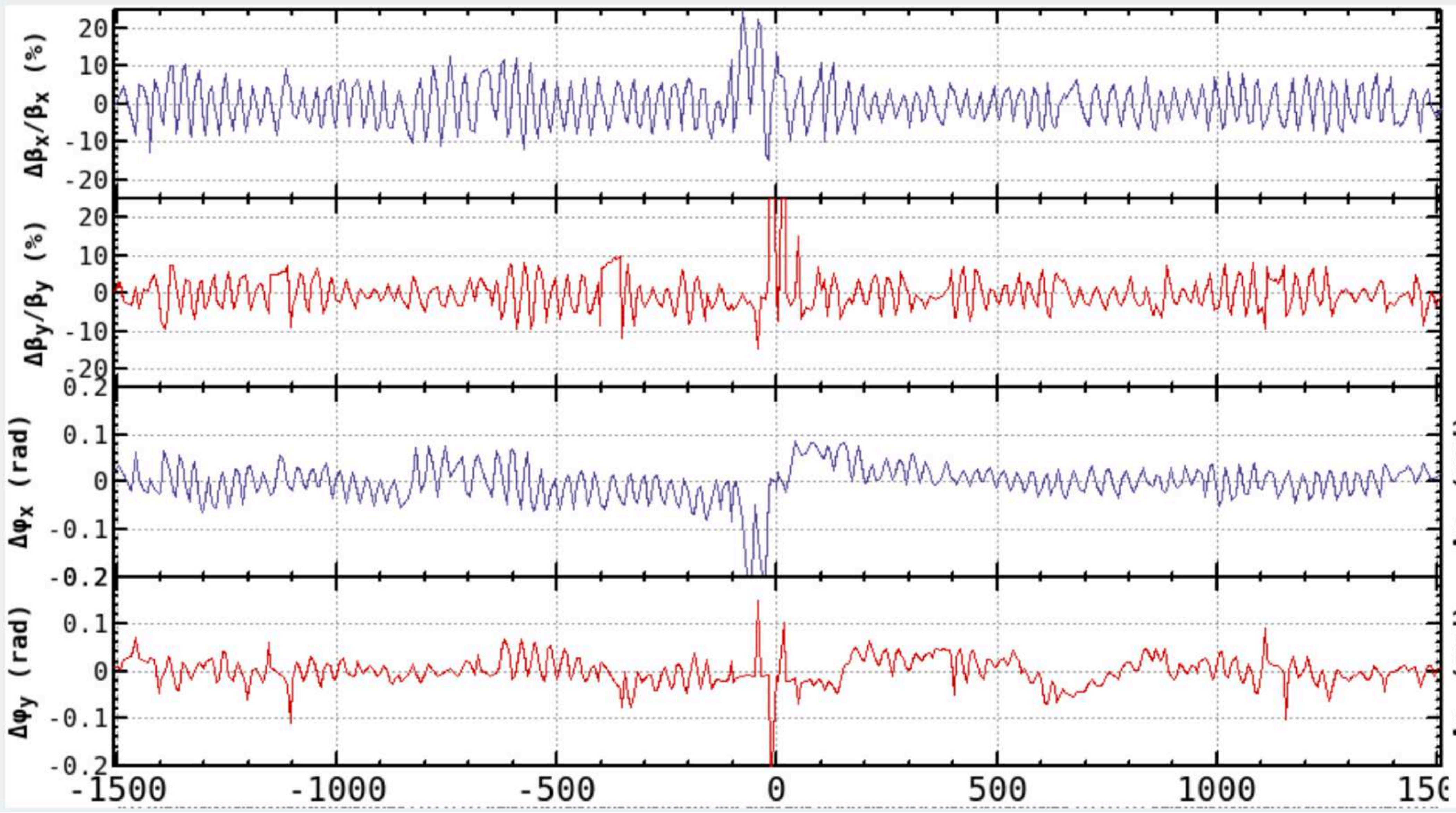
3. 4/26 Off -> On-resonance
4. 5/10 QC1RP & QC1LP quench
5. 5/12 Maintenance
6. 5/14 QC1RP quench
7. 5/23 QC1RP & QC1LP quench

Discrepancy between model and measurement of ν_y increases rapidly after QCS initialization with optics corrections.
When we skip the QCS initialization, the discrepancy becomes small. QCS coils move slowly or field/orbit drifting ?

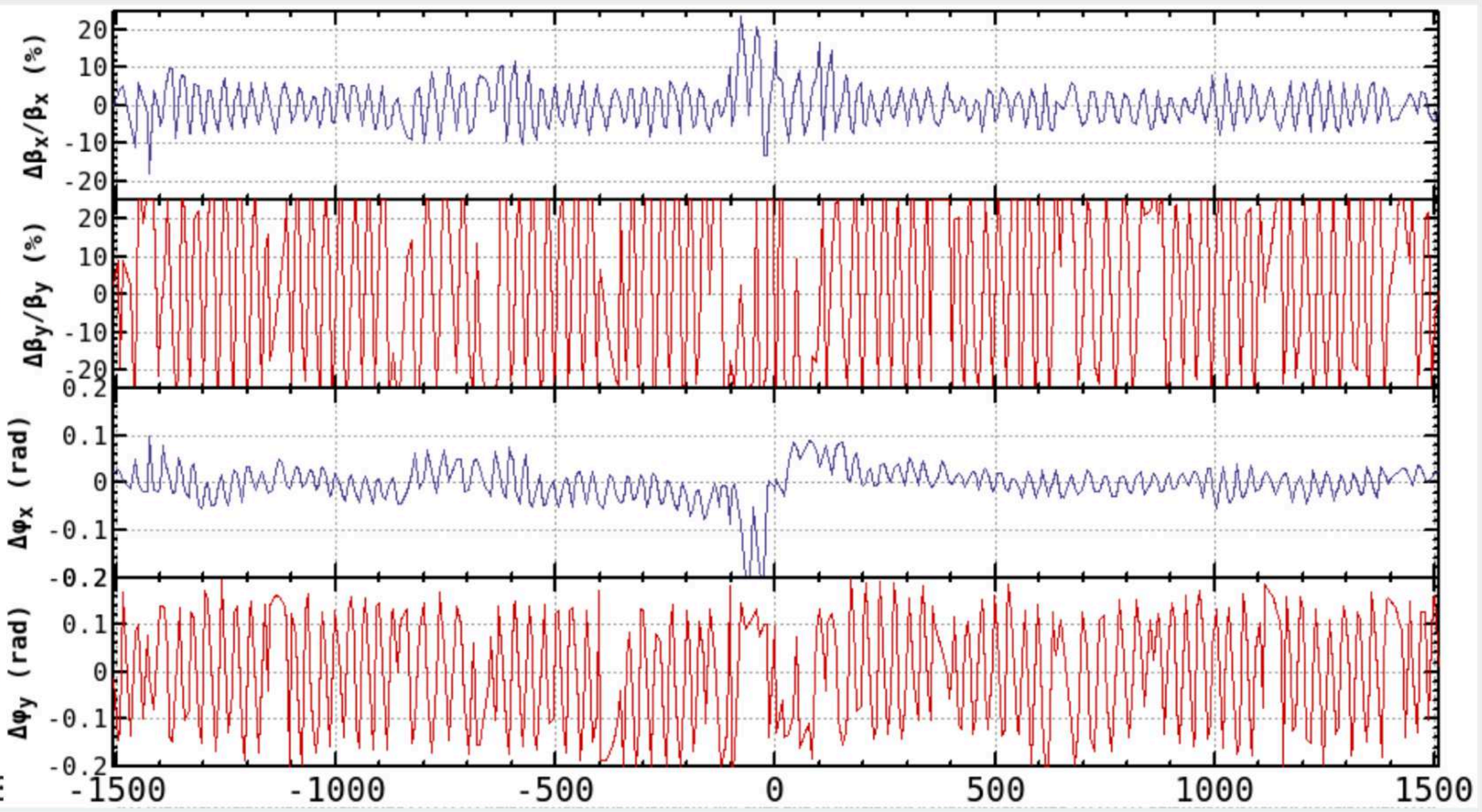
Optics degradation

H. Sugimoto

Optics correction after QCS initialization on March 29, 2021

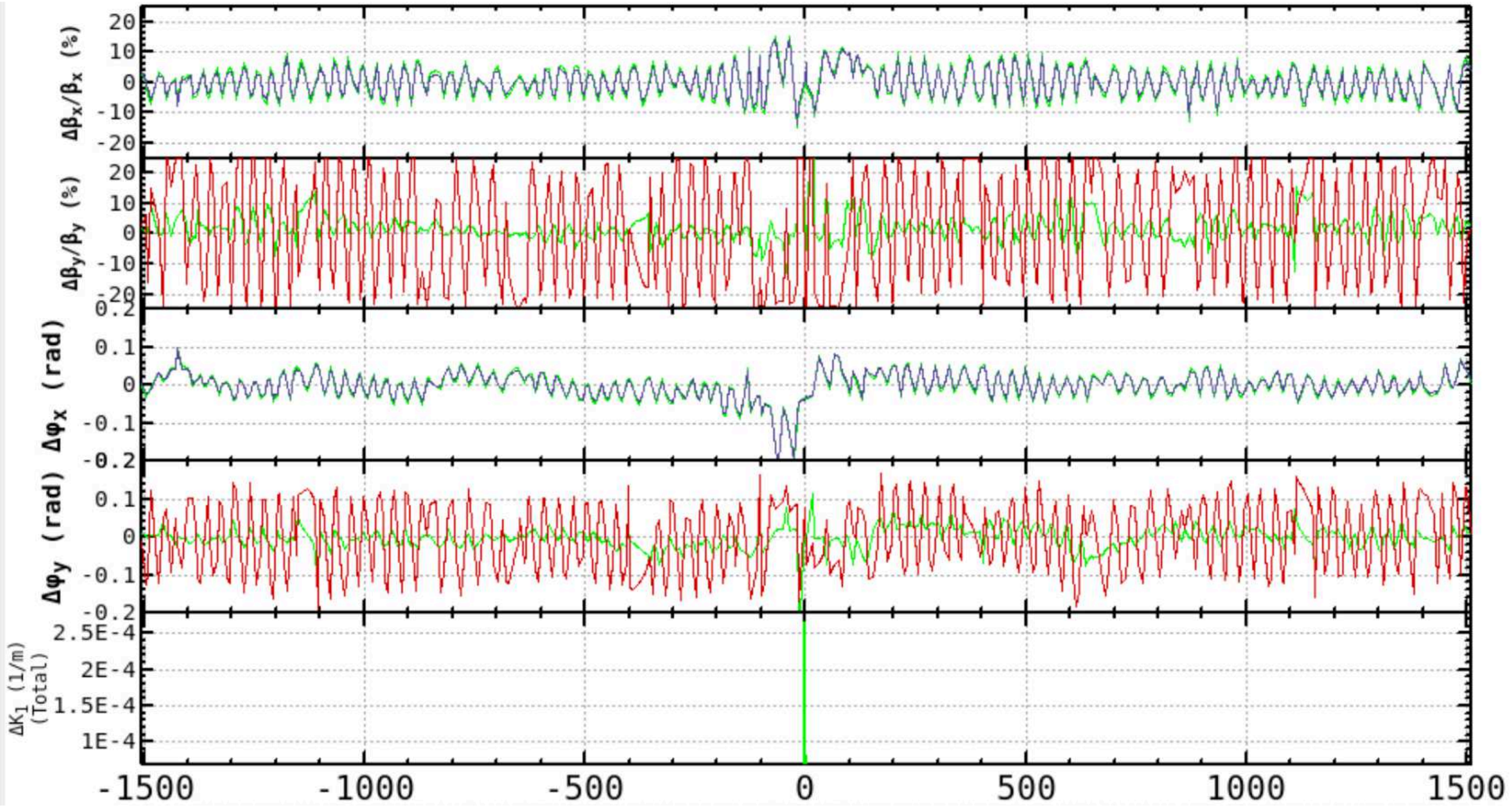


April 2, 2021 (five days after optics correction)



March 29	April 2
$\Delta\beta_x/\beta_x = 5.7$ %	$\Delta\beta_x/\beta_x = 5.4$ %
$\Delta\beta_y/\beta_y = 7.9$ %	$\Delta\beta_y/\beta_y = 24.6$ %

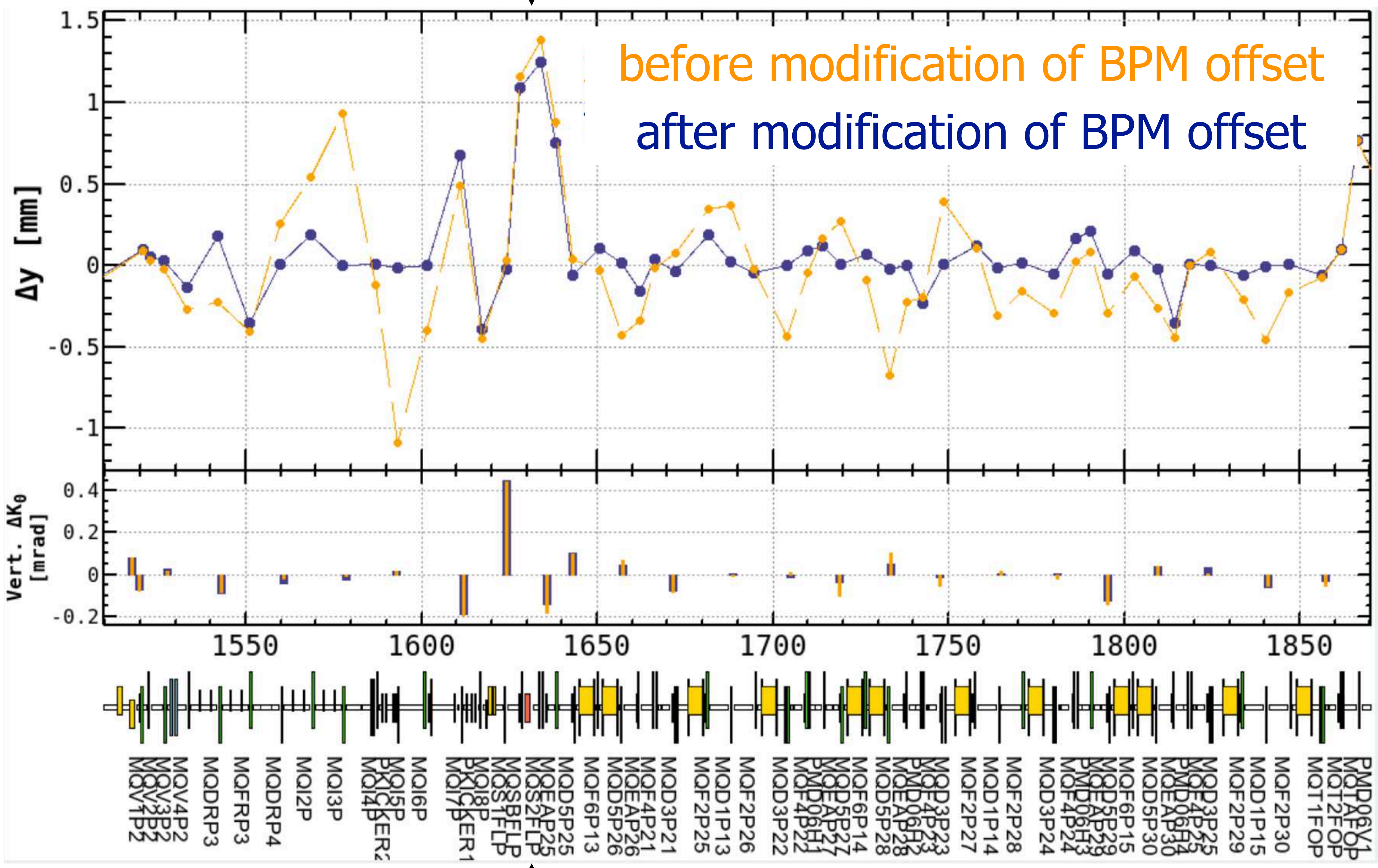
QC1LP/QC1RP can correct beta-beating.
Correction is $\Delta K_1 \sim 10^{-4}$ (1/m).



Implementation of BBA in the FUJI section

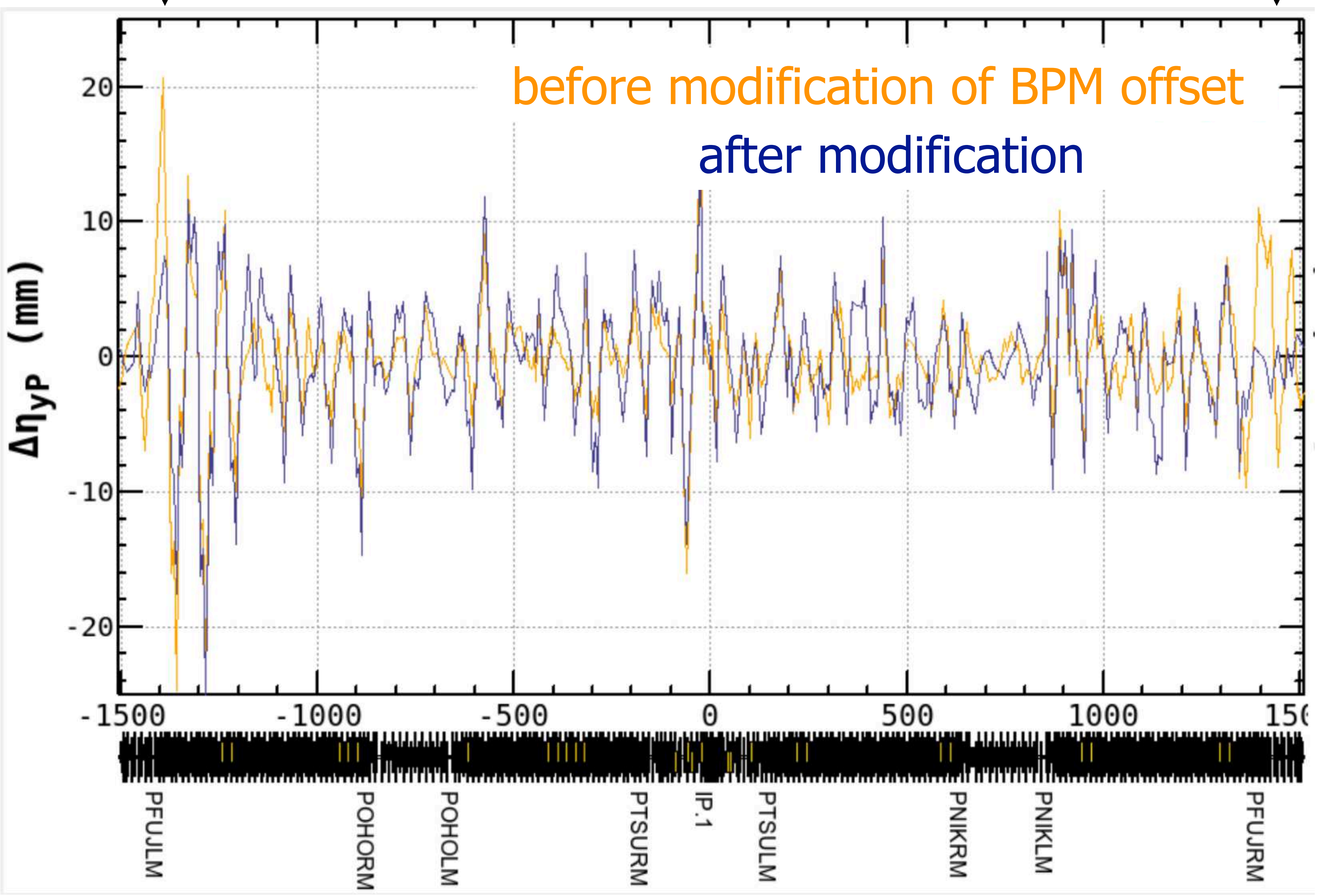
H. Sugimoto

Leakage vertical dipole field
from Lambertson



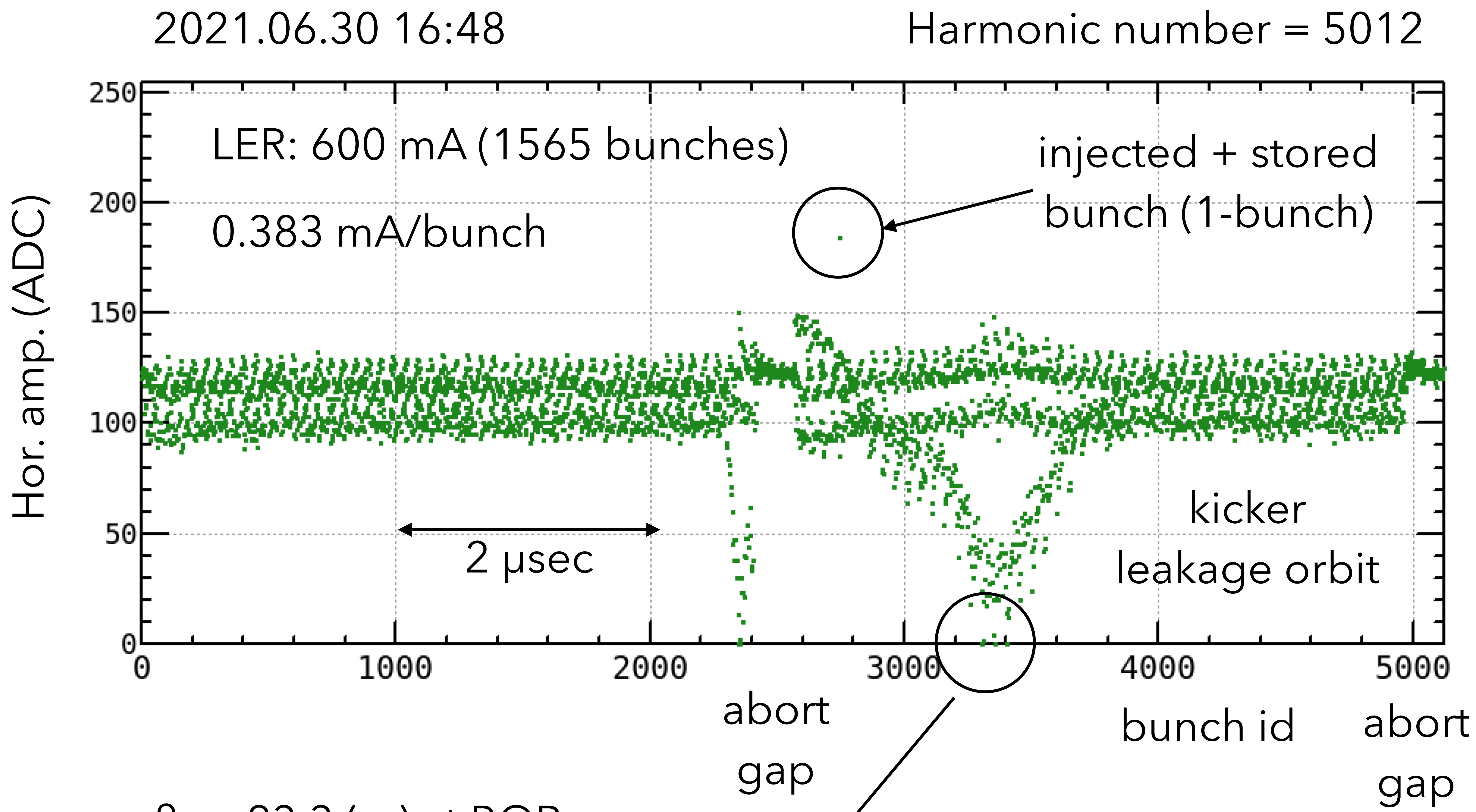
Lambertson magnet
(beam abort system)

Residual dispersions becomes small
in the FUJI section.

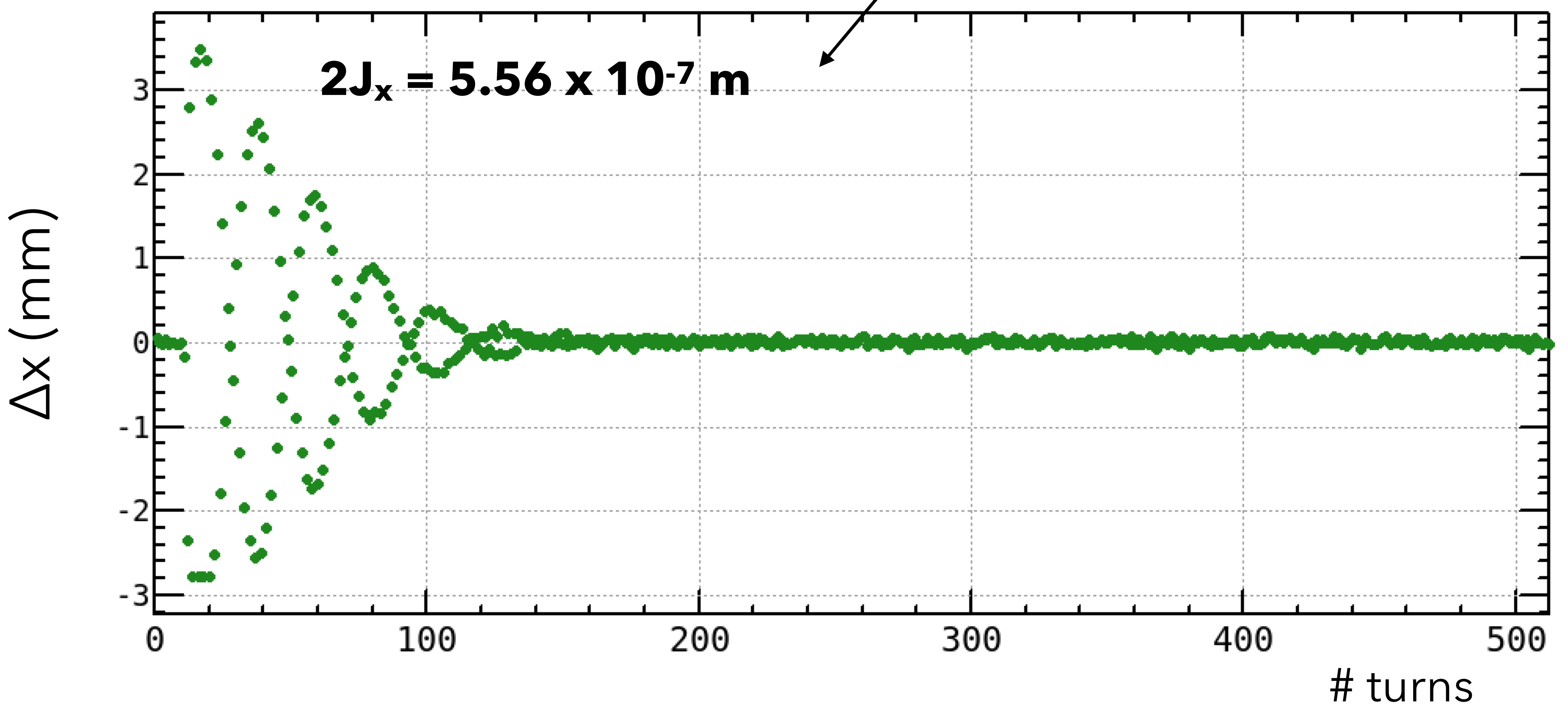


The vertical emittance did not change so much.

Leakage Orbit due to Injection Kickers



β_x = 23.3 (m) at BOR



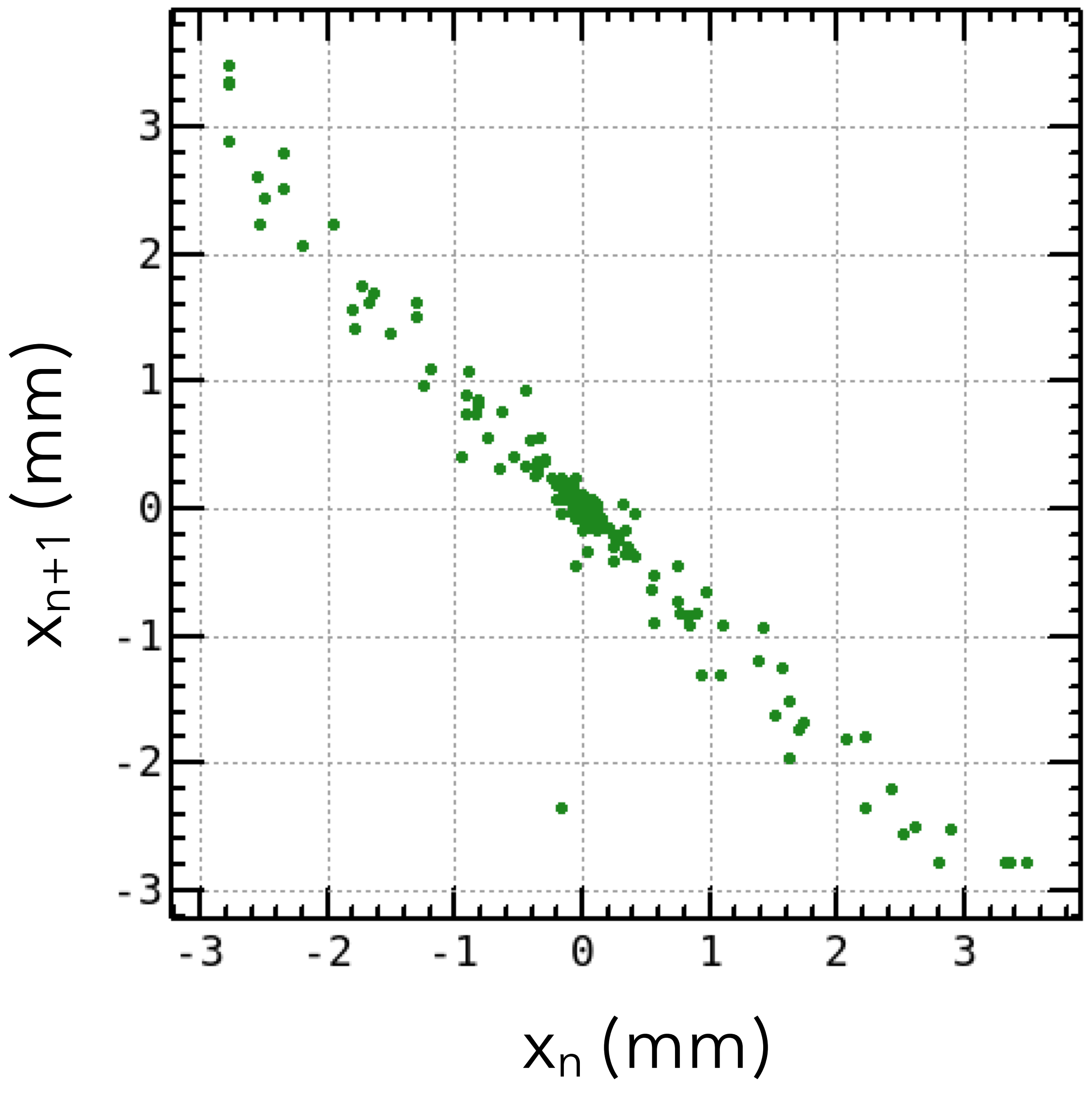
Large orbit leakage due to injection kickers is observed in the horizontal plane after injection in the LER by using BOR. Positions of all bunches for 4096 turns are stored.

Problem is that pulse shapes (half sine) are different among six injection kickers.

This might be **beam loss (BG)** at higher beam current and **source of instabilities**.

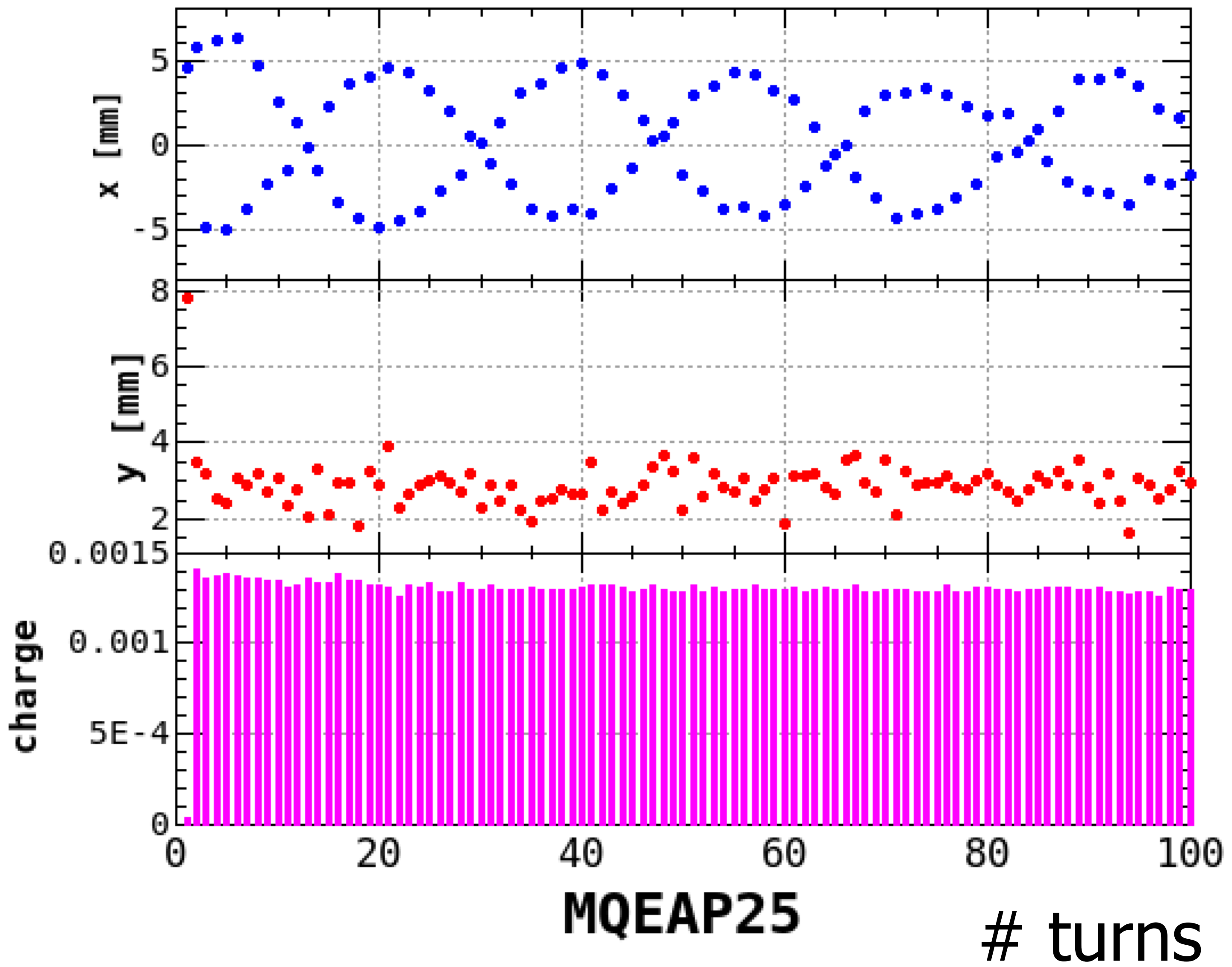
QC2LP (O) : radius = 30 mm

β_x = 163 m. Δx= 9.5 mm



Orbit of Injection Beam measured by TBT BPMs in LER

sample-1 βx =24.42 m



Horizontal injection error:

$2J_x$ = 1.47x10^{-6} m

QC2LP (O) : radius = 30 mm
β_x = 163 m. Δx= 15.5 mm

D06V1 : half width = 6 mm
β_x = 14.6 m. Δx= 4.6 mm

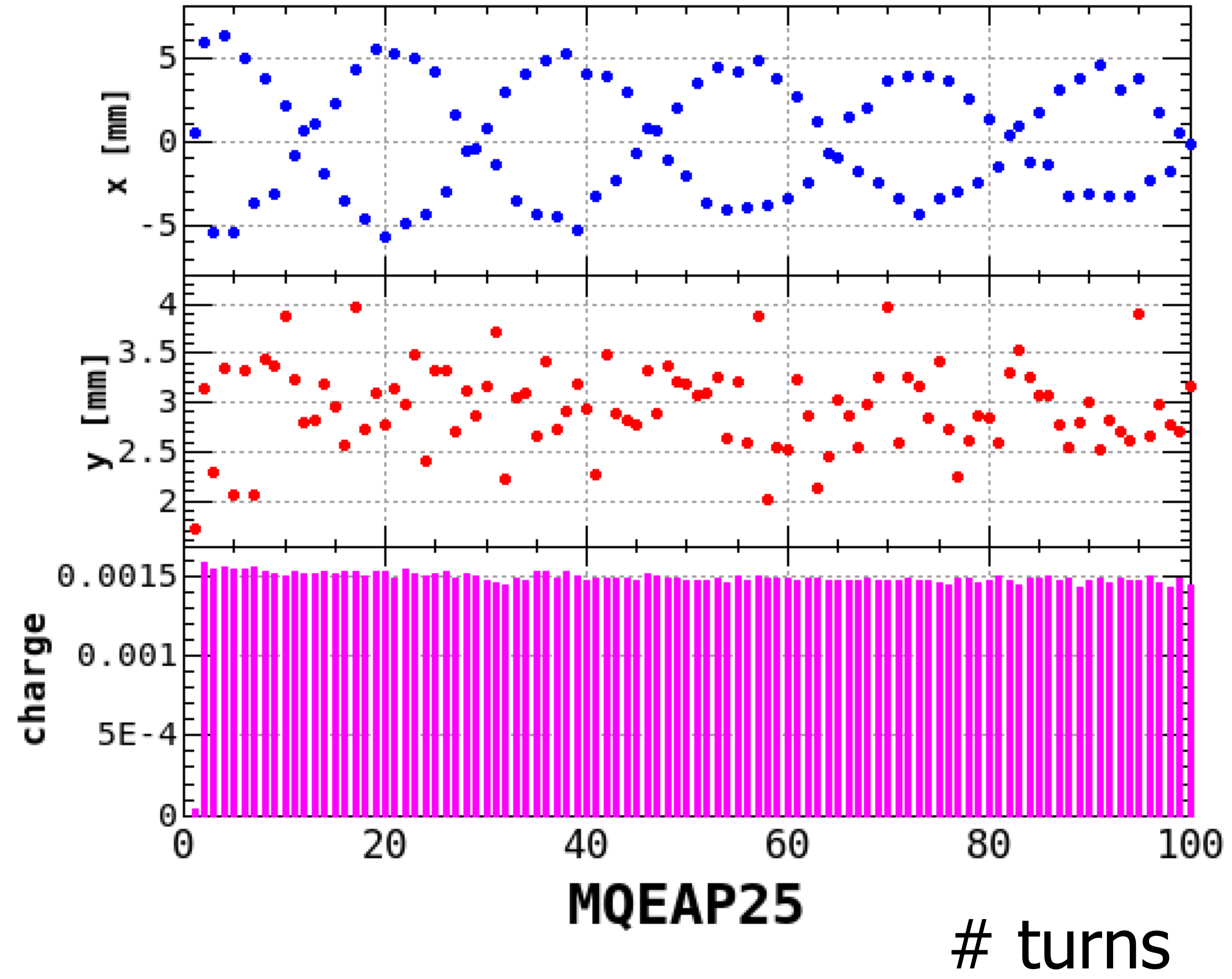
Kicker leakage orbit (stored beam):

$2J_x$ = 5.56 x 10^{-7} m 1/3 of injection error

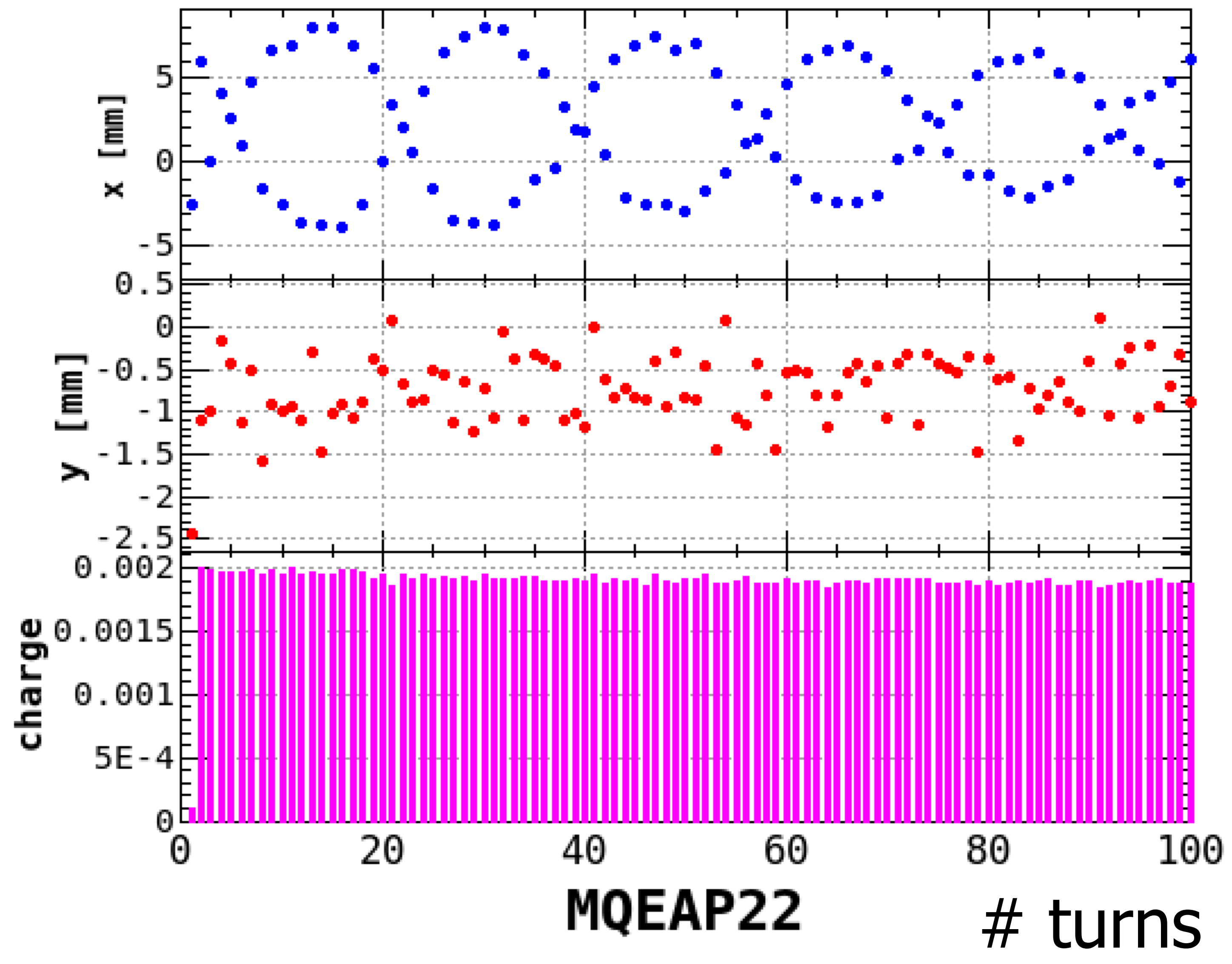
QC2LP (O) : radius = 30 mm
β_x = 163 m. Δx= 9.5 mm

D06V1 : half width = 6 mm
β_x = 14.6 m. Δx= 2.9 mm

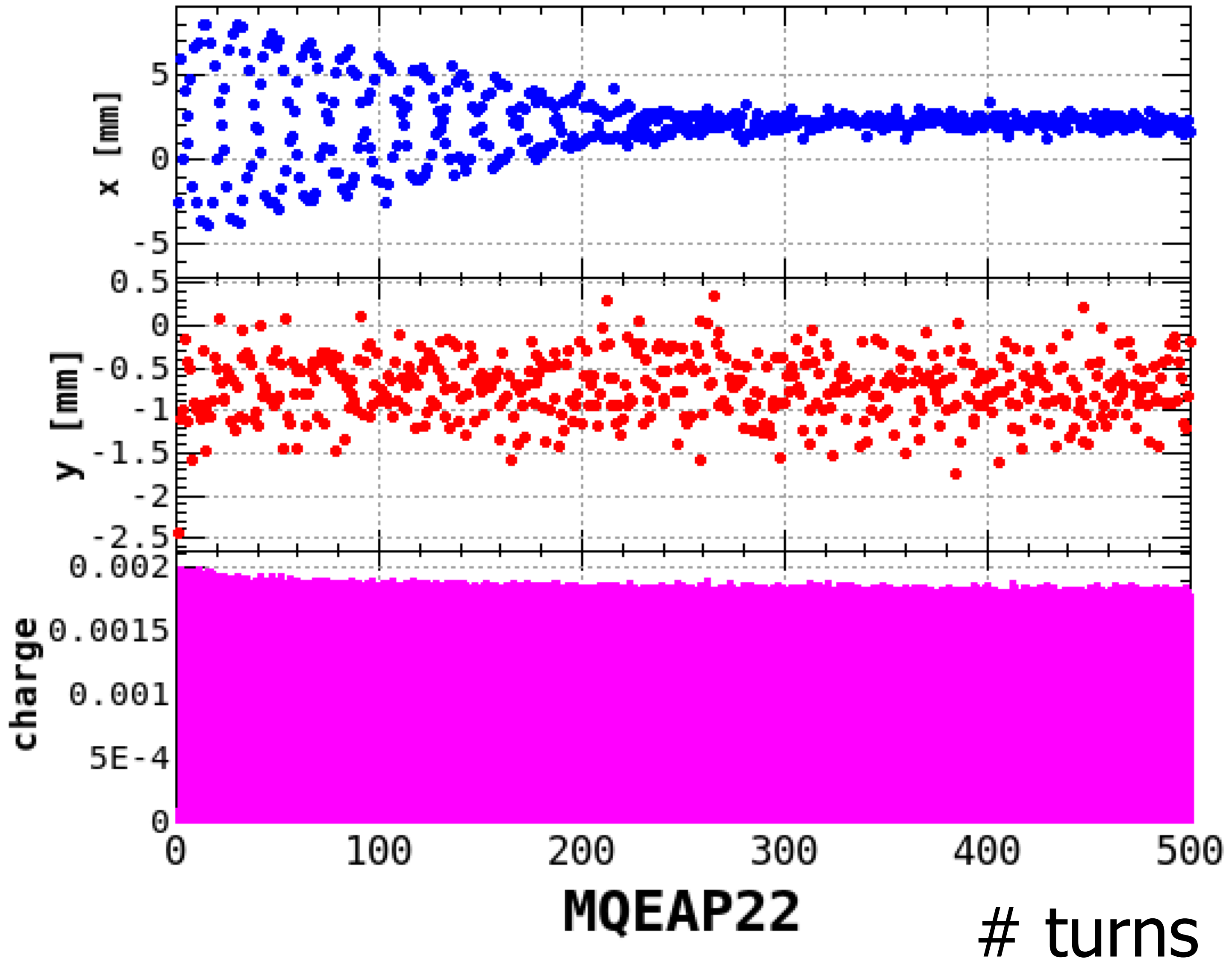
sample-2



sample-3 βx =24.42 m

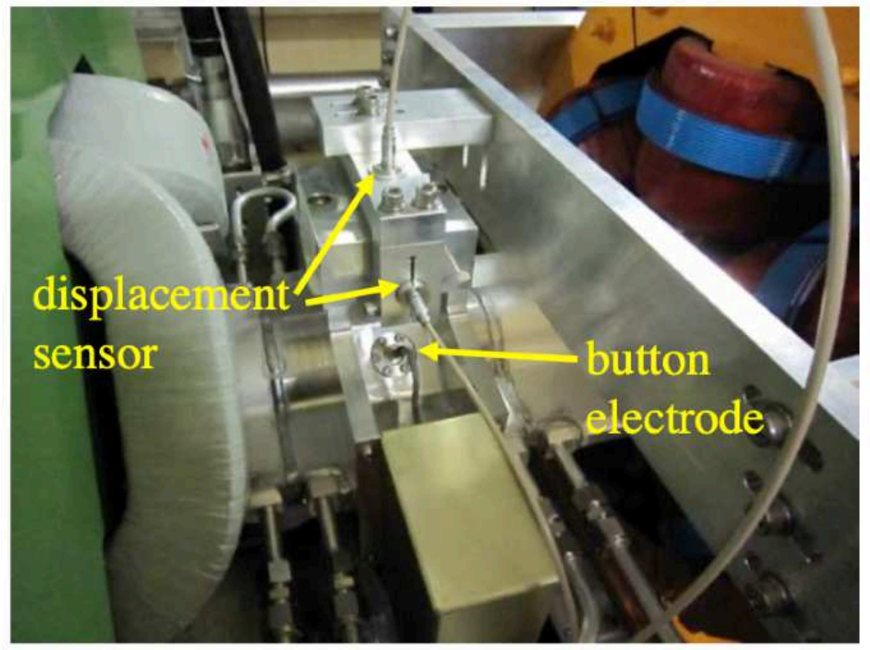


Oscillation is damped in 250 turns owing to BxB feed back system.



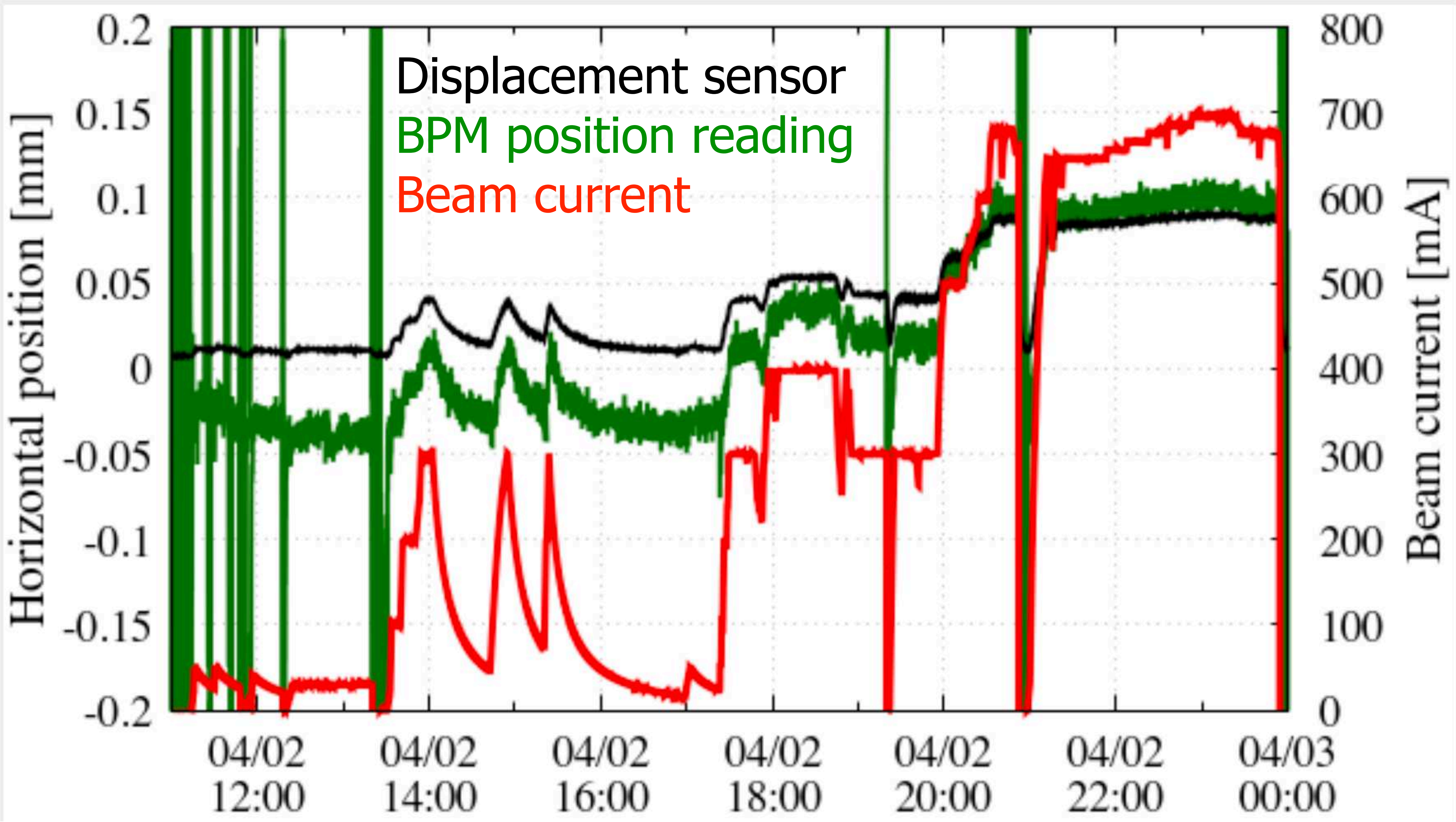
BPM Position Reading and Displacement Sensor

We noticed the relationship between BPM position reading near sextupole magnets and beam current. We figured out a sign of the displacement sensors was wrong in the Tsukuba straight section (D1 and D2) for LER and HER. This was since the beginning of SuperKEKB. We confirmed the definition and corrected a sign of the sensors on April 21, 2021.

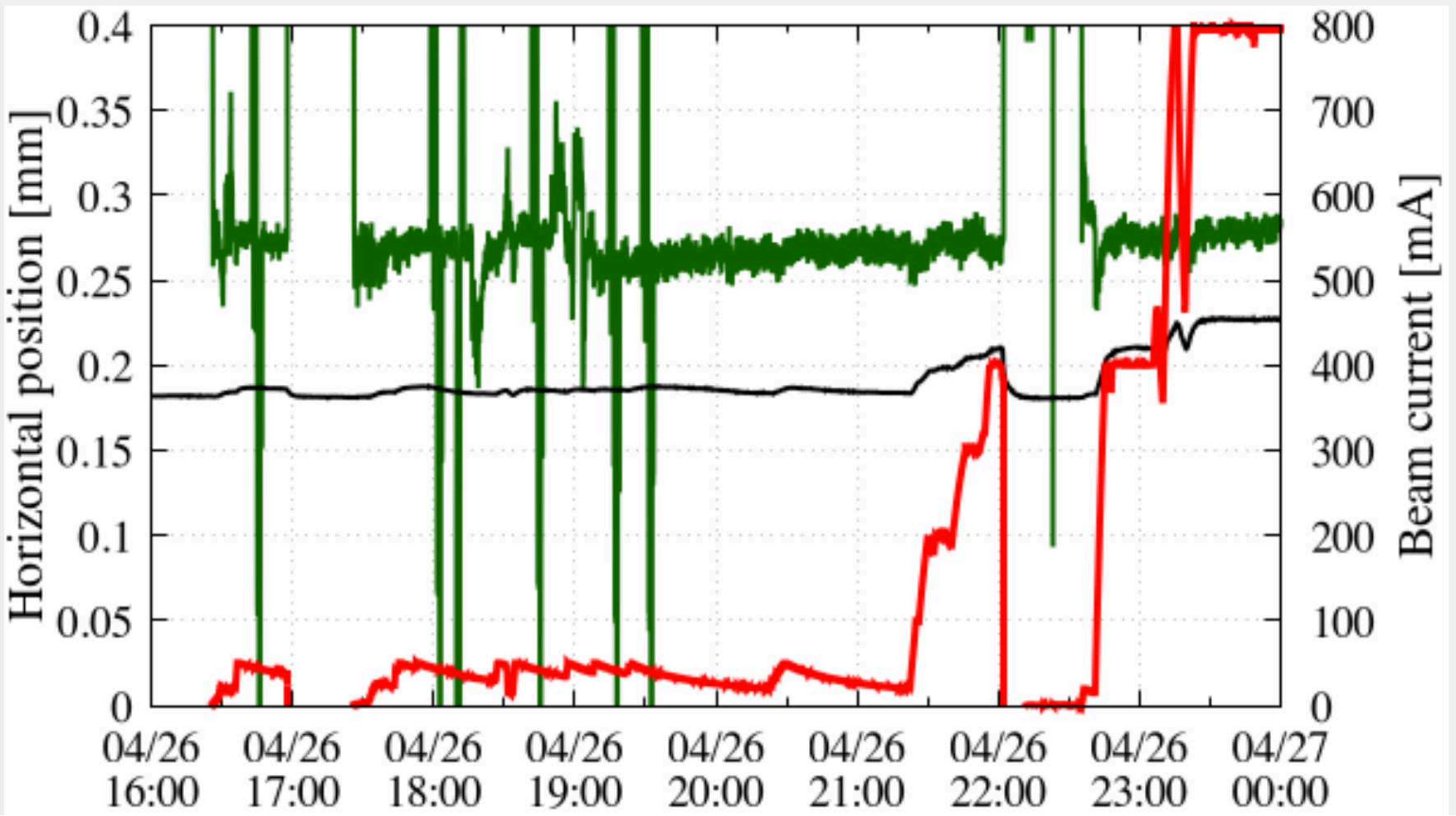


The displacement sensor is to correct the relative mechanical movement of BPM for the neighbor sextupole magnet.

before modification (SLYTRP1)



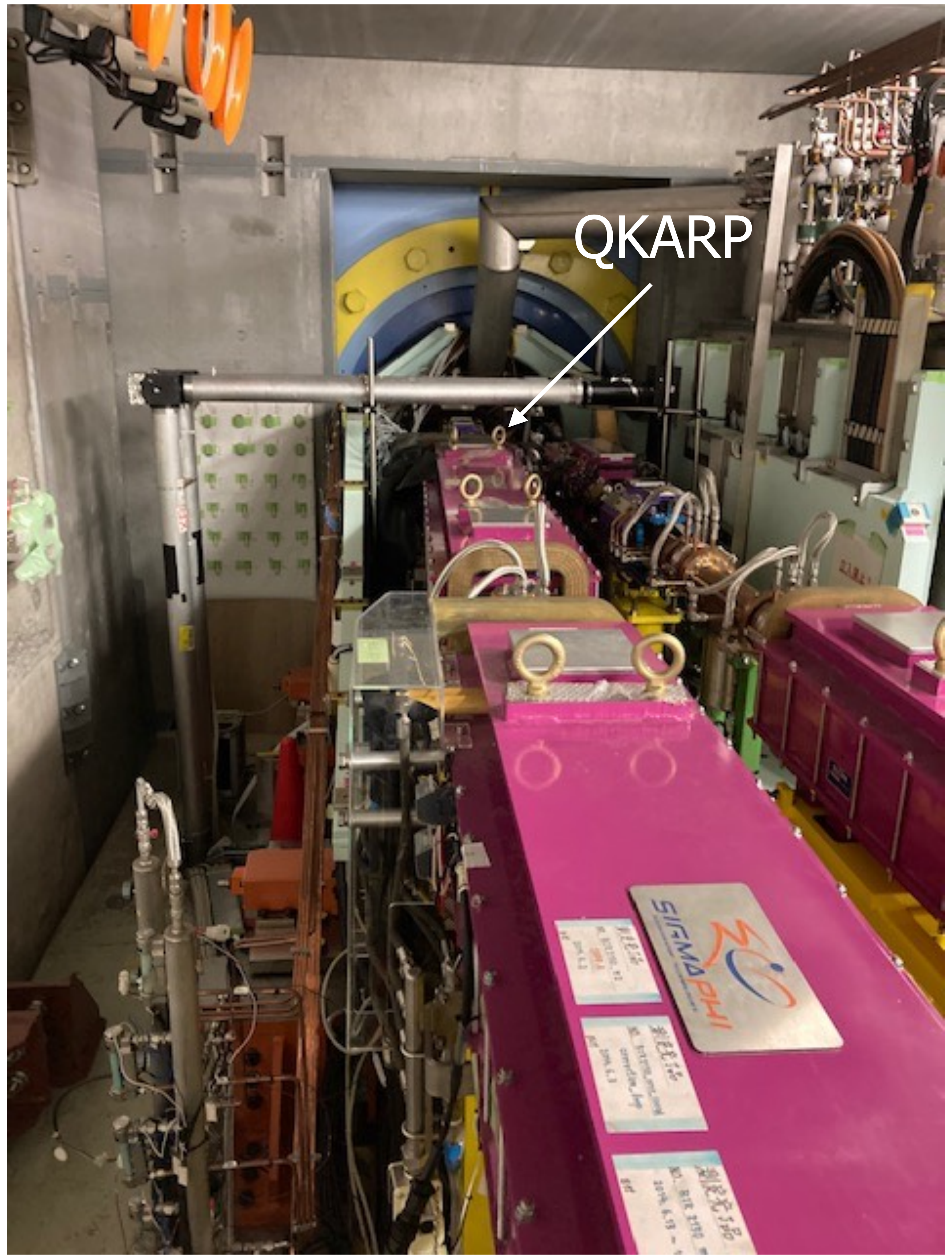
after modification (SLYTRP1)



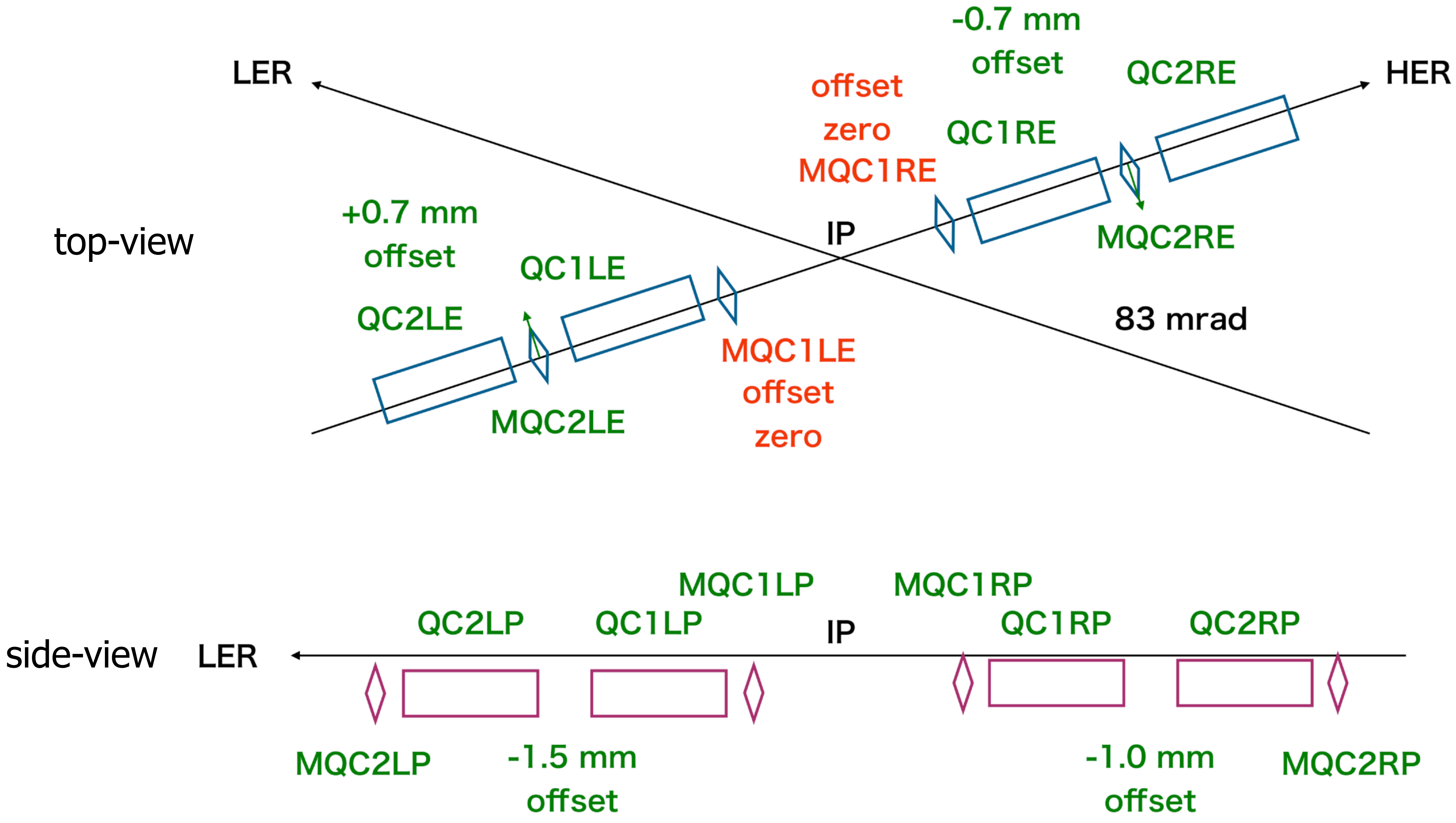
H. Sugimoto

Orbit in the vicinity of the IP

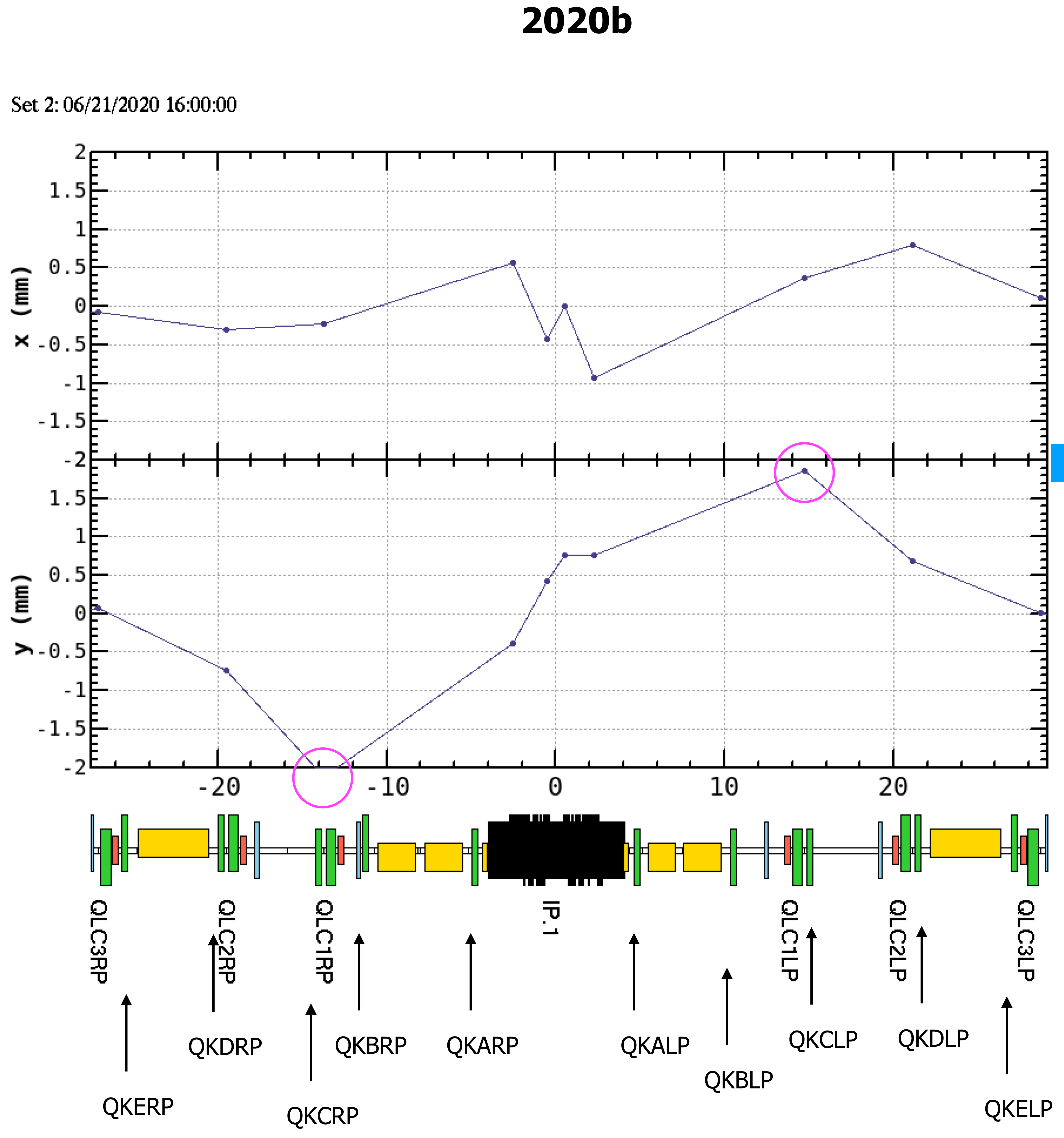
The IP knob uses QK*. Therefore, the orbit is induced by IP knob changes.



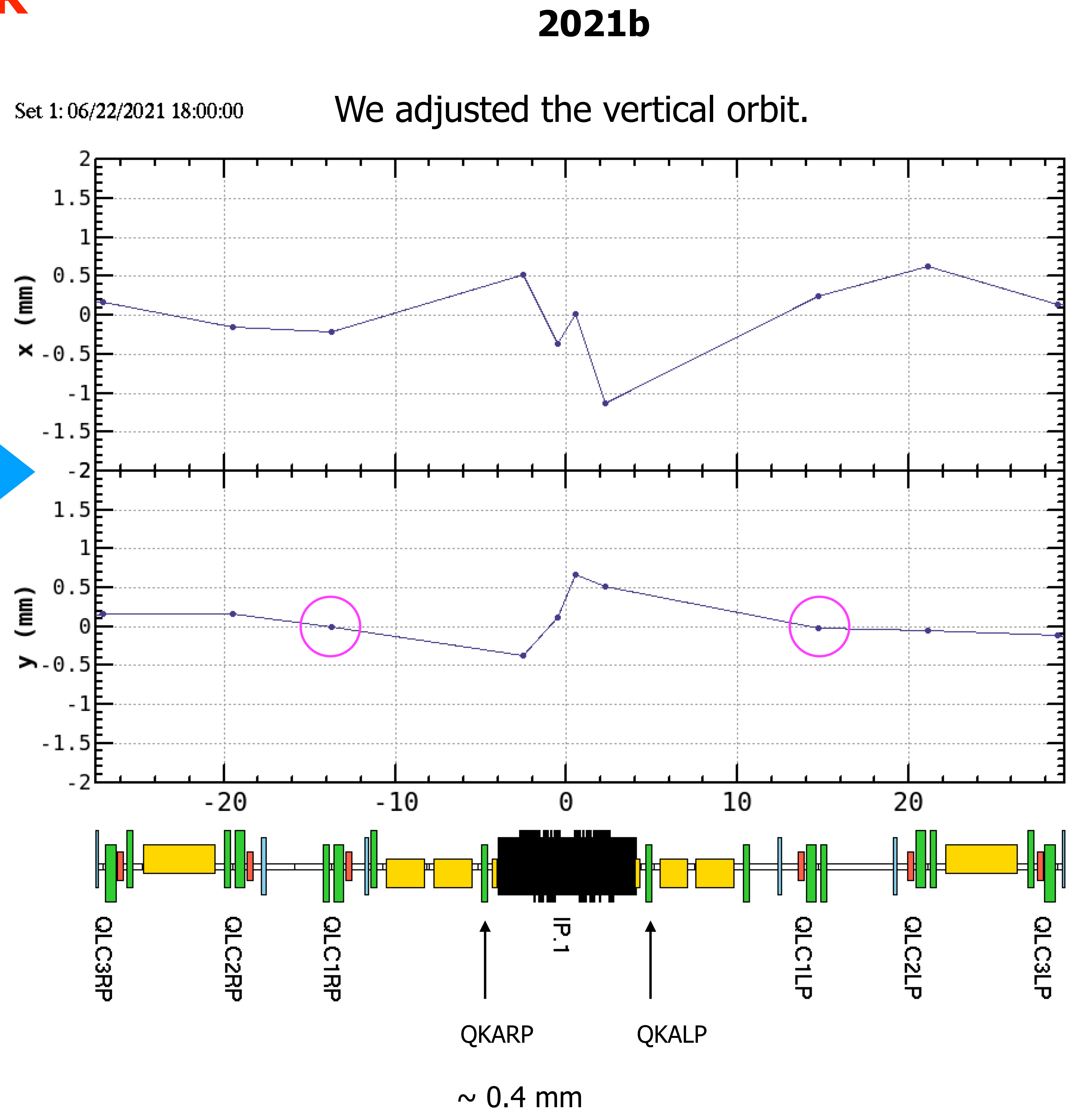
Alignment of QKARP and QKALP is difficult.



LER



2020b
Set 2: 06/21/2020 16:00:00
x (mm)
y (mm)
QLC3RP
QLC2RP
QLC1RP
IP.1
QLC1LP
QLC2LP
QLC3LP
QKERP
QKDRP
QKCRP
QKBRP
QKARP
QKALP
QKBLP
QKCLP
QKDLP
QKELP



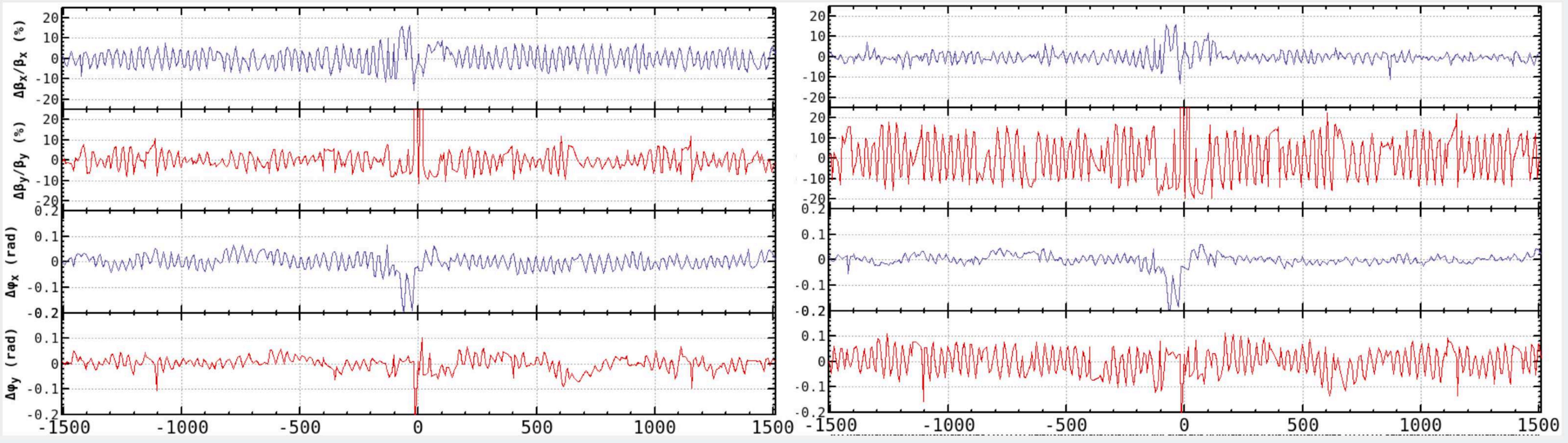
2021b
Set 1: 06/22/2021 18:00:00
We adjusted the vertical orbit.
x (mm)
y (mm)
QLC3RP
QLC2RP
QLC1RP
IP.1
QLC1LP
QLC2LP
QLC3LP
QKARP
QKALP
~ 0.4 mm

IP X-Y Couplings/Dispersion Knob and Beta-Beating in the LER

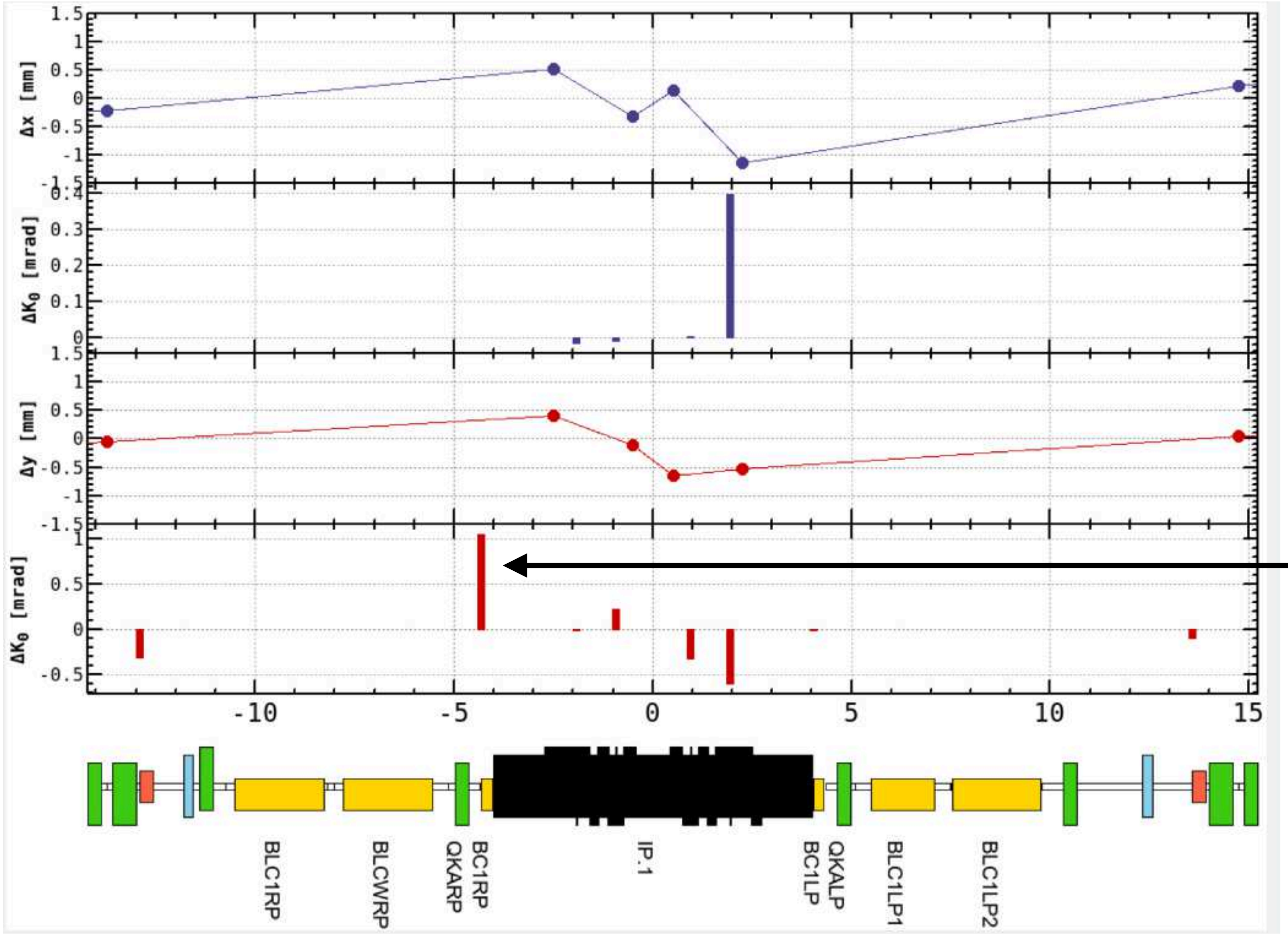
H. Sugimoto

The beta-beating was induced by orbit change due to IP knob ON and OFF in the LER.
Skew quadrupole magnets (QK*) misalignment seems to be source of the beta-beating.

LER IP Knob OFF | LER IP Knob ON



SAD coordinate



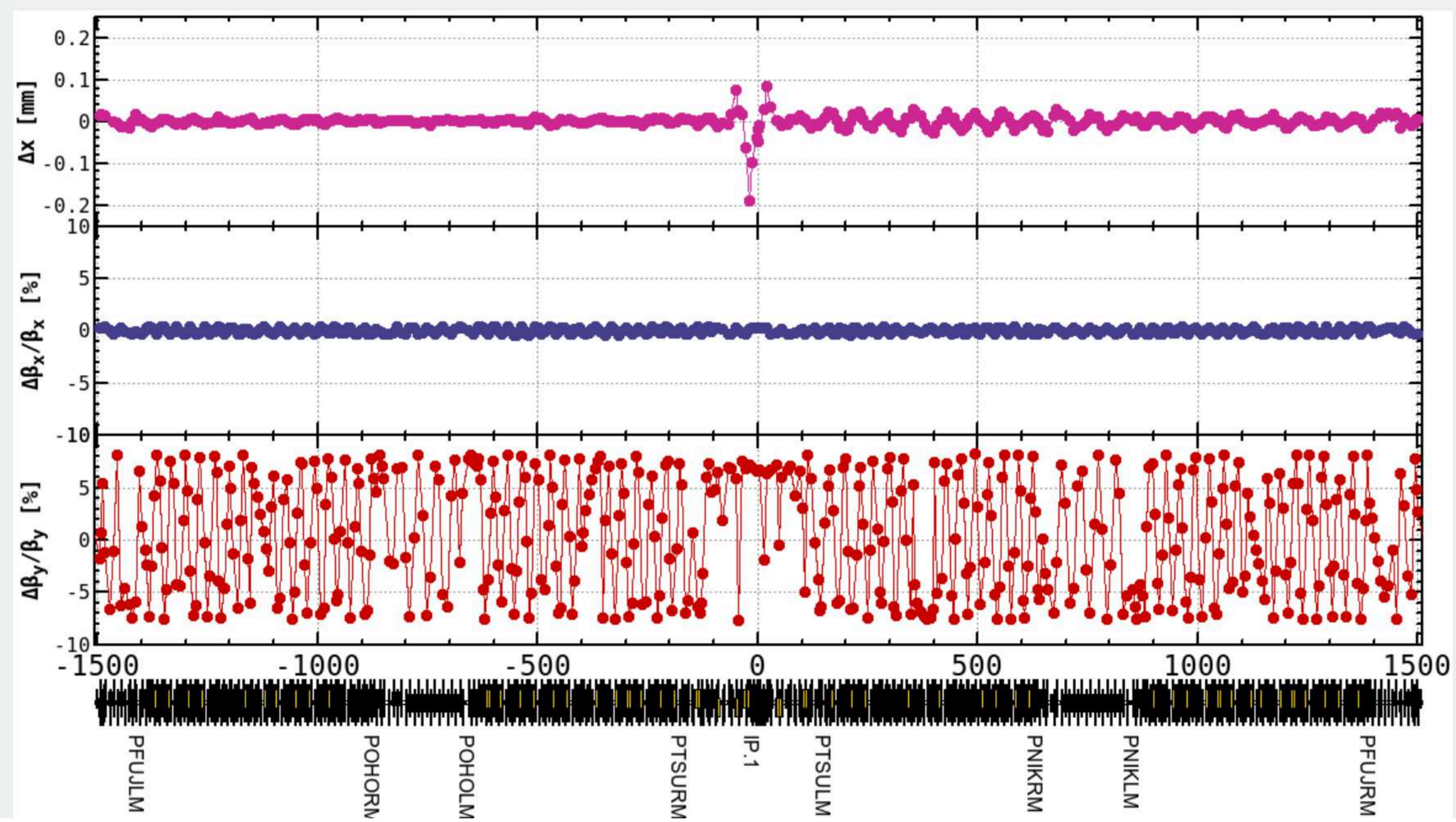
QKARP : H offset = +0.8 mm / V offset = +1.9 mm
QKALP : H offset = -0.8 mm / V offset = +0.2 mm

Large QKARP V offset is consistent with large K_0 of BC1RP corrector.

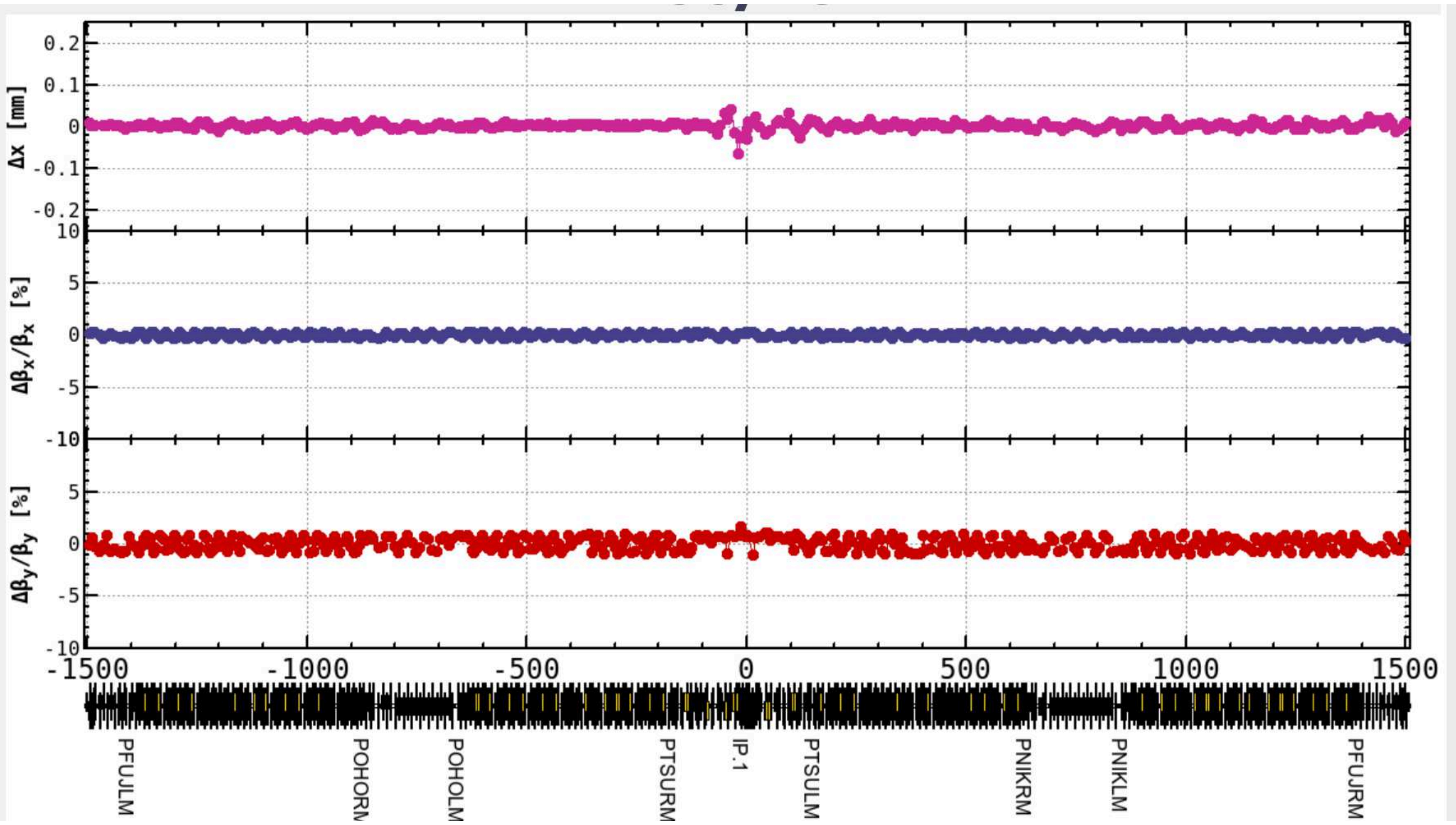
Measured beta-beating due to orbit change

H. Sugimoto

May 12 (before)

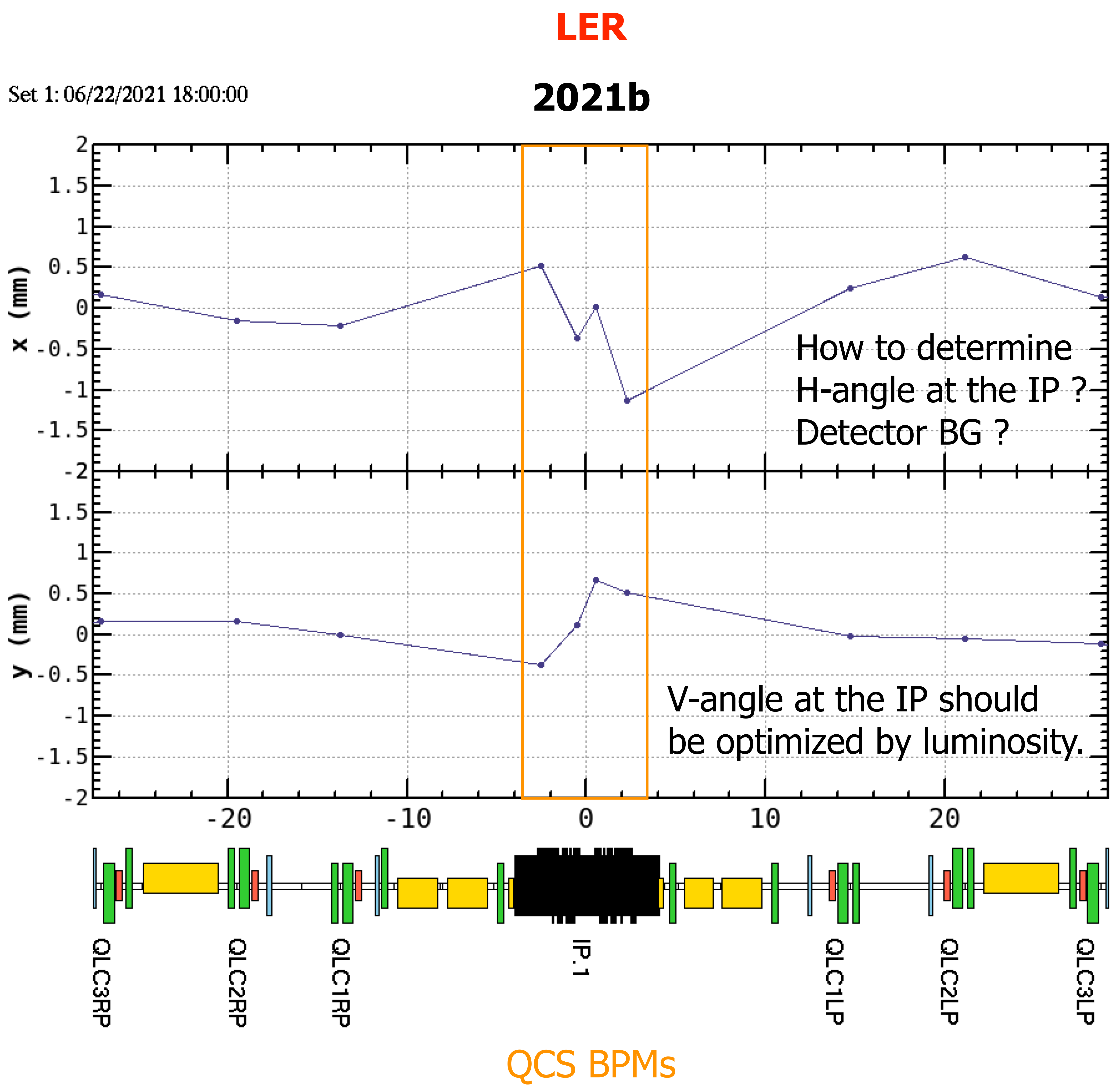


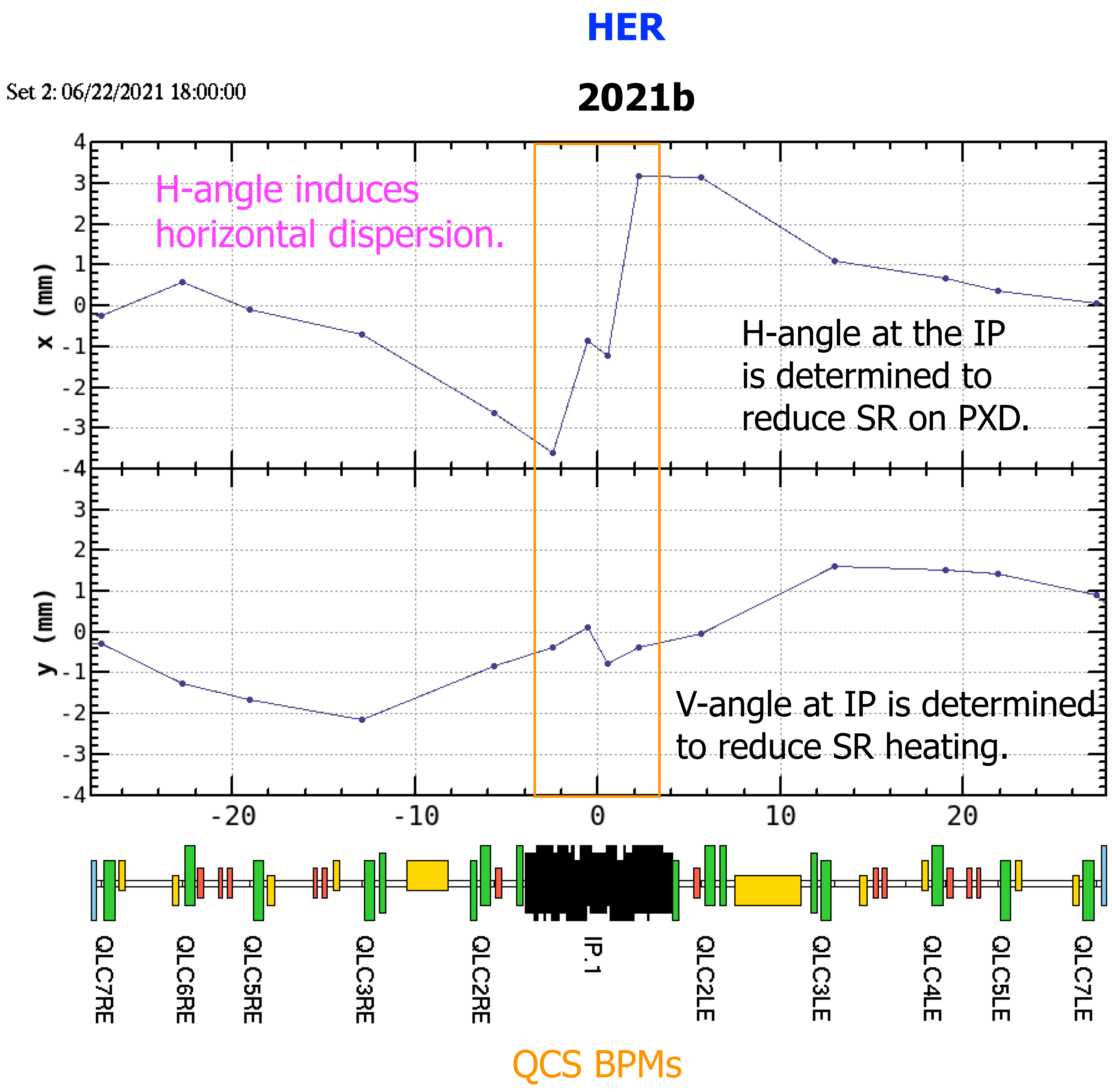
June 18 (after)



Orbit distortion due to IP knob ON and OFF becomes small after using ZHQC1RP (one of QCS horizontal dipole correctors) .

The orbit in the vicinity of IP is reasonable ?

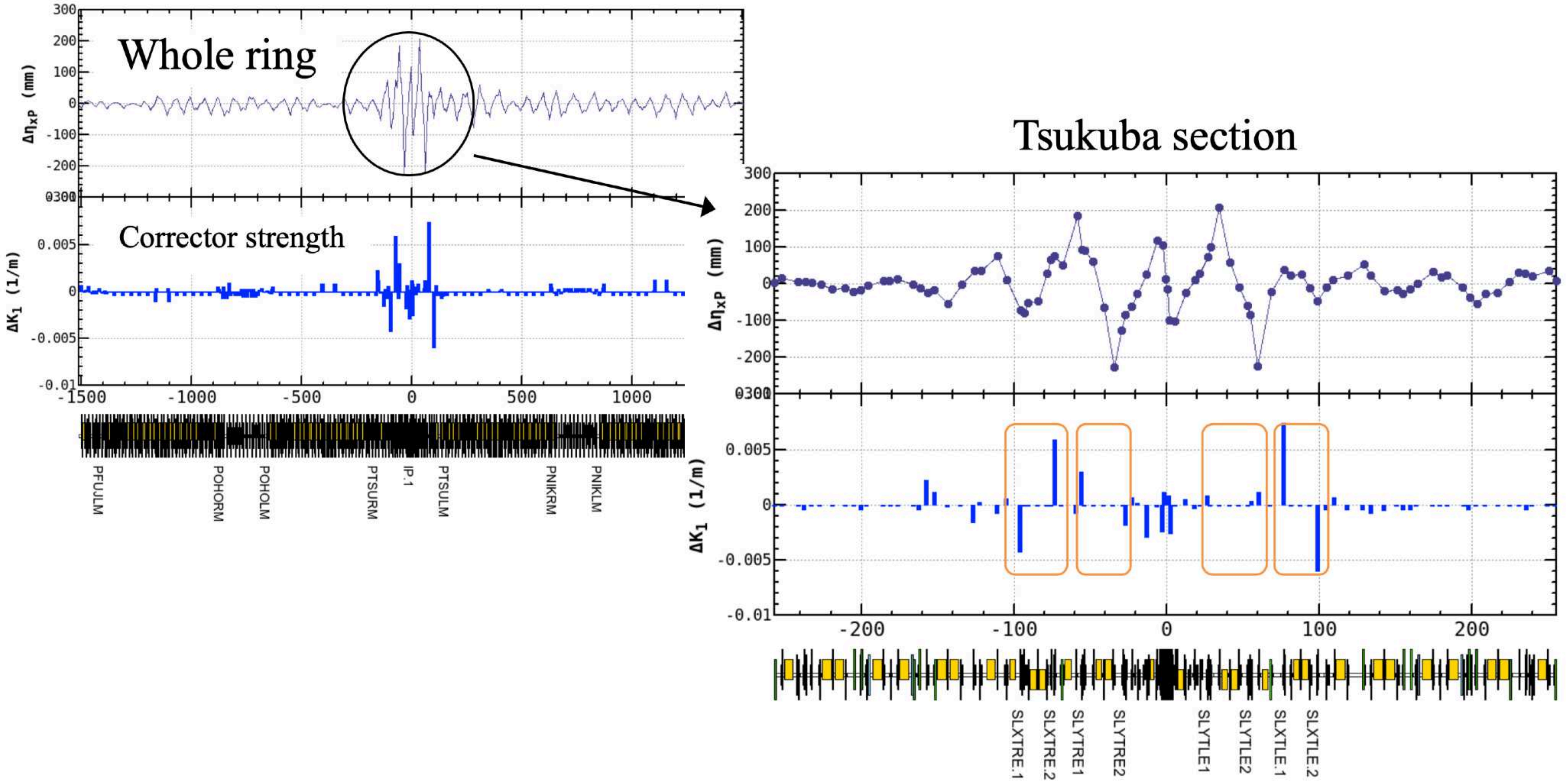


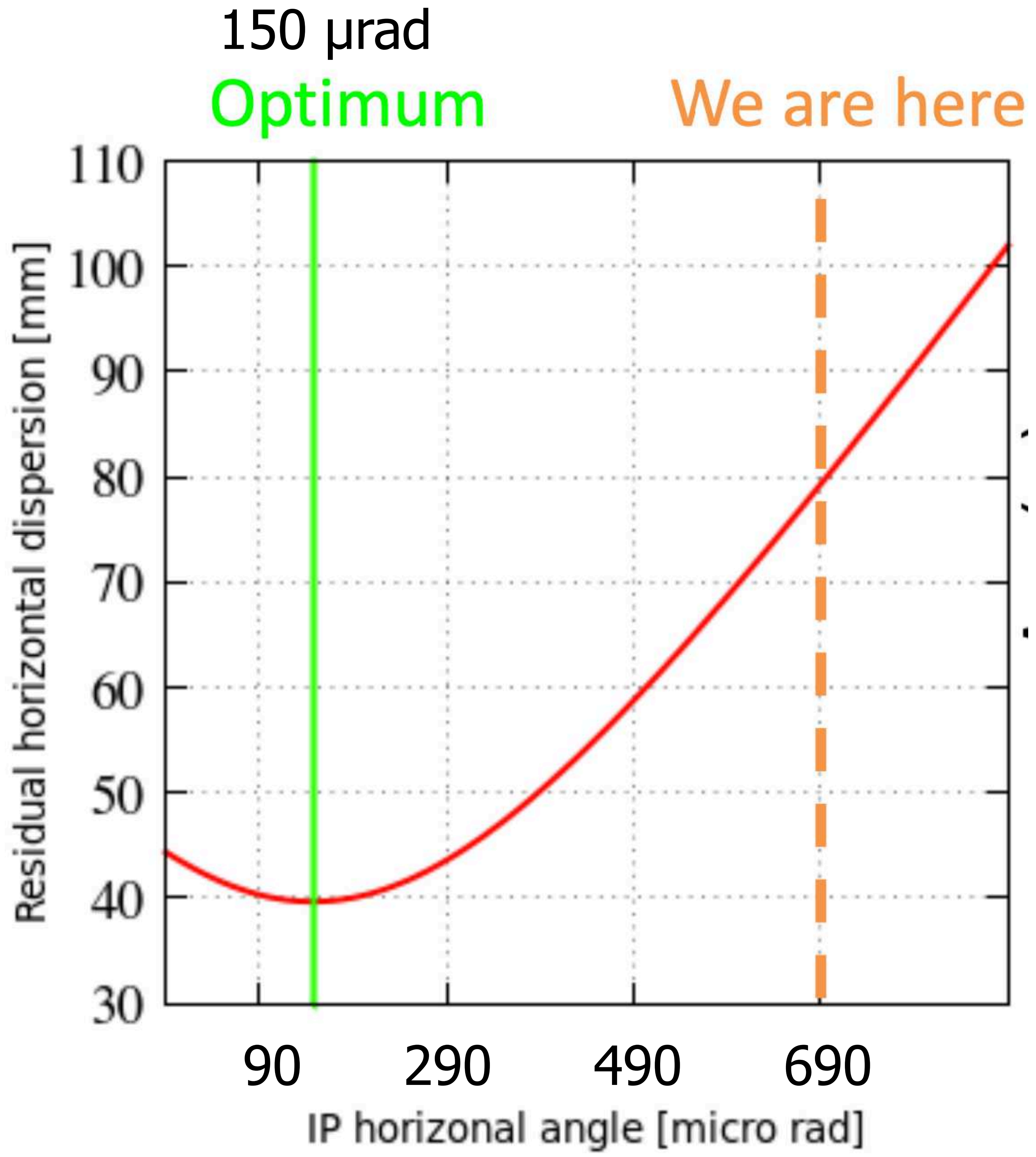


Horizontal Angle at the IP and Horizontal Dispersions in the HER

H. Sugimoto

Horizontal angle at the IP is 690 μrad to reduce SR background on PXD.
Horizontal dispersions induced by the orbit are corrected in the Tsukuba section by using quadrupole magnets near the LCC sextupoles.





2020/05/11

Estimated $\Delta\eta_p$@PSL* [mm]

PSLYTLC.1 :	78.6 /	-0.1
PSLYTLC.2 :	-77.3 /	-0.6
PSLXTLC.1 :	36.6 /	1.3
PSLXTLC.2 :	-43.3 /	-1.2
PSLXTRC.1 :	-75.4 /	1.5
PSLXTRC.2 :	75.5 /	-1.4
PSLYTRC.1 :	93.0 /	-3.7
PSLYTRC.2 :	-95.0 /	1.0

Expected after the correction

Estimated $\Delta\eta_p$@PSL* [mm]

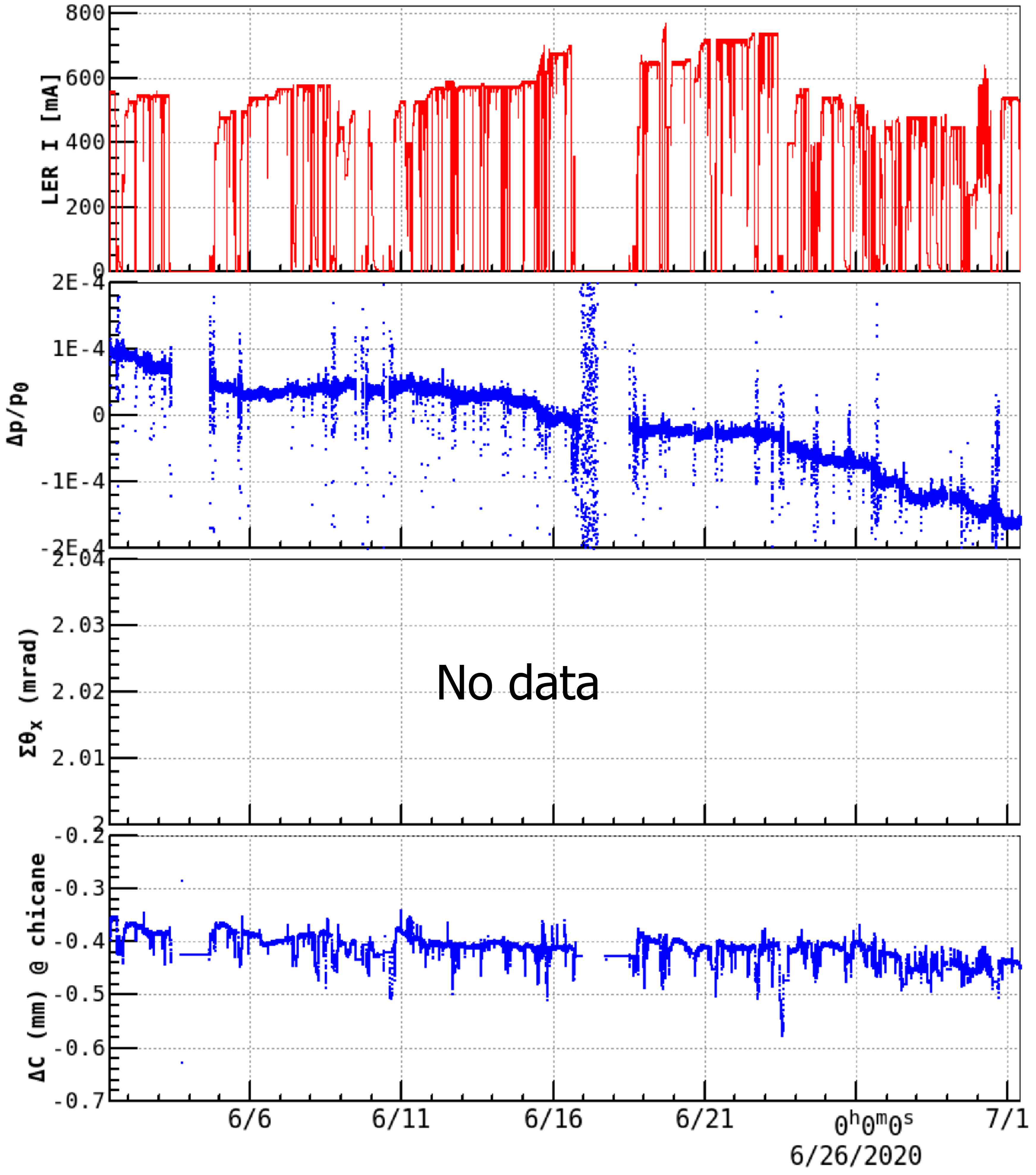
PSLYTLC.1 :	9.6 /	-0.1
PSLYTLC.2 :	-8.3 /	-0.6
PSLXTLC.1 :	6.7 /	1.3
PSLXTLC.2 :	-13.3 /	-1.2
PSLXTRC.1 :	-22.9 /	1.5
PSLXTRC.2 :	23.1 /	-1.4
PSLYTRC.1 :	38.9 /	-3.7
PSLYTRC.2 :	-41.0 /	1.0

The optimized horizontal angle is 150 μrad at the IP.
The rms residual dispersion will reduce from 33 mm to 14 mm.
The residual dispersion at the LCC sextupole is also reduced.

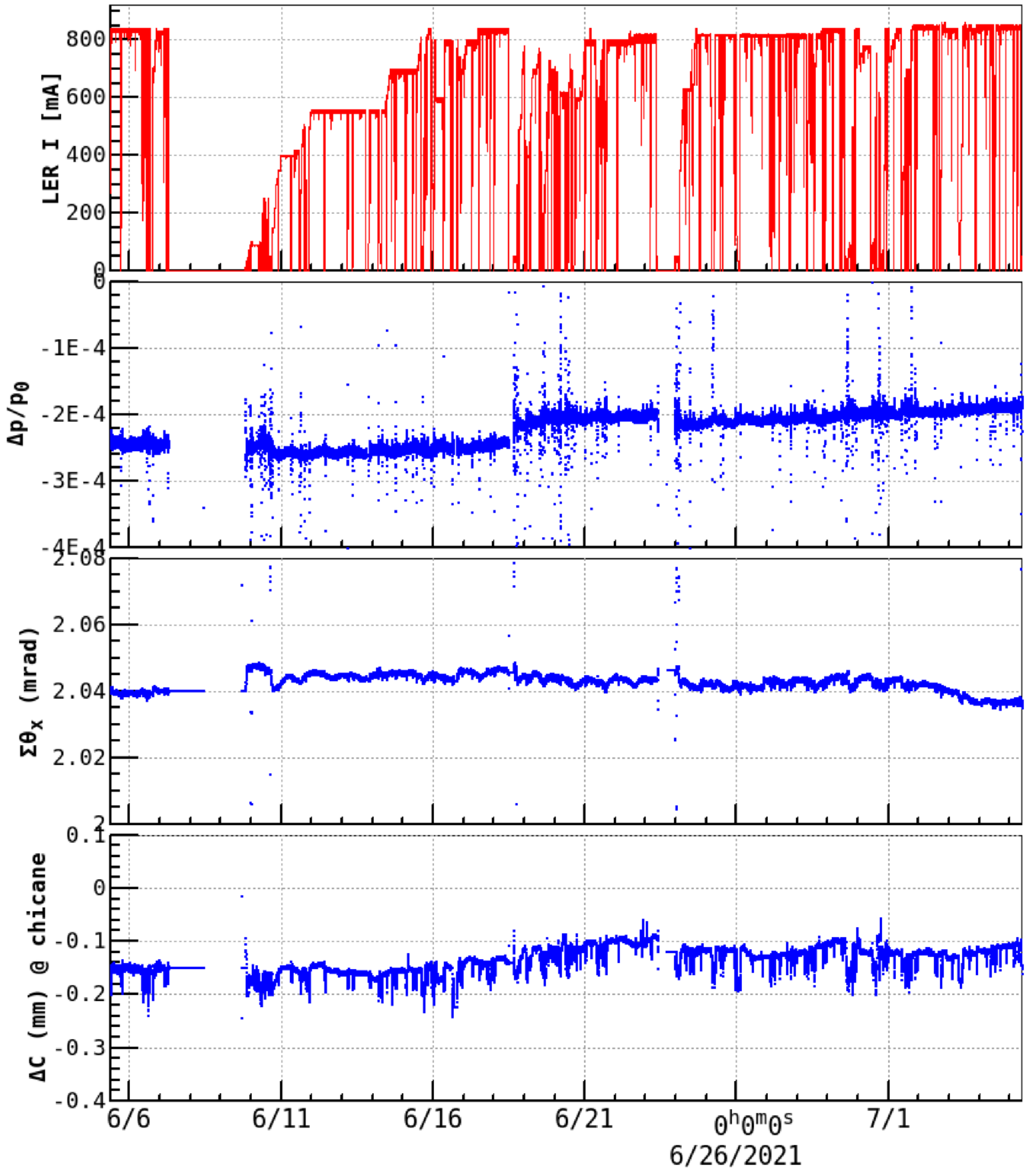
We changed the horizontal orbit correction algorithm.
The integrated horizontal kick angle was not constant sufficiently before 2021a due to poor accuracy of convergence. So we modified the algorithm to guarantee the constant value for the total horizontal kick angle.
(We had minor bug at the beginning of 2021ab, we fixed the bug.)

2020b

LER



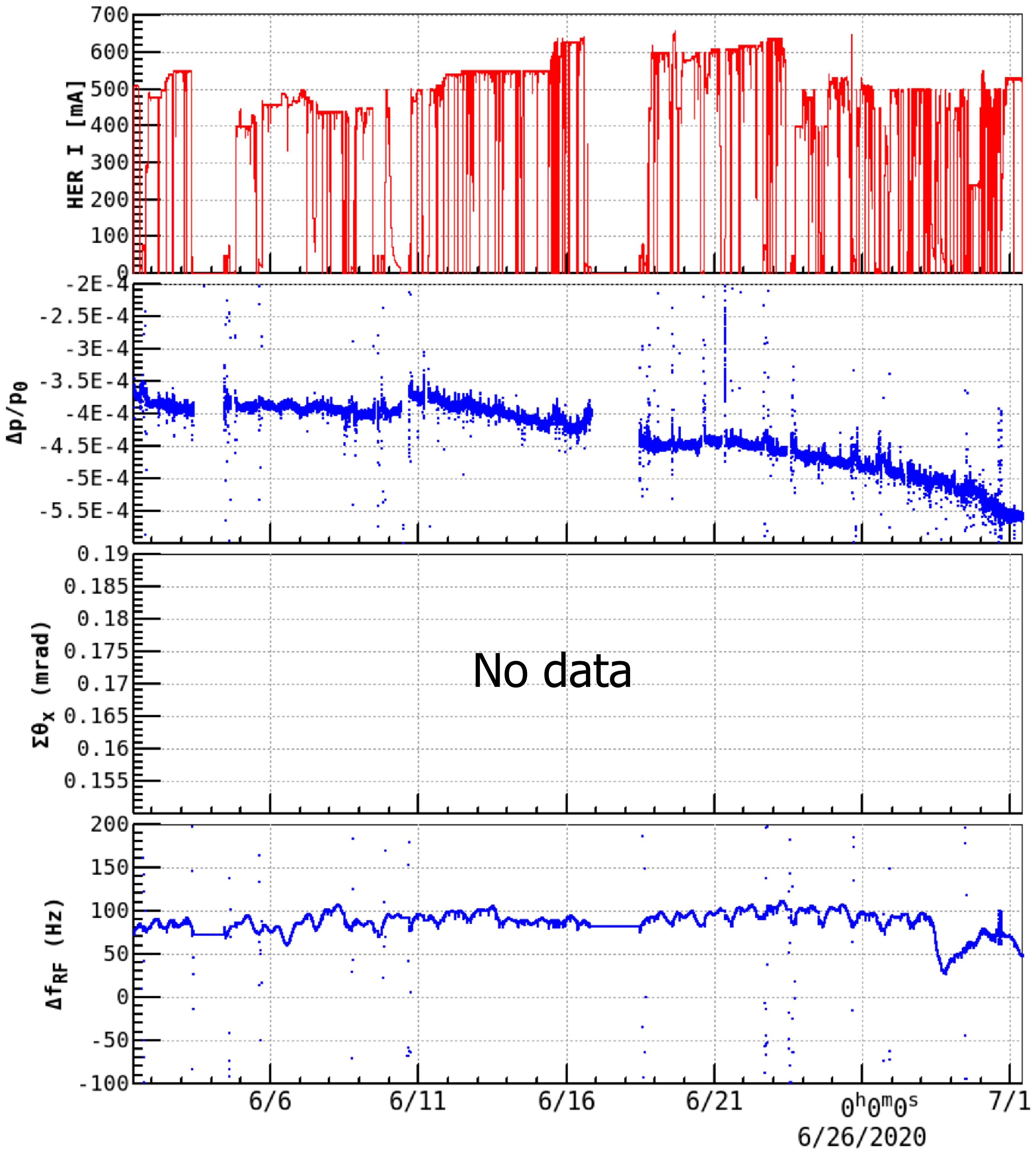
2021b



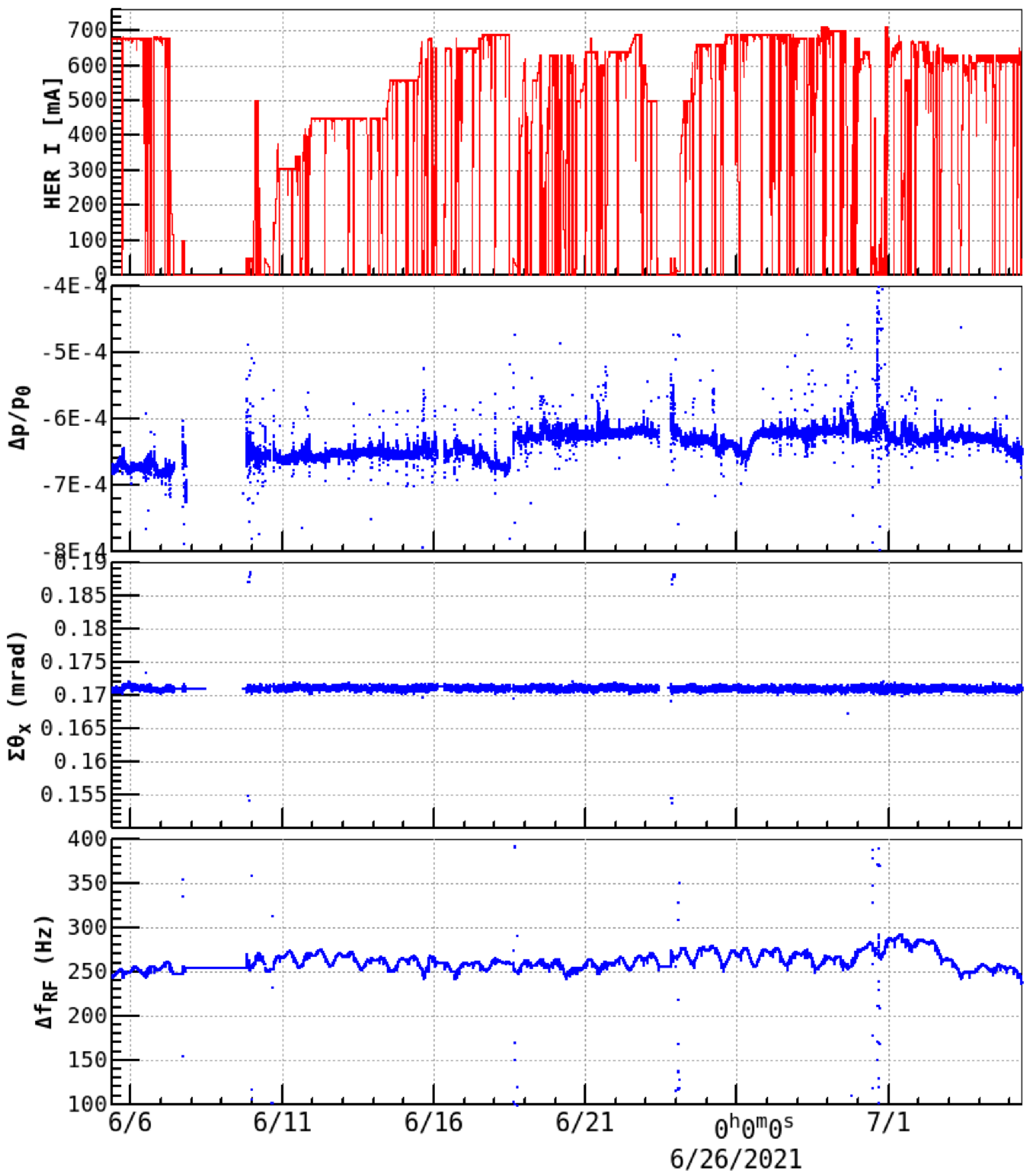
The momentum deviation becomes almost constant.

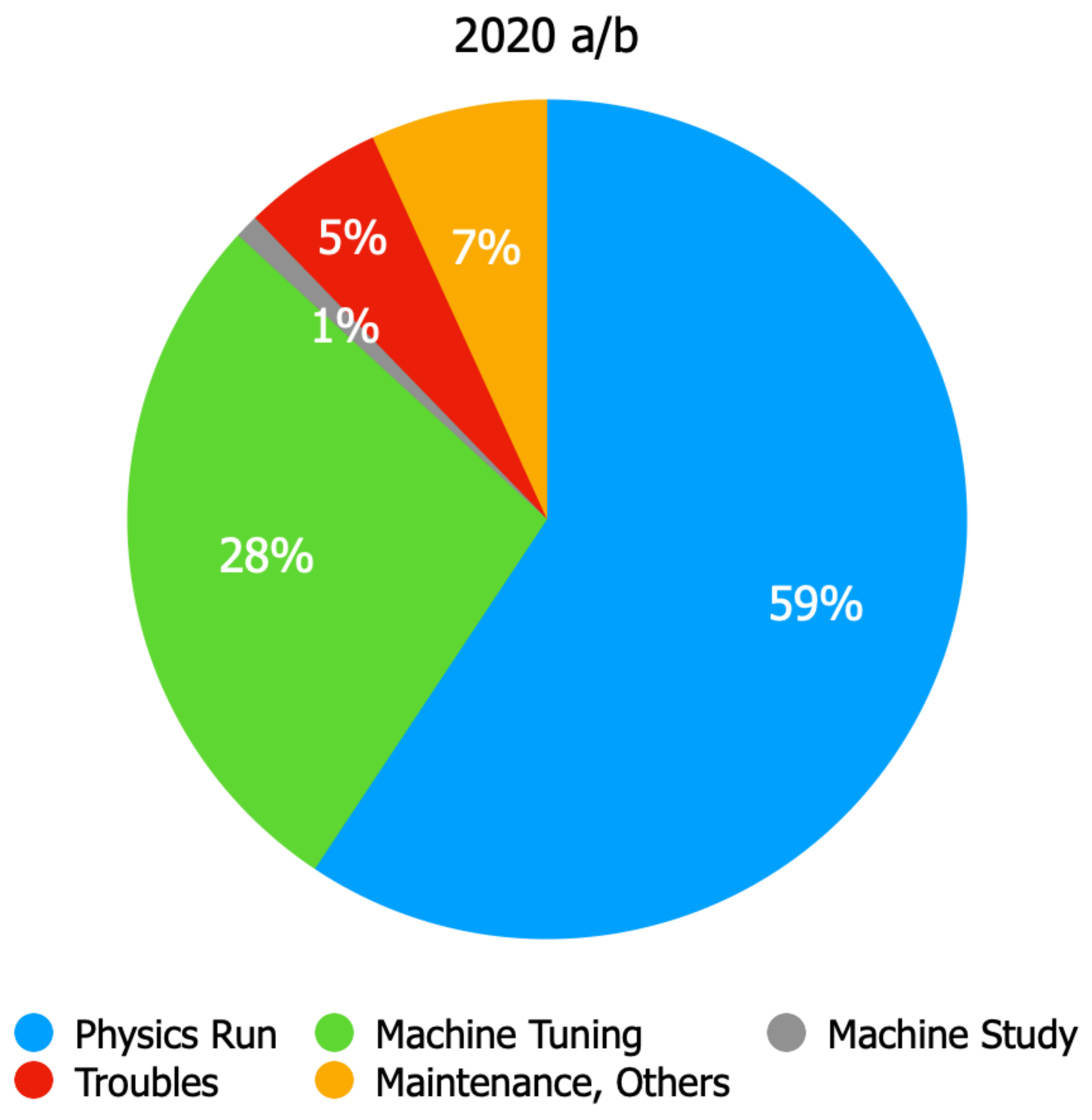
HER

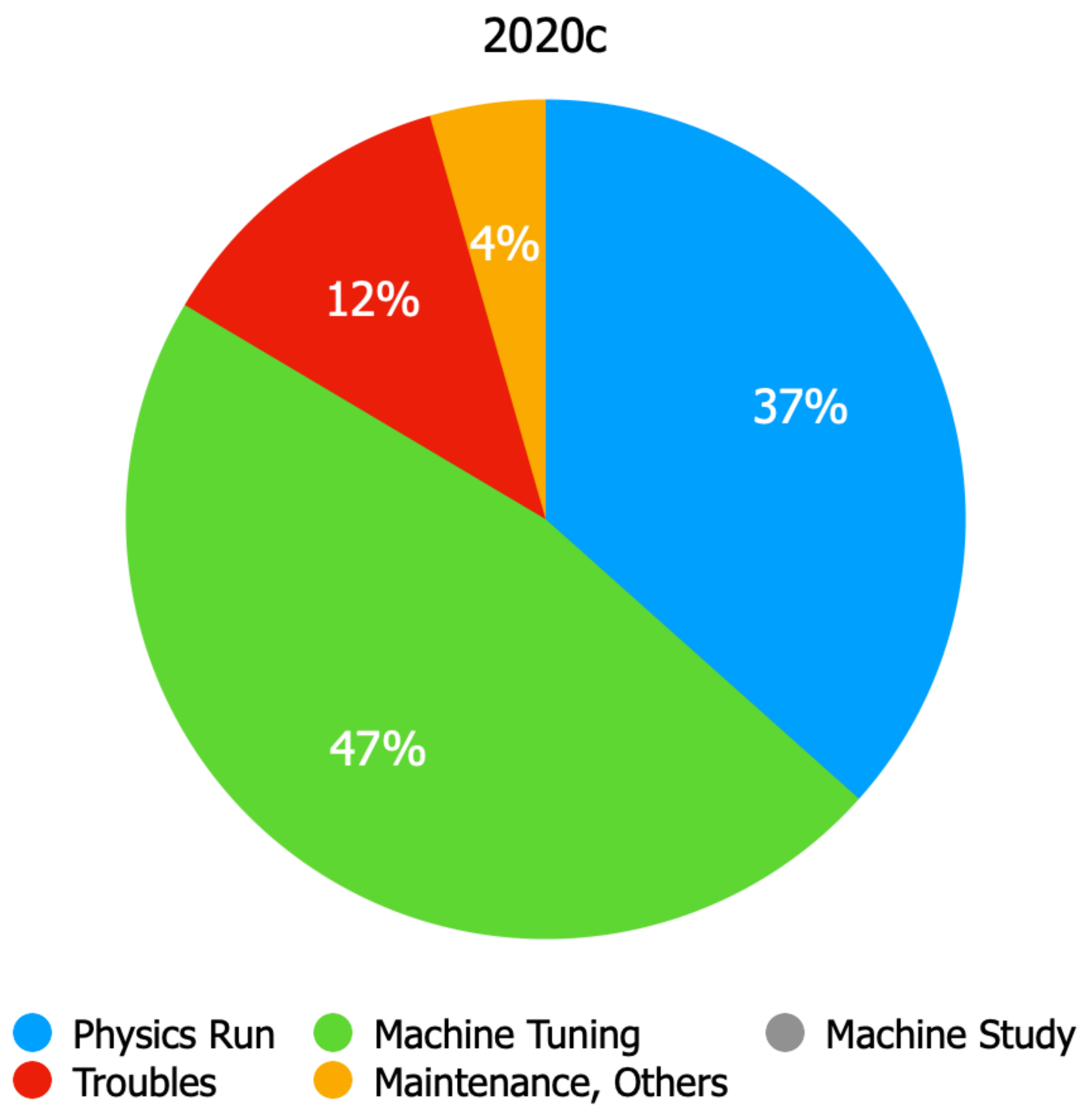
2020b



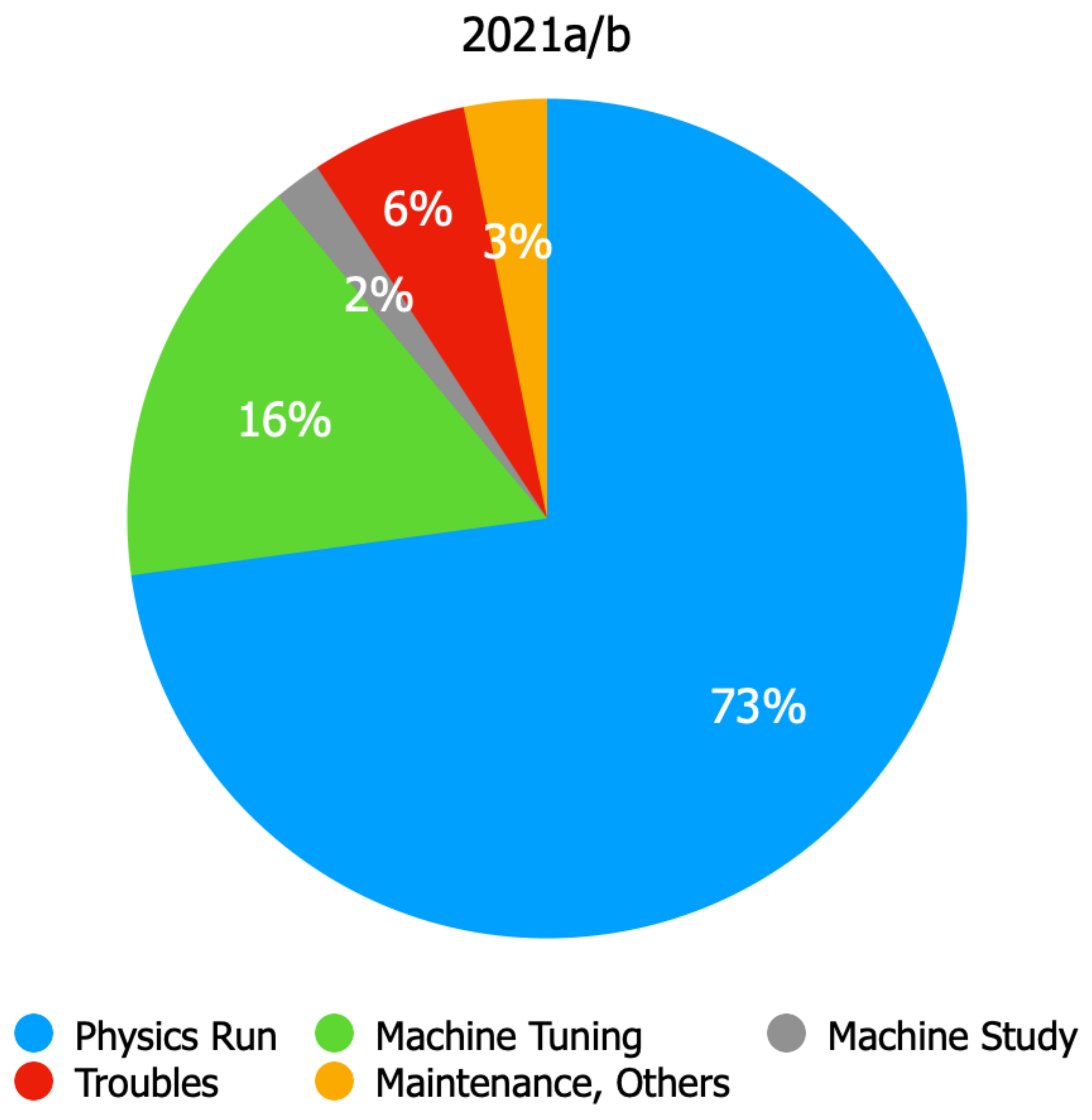
2021b







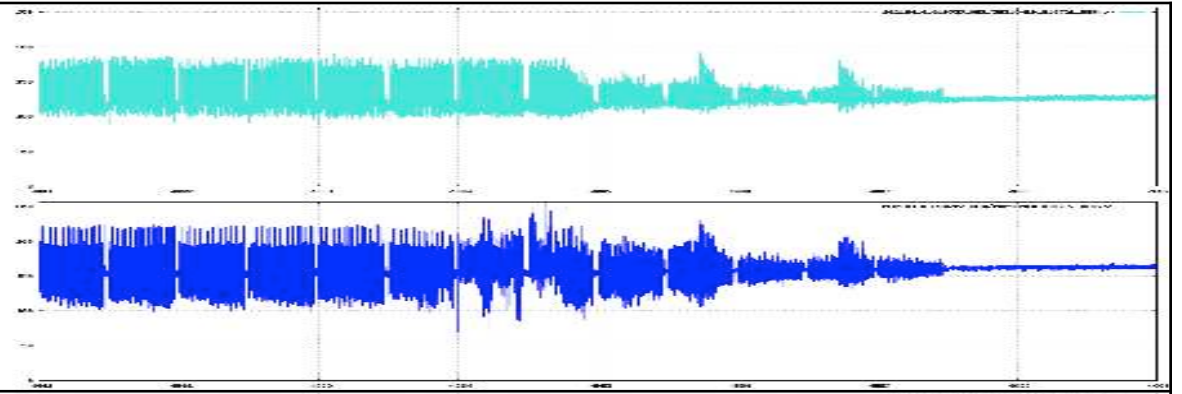
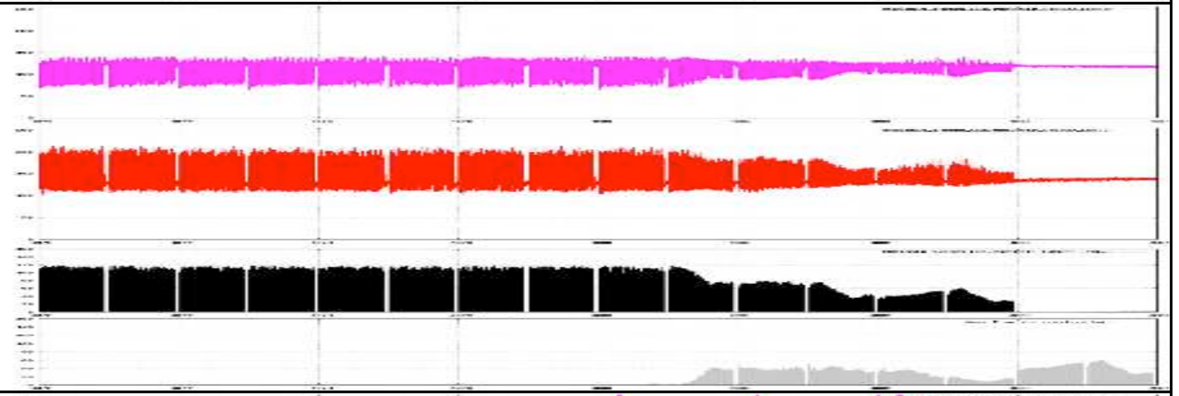
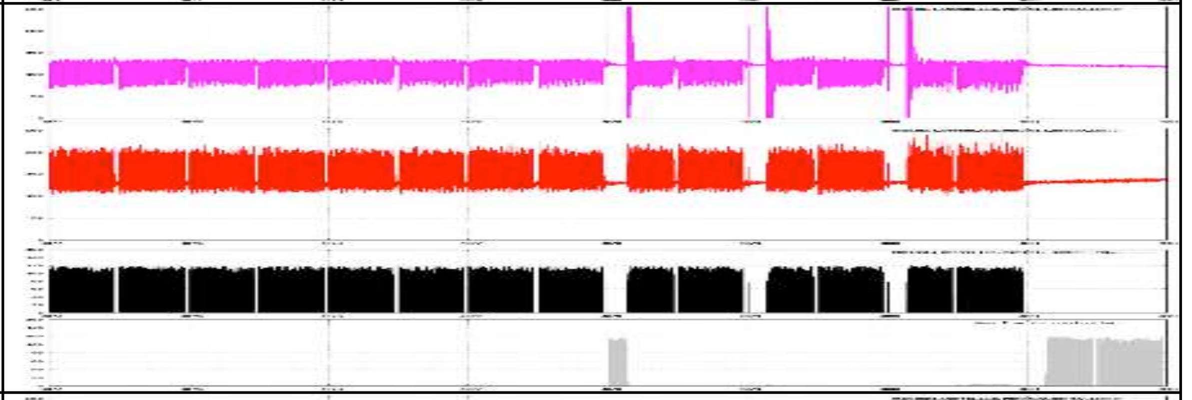
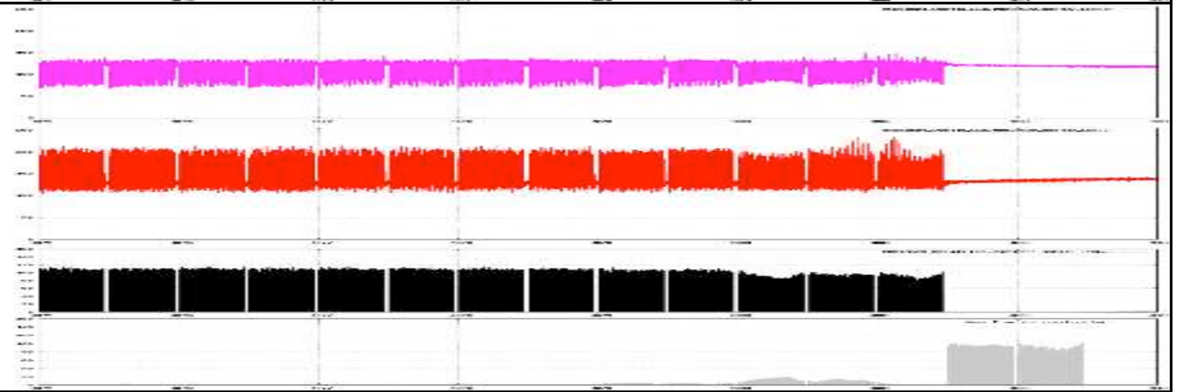
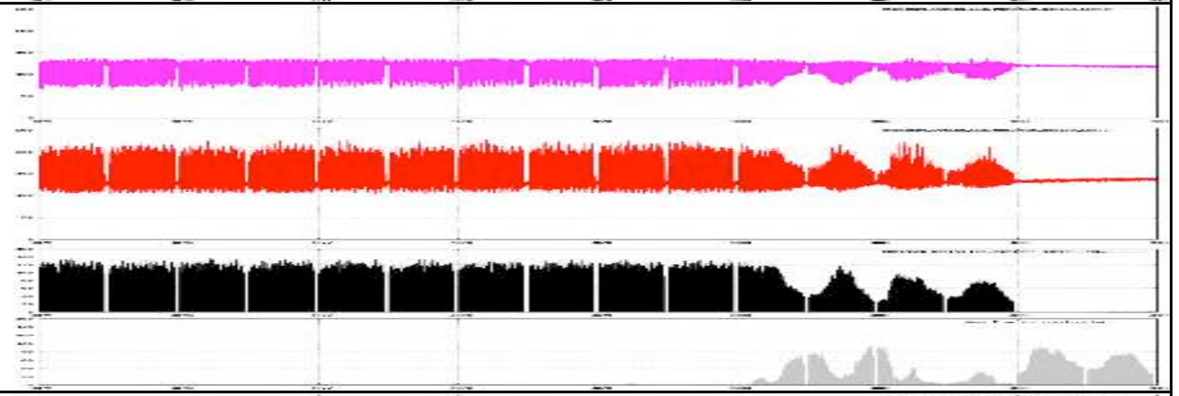
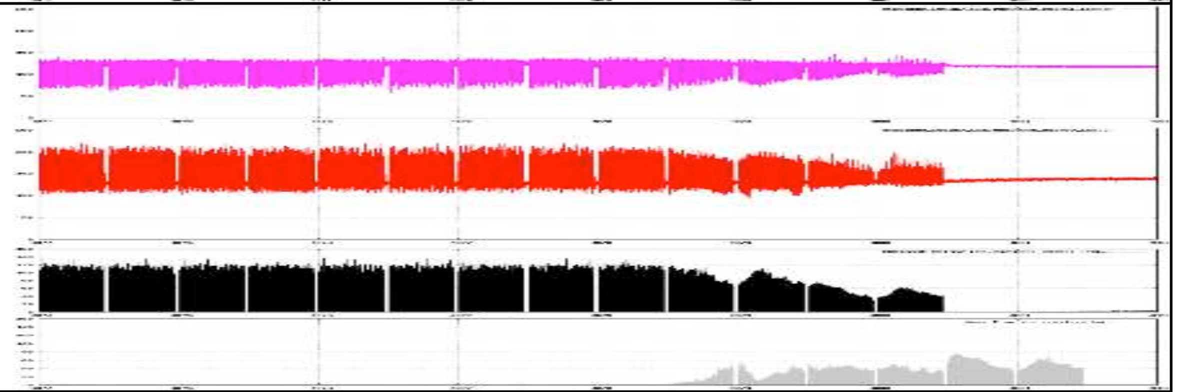
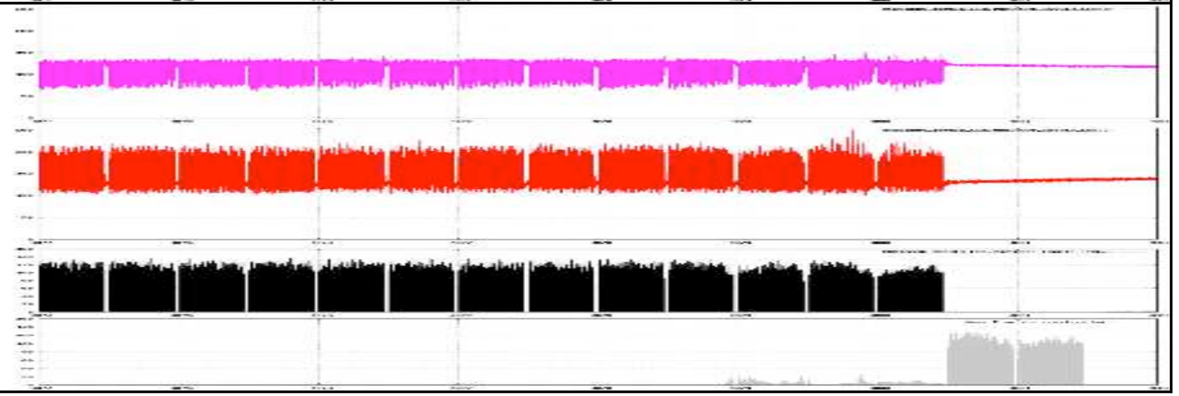
Maintenance day is every two weeks.
Maintenance is usually until 17:00, the injection tuning for SuperKEKB starts following PF and PF-AR.
Startup with stable operation of injector linac is a key to resume SuperKEKB as quickly as possible.



We developed a resumption strategy to reduce machine tuning at a startup after maintenance.

QCS Quench
and
Collimator Damage

QCS Quench List (except for earthquake and PS trouble)

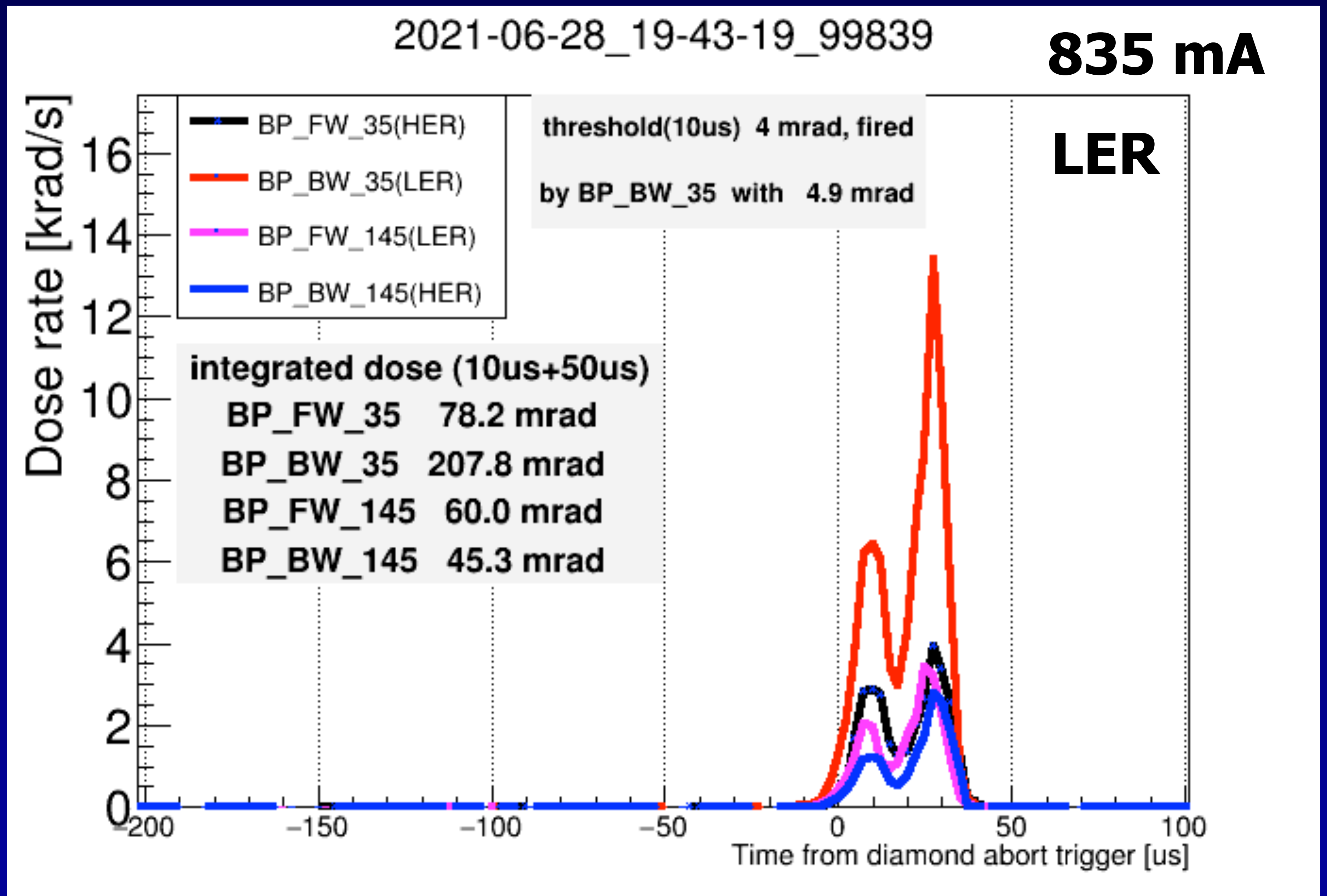
4/19 (MO) Owl	1:07	HER QC1LE	LER: 836 mA / HER: 819 mA HER D09V1 damaged	
5/10 (MO) Day	14:26	LER QC1LP, QC1RP	LER: 906 mA / HER: 726 mA LER D02V1 damaged	
5/14 (FR) Owl	0:35	LER QC1RP	LER: 837 mA / HER: 679 mA **LER kicker misfire**	
5/23 (SU) Owl	8:24	LER QC1LP, QC1RP	LER: 836 mA / HER: 678 mA LER D06V1 damaged	
5/28 (FR) Owl	3:21	LER QC1RP	LER: 834 mA / HER: 677 mA LER D06V1 damaged	
6/2 (WE) Swing	20:13	LER QC1LP, QC1RP	LER: 840 mA / HER: 678 mA LER D02V1 damaged	
6/6 (SU) Day	16:06	LER QC1LP, QC1RP	LER: 838 mA / HER: 677 mA	

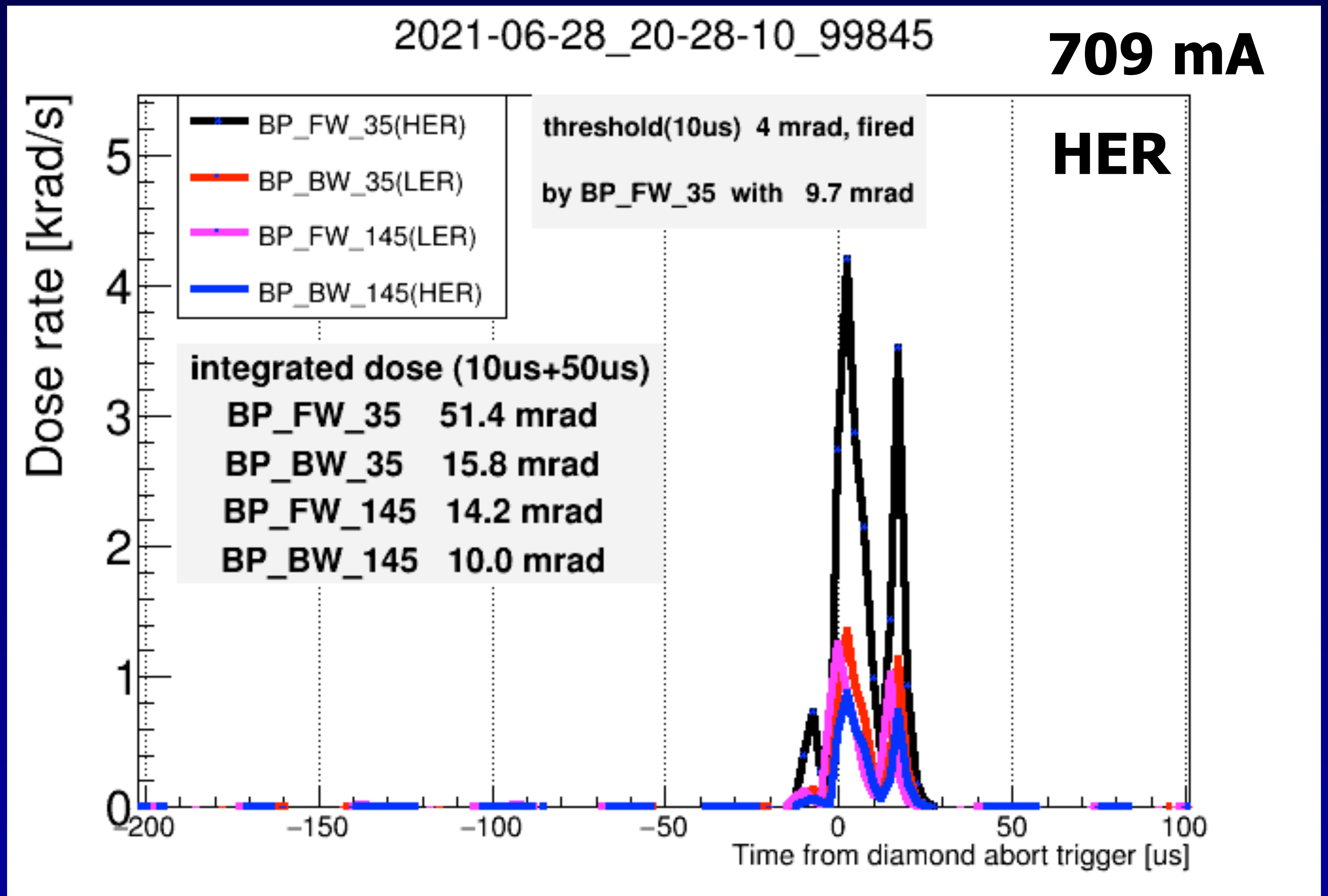
LER and HER Abnormal Beam Abort

H. Nakayama

typical samples

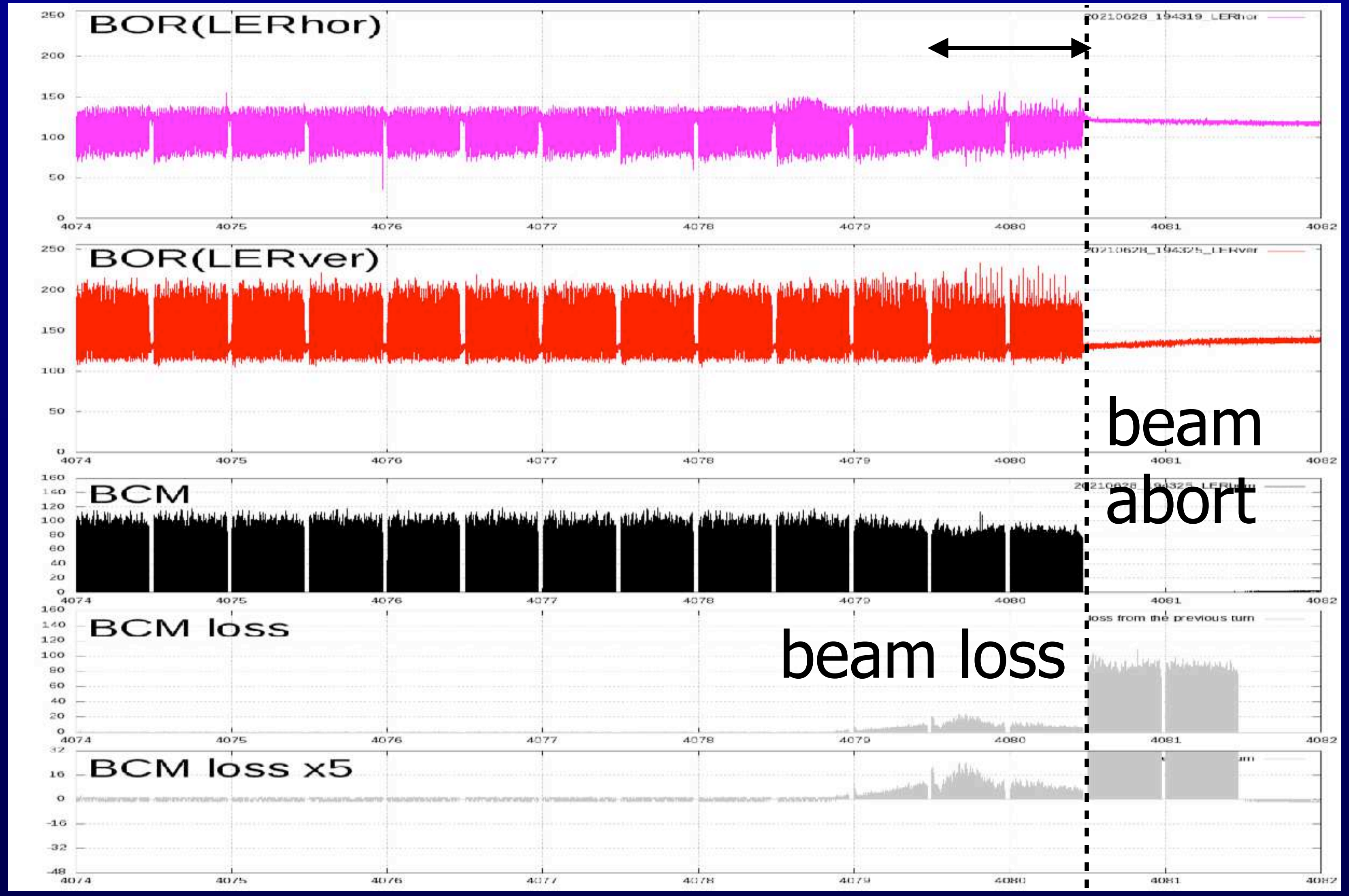
Beam dose at IP beam pipe



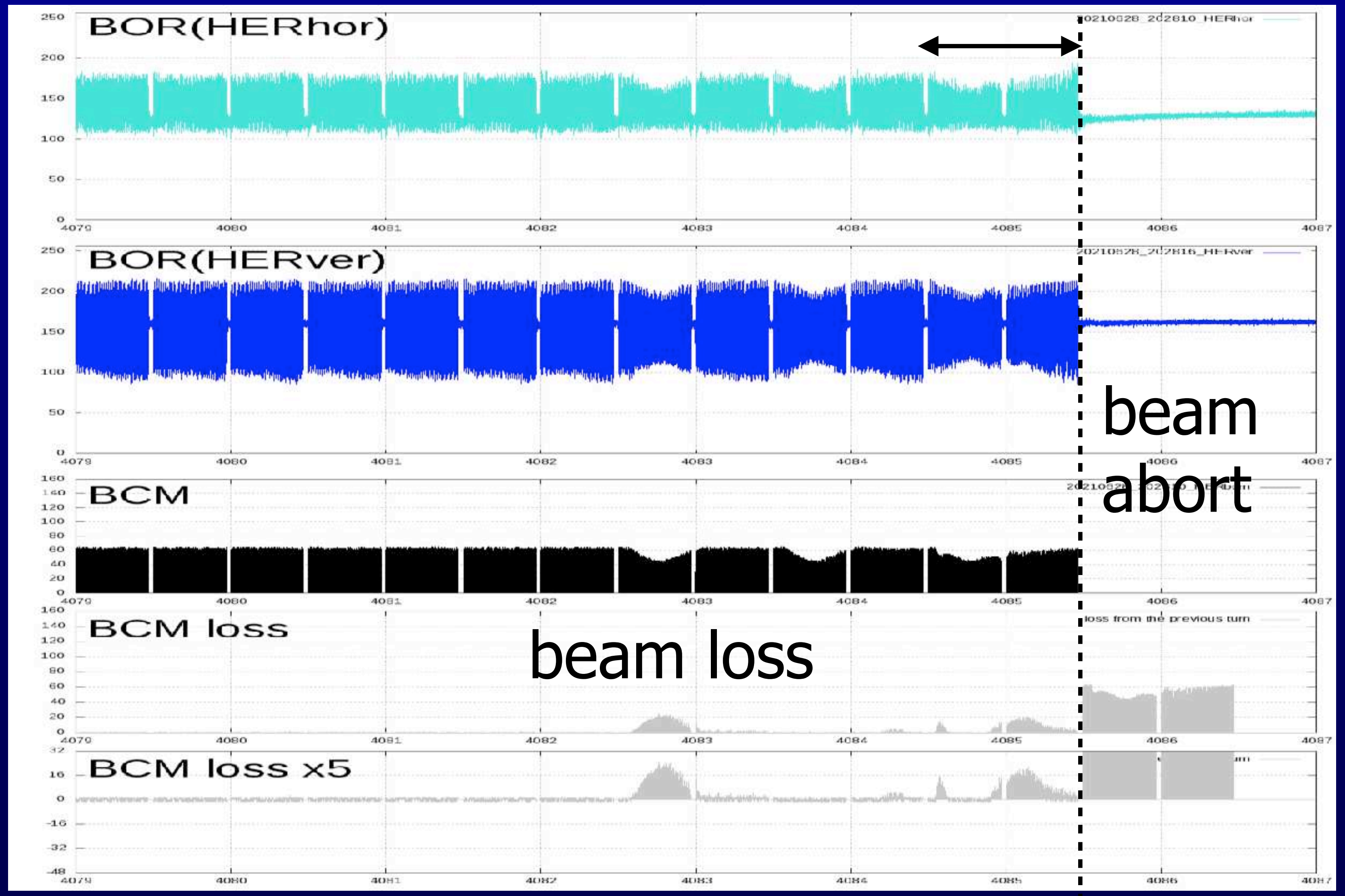


TBT orbit measurement
4096 turns for every bunches

one turn



one turn



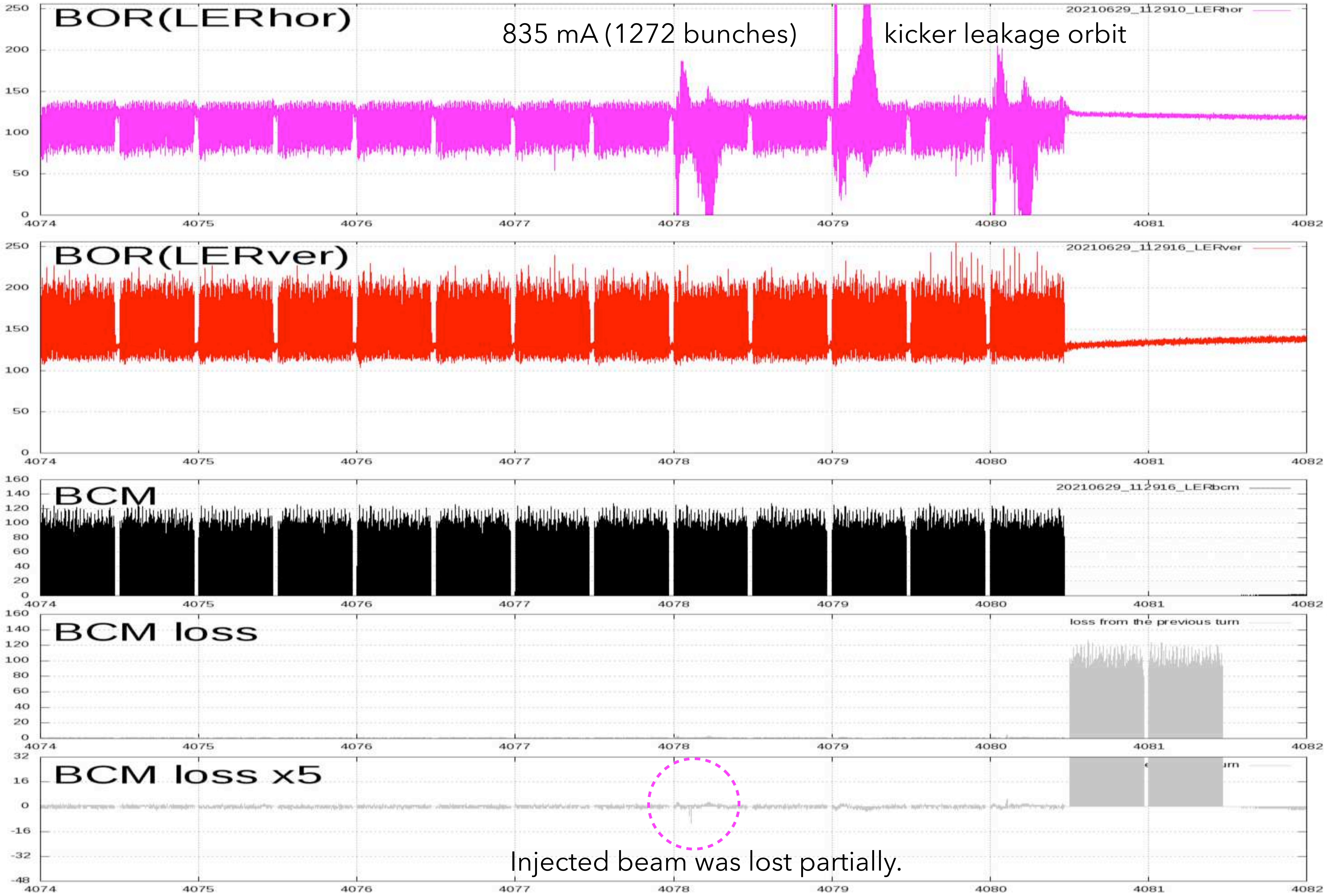
← **Horizontal orbit** →

← **vertical orbit** →

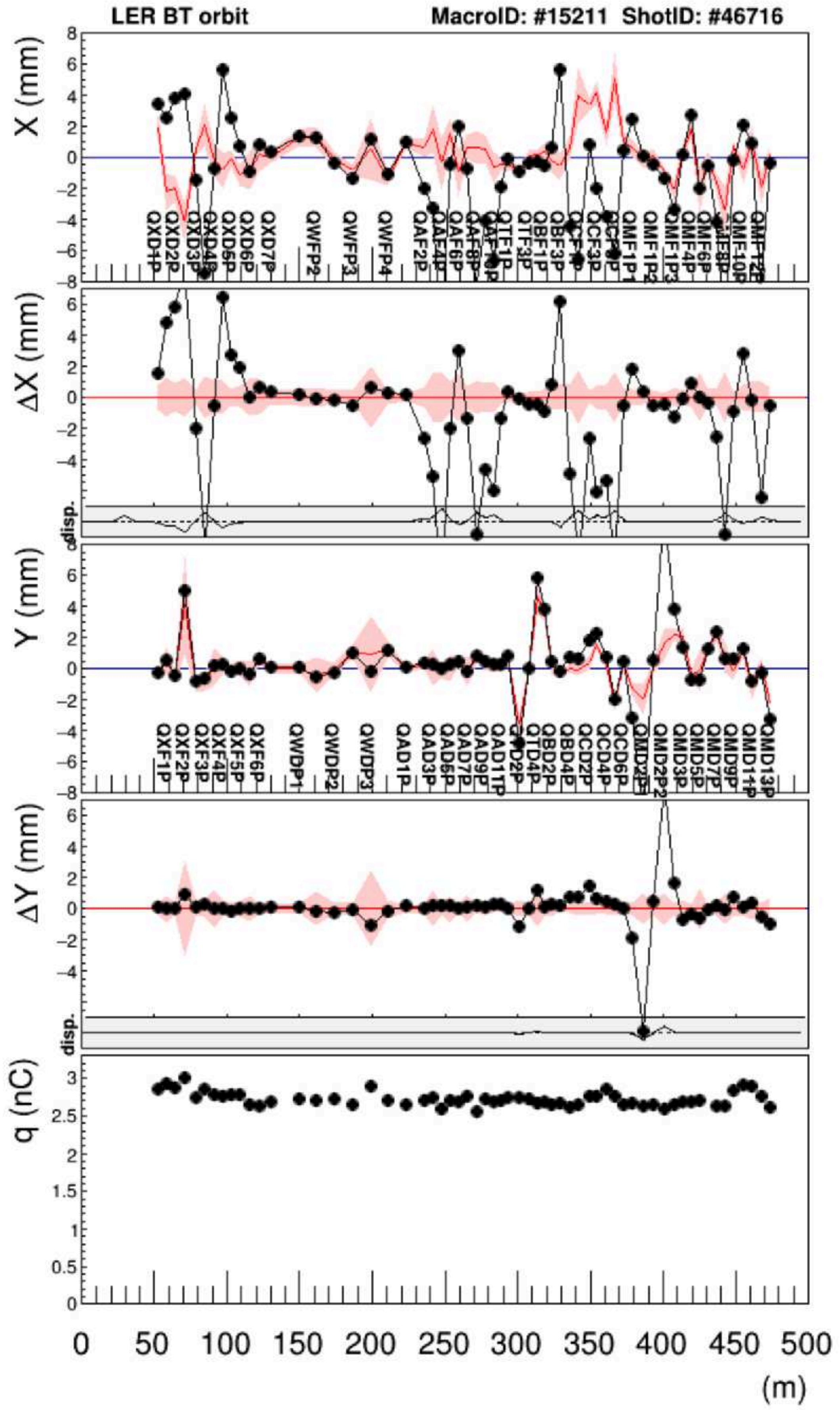
← **bunch current** →

- **No orbit oscillation**
- **Very fast beam loss within a few turns**

Beam Abort due to Injection Beam



Orbit in beam transport line
Energy deviation was large.

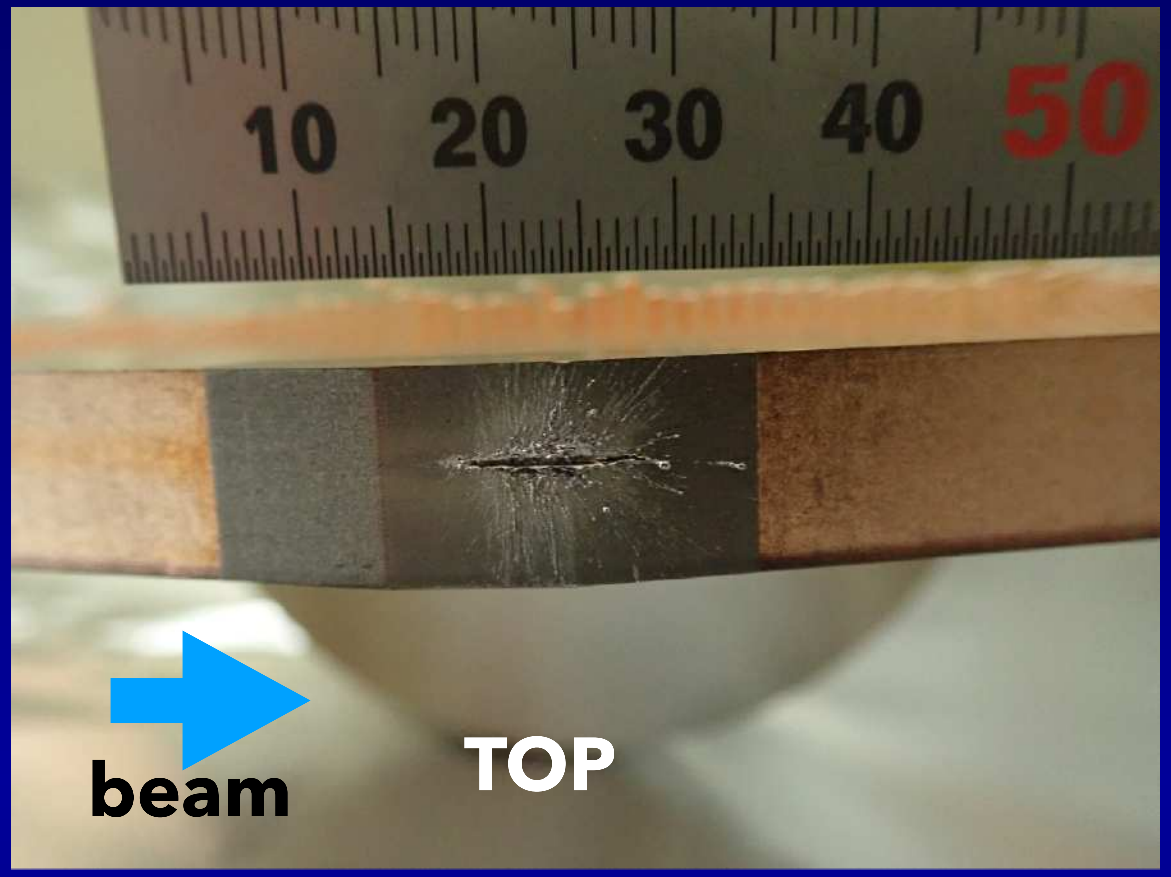


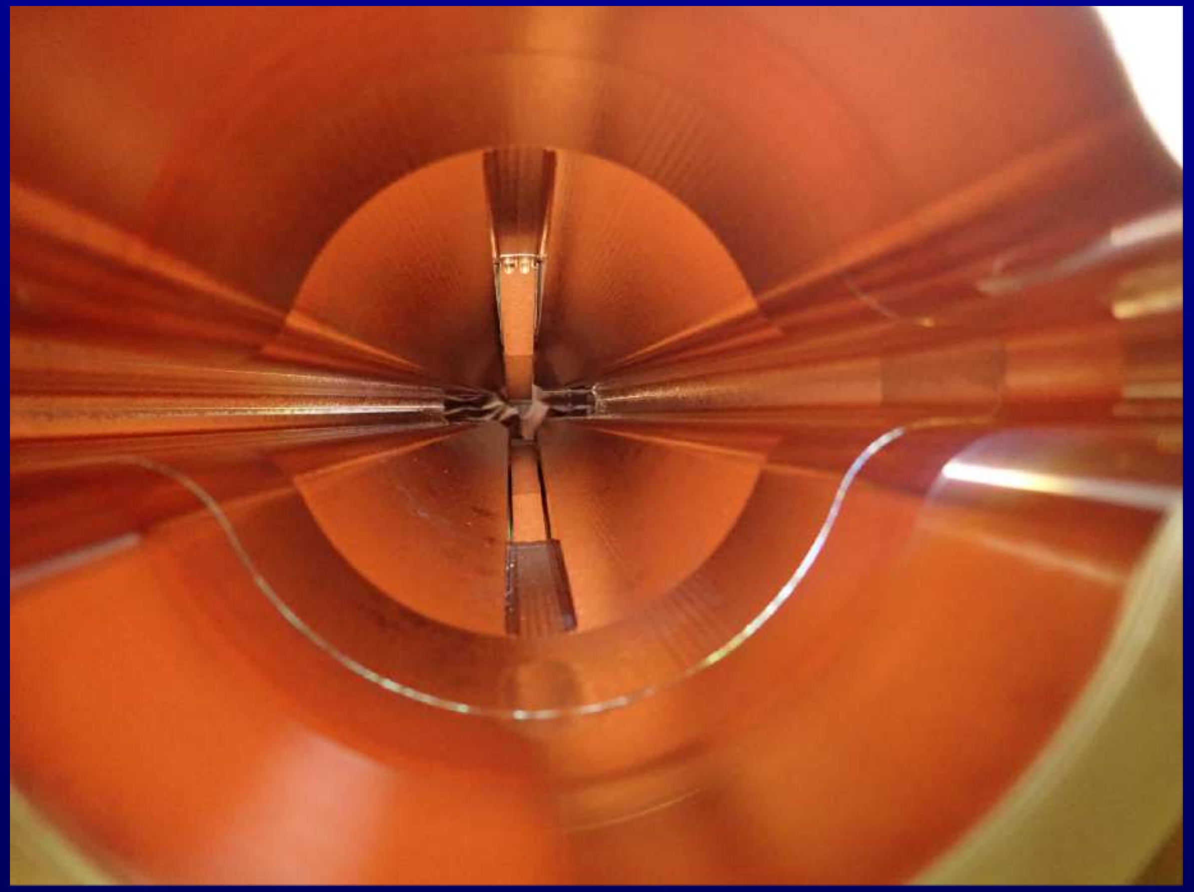
H. Nakayama
H. Kaji

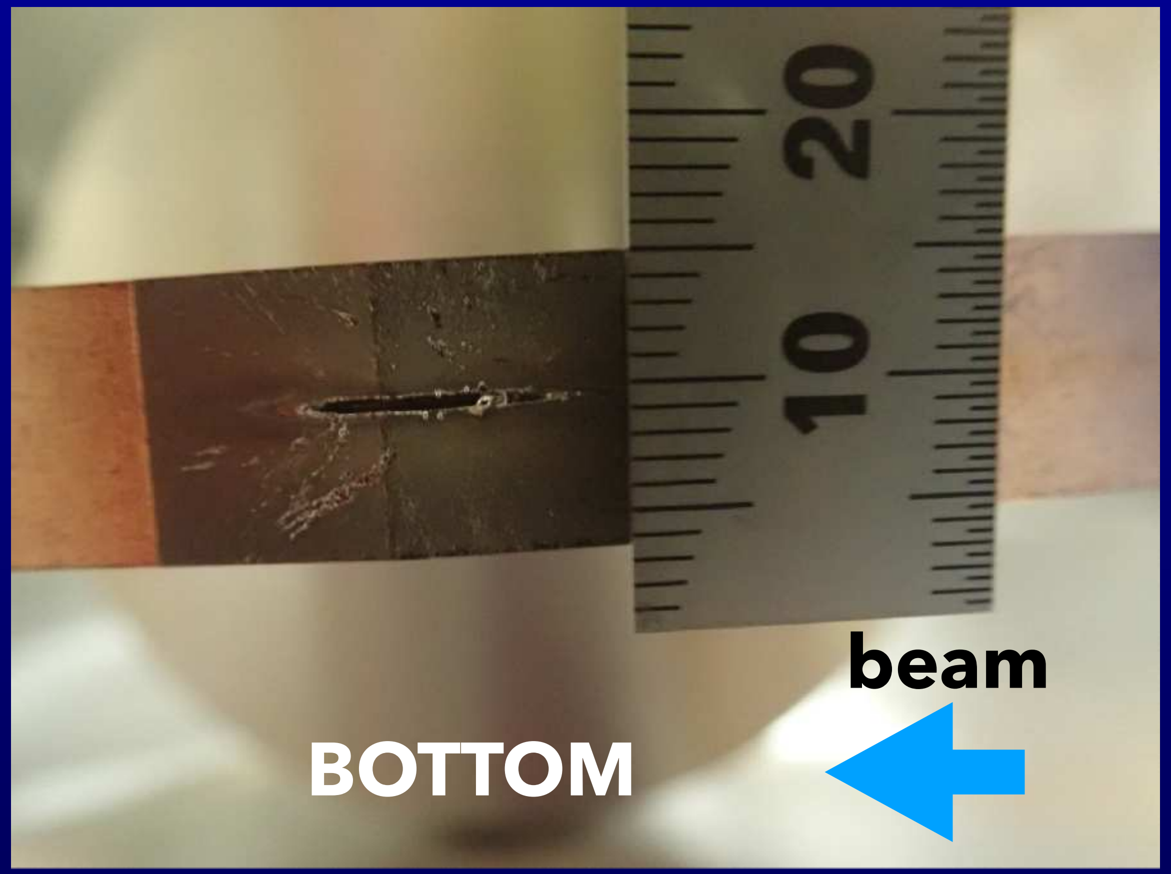
Movable collimator to reduce beam background

S. Terui
T. Ishibashi
Y. Suetsugu

Damage due to beam loss



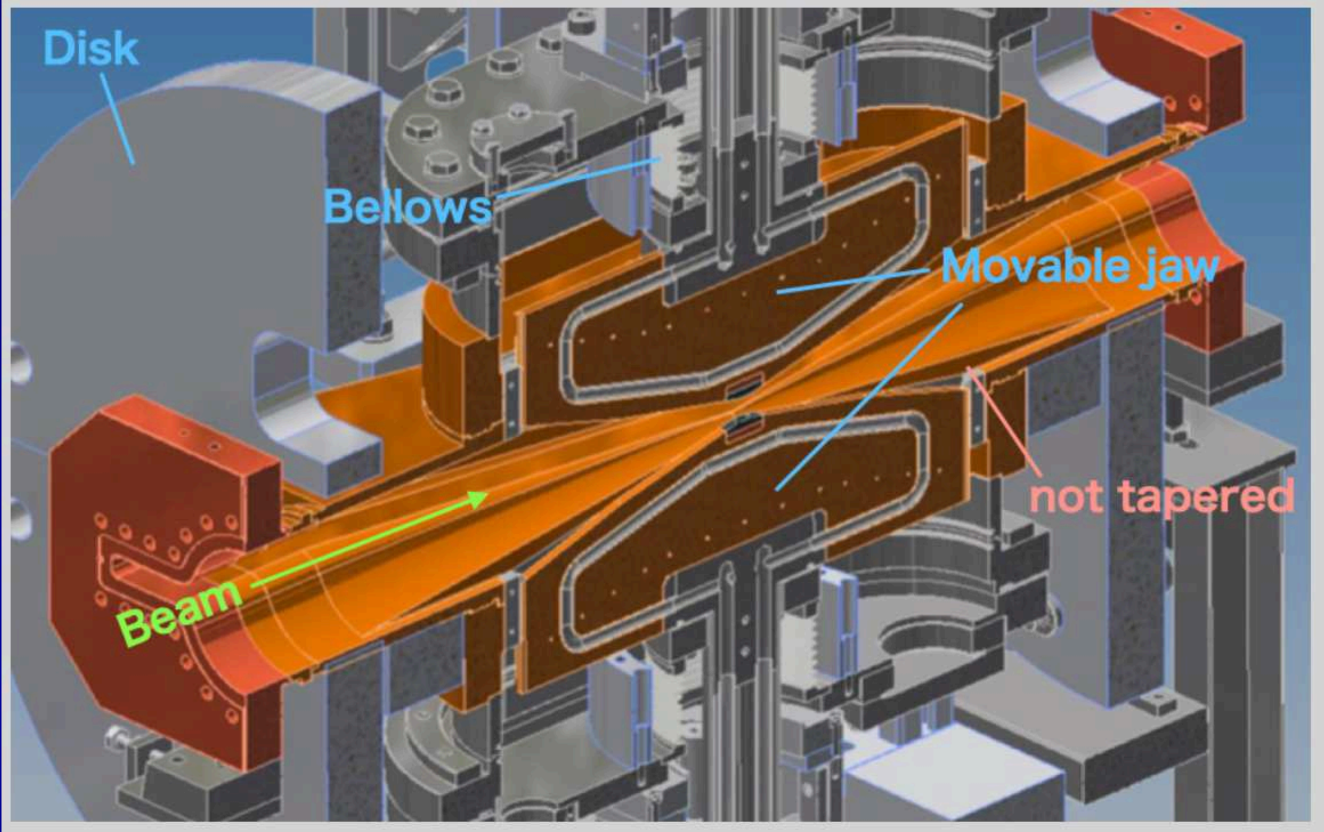




June 8, 2021

Vertical collimator: D02V1 (LER)

tantalum (Ta) head with 10 mm long tip



Horizontal collimator: D06H3 (LER)
tungsten (W)

Stored beams hit the collimator head due to misfire of injection kicker.

Summary of Machine Operation

1. Difficulties of increasing beam currents
   - Abnormal beam abort with beam loss; no oscillation, very fast beam loss within a few turns. Damaged collimator head enhances the aborts ?
   - Collimator aperture (physical aperture: PA) is narrow which is smaller than dynamic aperture (DA).
   - Short lifetime in the LER; Crab waist reduces DA. However, the aperture in the LER is PA = DA.
   - Lower "TMCI" threshold; 0.9 mA/bunch, large tune shift of single bunch ~0.013 > half of synchrotron tune in the LER
   - Synchro-beta resonance structure; good working area is small. Luminosity and DA is compatible ?
   - Injection kicker leakage orbit in the LER; It becomes a source of instabilities. Beam loss is proportional to stored beam current. We measured the beam loss owing to orbit oscillation using BOR.
   - BxB FB in the HER; noise effect (fixed) and feedback gain, feedback gain and luminosity.
   - Stabilities of linac injector; Many types of feedback system should work sufficiently. Stability of injection system; septum and kickers, especially HER septum behavior.
2. Beam-beam blowup
   - Effect of chromatic X-Y couplings is still unclear or IP knob is not sufficient. Rotating sextupoles in LER is effective.
   - Beam current ratio between LER and HER affects flip-flop of the beam size.
   - We prepare β_x^* = 60 mm lattice in LER (current β_x^* : 80 mm) to cure BBHT(XZ) if necessary.
3. Beta squeezing (not performed in 2021ab)
   - Down to 0.8 - 0.6 mm is necessary to improve luminosity. Training process is needed. (It takes time; see β_y^* = 1 mm)