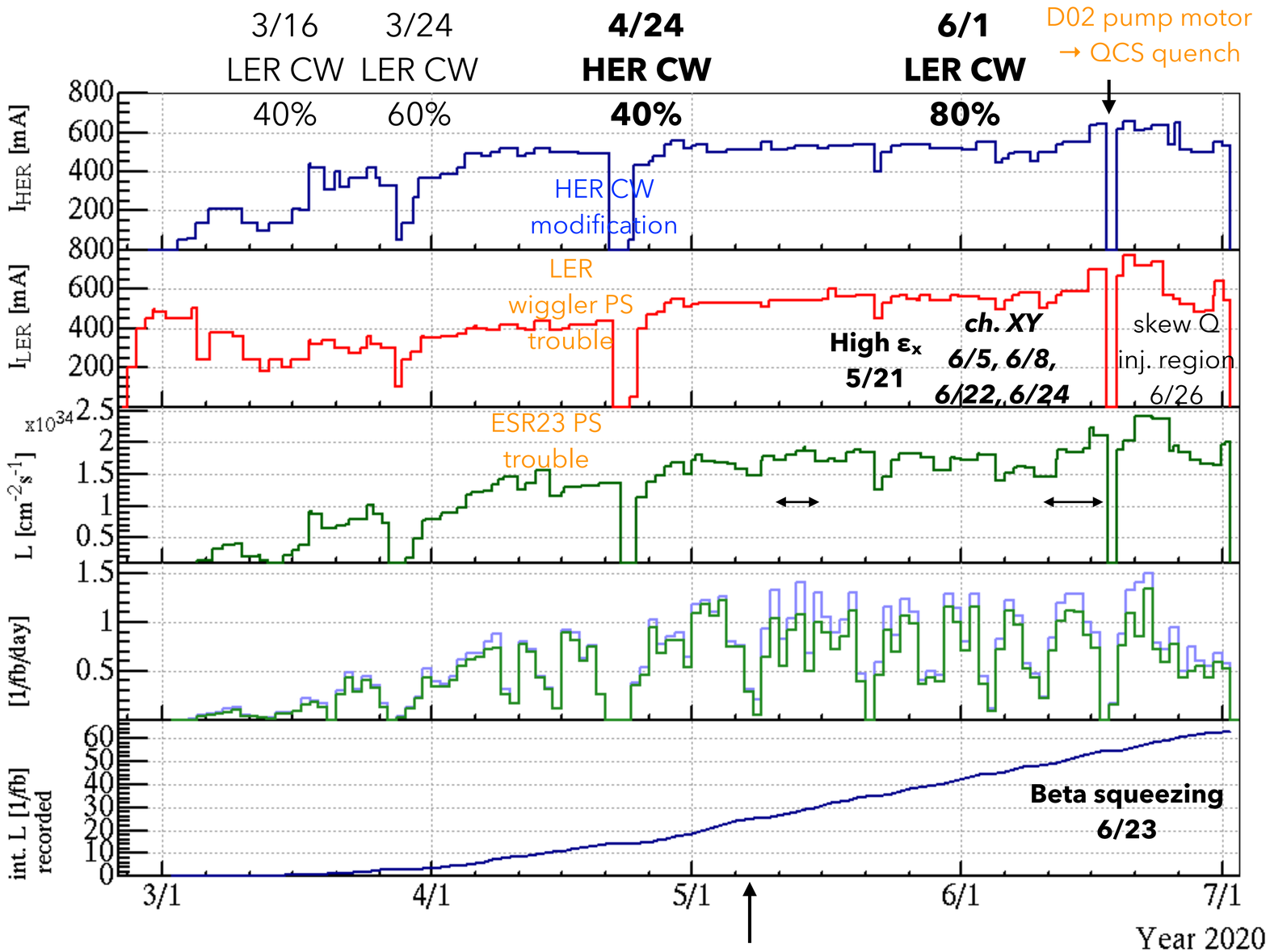
Overview of 2020a and b Run

February 25 - July 1, 2020

Y. Ohnishi

Operation Summary



LER started on Feb. 25

HER started on March. 2

Max. current
LER : 770 mA
HER : 660 mA

Peak luminosity : 2.4 x 10^{34} $cm^{-2}s^{-1}$

Int. luminosity/day : 1.346 / 1.498 fb^{-1}

5/11-5/14	6/10-6/17
off-resonance	off-resonance

LER :

$\beta_x^*/\beta_y^* = 80\ mm/1\ mm$

$\rightarrow \beta_x^*/\beta_y^* = 60\ mm/0.8\ mm$

HER :

$\beta_x^*/\beta_y^* = 60\ mm/1\ mm$

$\rightarrow \beta_x^*/\beta_y^* = 60\ mm/0.8\ mm$

Remarks : ECL online luminosity does not include trigger veto dead time before May 7.

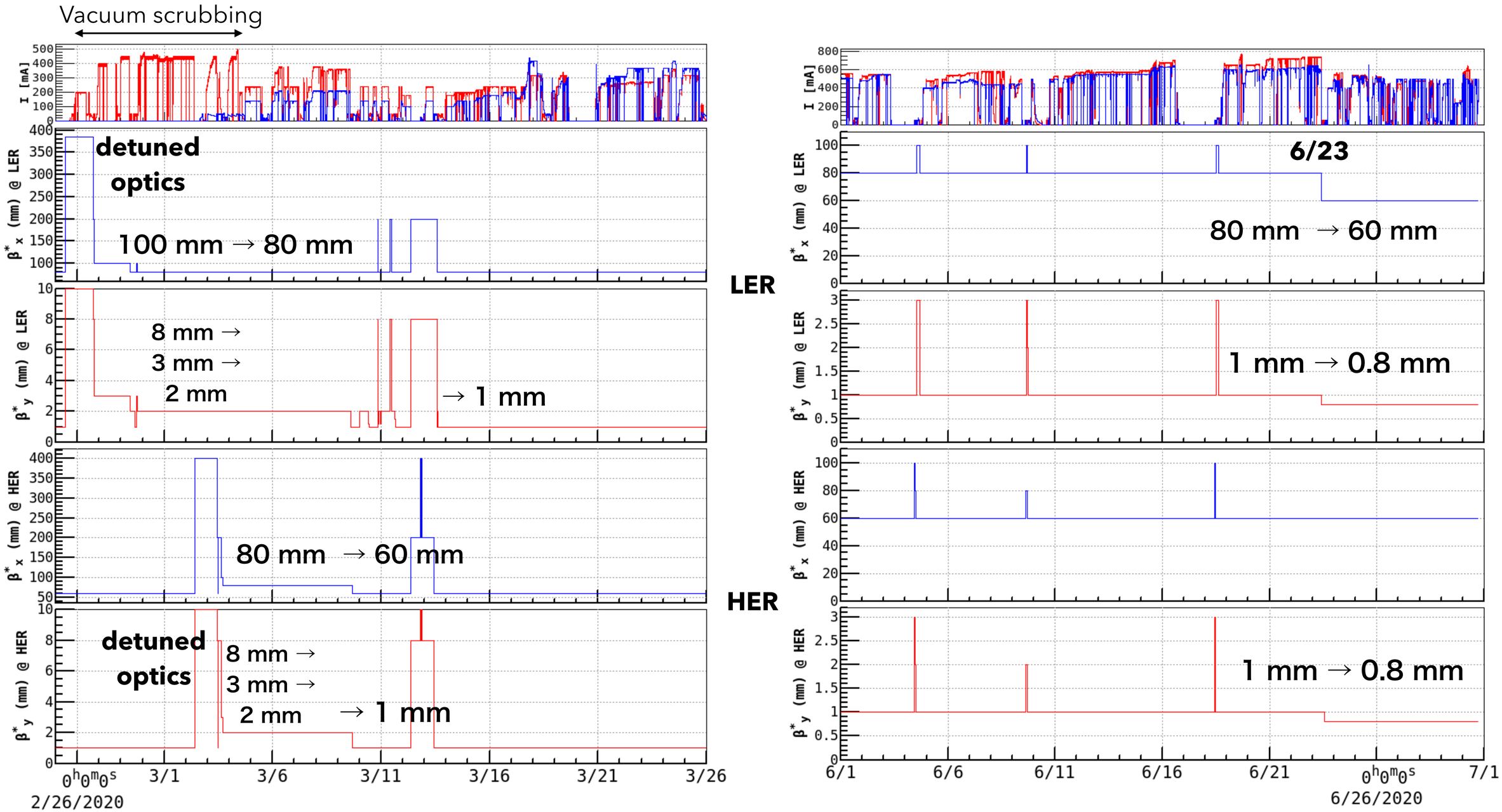
Major Issues

- Crab waist*1 by using the local chromaticity correction sextupoles (FCC-ee style*2)
- Chromatic X-Y coupling correction in the LER by using the rotatable sextupoles (24 magnets)
- Beta squeezing from 1 mm to 0.8 mm in the vertical direction.
- High emittance optics in the LER (dispersion adjustment in the NIKKO wiggler section)
  - ε_x : 1.5 nm to 4.0 nm
- Effect of horizontal angle at the IP in the HER
  - Large angle is needed to reduce SR on PXD (the most inner detector) from injected beams, however horizontal dispersions remain in the whole ring. We compared 0.59 mrad and 0.04 mrad for luminosity performance.
- Skew quadrupole (small permanent magnet) was installed between injection kickers to reduce vertical orbit oscillations (due to X-Y coupling) in the LER. The luminosity degradation at injections was reduced.

*1 P. Raimondi et al., SuperB CDR

*2 K. Oide et al., ICHEP 2016

Beta Squeezing



Luminosity

General formula:

$$L = \frac{N_+ N_- n_b f_0}{2\pi \Sigma_x^* \Sigma_y^*}$$

$$= \frac{N_+ N_- n_b f_0}{2\pi \phi_x \sqrt{\sigma_{z+}^2 + \sigma_{z-}^2}\sqrt{\varepsilon_{y+}\beta_{y+}^* + \varepsilon_{y-}\beta_{y-}^*}}$$

$$\Sigma_x^* = \sqrt{\sigma_{x+}^{*2} + \sigma_{z+}^2 \tan^2\phi_x + \sigma_{x-}^{*2} + \sigma_{z-}^2 \tan^2\phi_x}$$

$$= \sqrt{\sigma_{x+}^{*2}(1+\Psi_+^2) + \sigma_{x-}^{*2}(1+\Psi_-^2)}$$

$$\simeq \phi_x \sqrt{\sigma_{z+}^2 + \sigma_{z-}^2}$$

$$\Psi_\pm = \frac{\sigma_{z\pm}}{\sigma_{x\pm}^*}\tan\phi_x$$

$\sigma_{z+} = 4.6\ mm \quad \sigma_{z-} = 5.1\ mm$ (zero current)

Nano-beam scheme Piwinski angle : $\Psi_\pm = 13 \sim 18 >> 1$

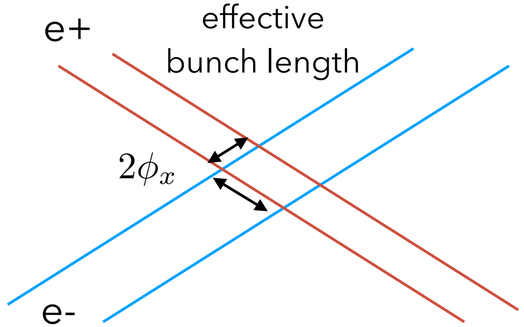
Vertical emittance is important.
X-Y couplings and vertical dispersion affect the vertical emittance.

Bunch lengthening is important.
For instance, impedance affects bunch lengthening.

To avoid **hourglass effect**:

$$\beta_y^* > \tilde{\sigma}_z = \frac{\sigma_x^*}{\phi_x} = \frac{\sigma_z}{\Psi}$$

$$\sigma_x^* = \sqrt{\varepsilon_x \beta_x^*}$$



Horizontal emittance : $\varepsilon_{x+} = 2\ nm$ *(4 nm)*

$\varepsilon_{x-} = 4.6\ nm$

$\beta_{x+}^* = 80\ mm / \beta_{x-}^* = 60\ mm$ $\quad \tilde{\sigma}_{z+} = 305\ \mu m / \tilde{\sigma}_{z-} = 400\ \mu m$

(431 μm)

Definition of specific luminosity

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

Definition of beam-beam parameter (here)

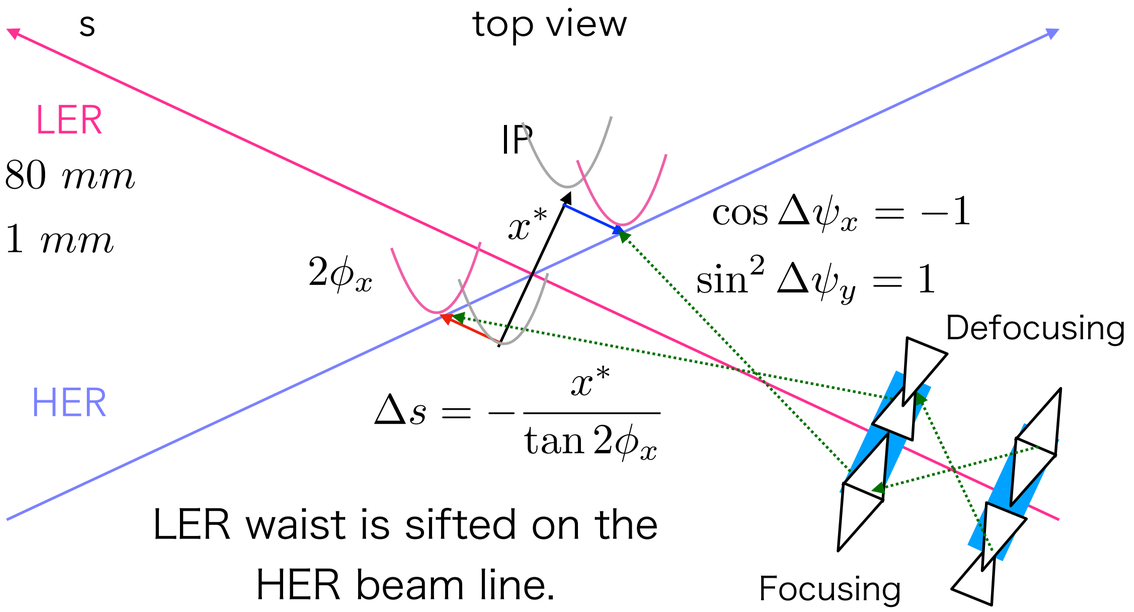
$$\xi_{y\pm} = \frac{2 e r_e \beta_{y\pm}^*}{\gamma_\pm I_\pm} L$$

Waist shift :

$$\begin{pmatrix} \tilde{y}^* \\ \tilde{p_y}^* \end{pmatrix} = \begin{pmatrix} 1 & \Delta s \\ 0 & 1 \end{pmatrix} \begin{pmatrix} y^* \\ p_y^* \end{pmatrix}$$

$$\tilde{y}^* = y^* - \frac{x^*}{\tan 2\phi_x} p_y^*$$

$$H_{CW} = -\frac{1}{2\tan 2\phi_x} x^* p_y^{*2}$$



LER waist is sifted on the HER beam line.

On the other hand, Hamiltonian of sextupole :

$$H = \frac{K_2}{6}(x^3 - 3xy^2)$$
$$= \frac{K_2}{6}\beta_x^{3/2} X^2 - \frac{K_2}{2}\sqrt{\beta_x}\beta_y XY^2$$

$$H_{CW} = -\frac{K_2}{2}\beta_y\beta_y * \sqrt{\frac{\beta_x}{\beta_x^*}}\cos\Delta\psi_x \sin^2\Delta\psi_y x^* p_y^{*2}$$

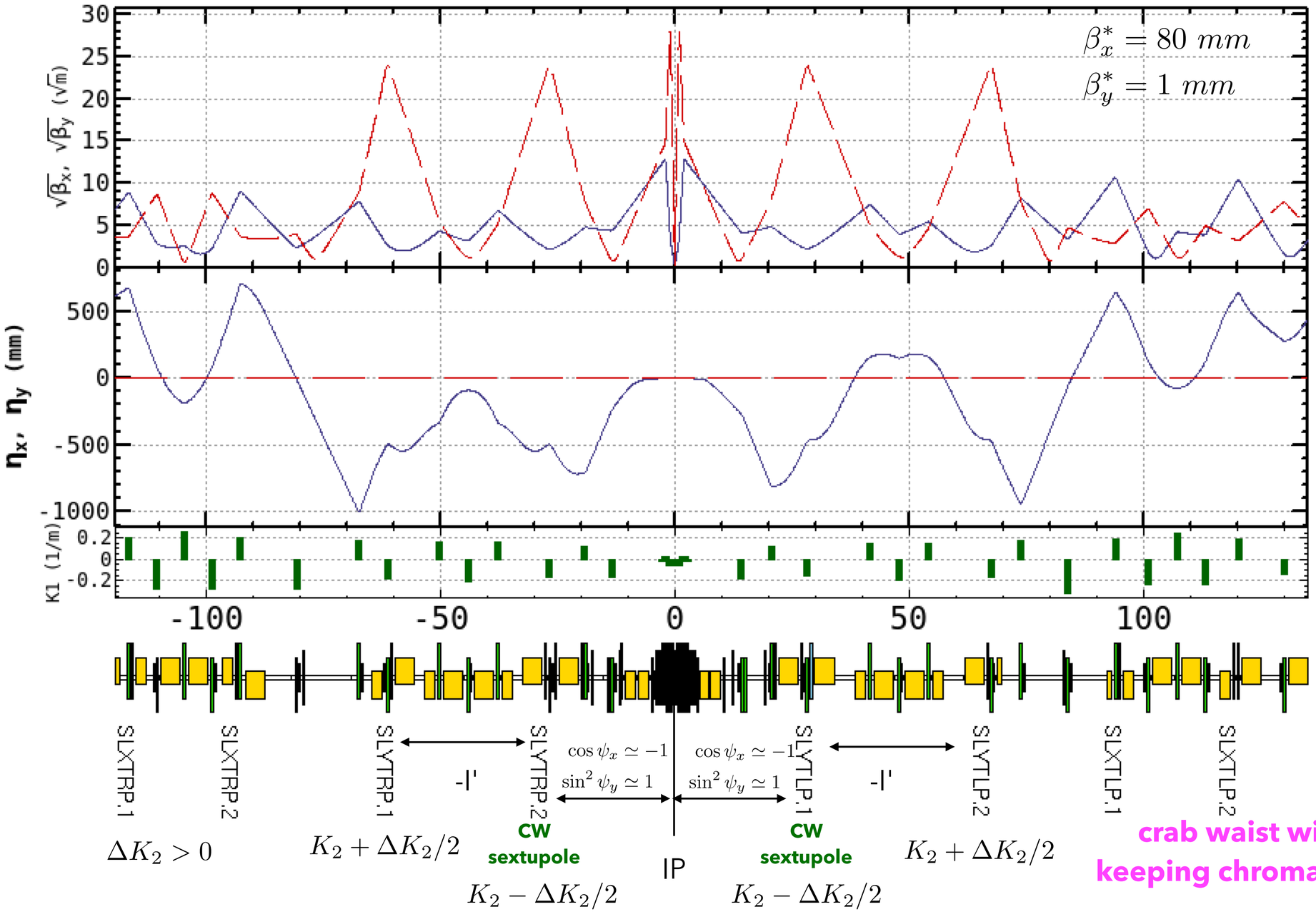
Crab waist sextupoles (-I' transfer)
(opposite deviation from the reference field for each)

IP to CW sextupole :

$$\begin{pmatrix} X, Y \\ P_{X,Y} \end{pmatrix} = \begin{pmatrix} \cos\Delta\psi_{x,y} & -\sin\Delta\psi_{x,y} \\ \sin\Delta\psi_{x,y} & \cos\Delta\psi_{x,y} \end{pmatrix} \begin{pmatrix} X^*, Y^* \\ P^*_{X,Y} \end{pmatrix}$$

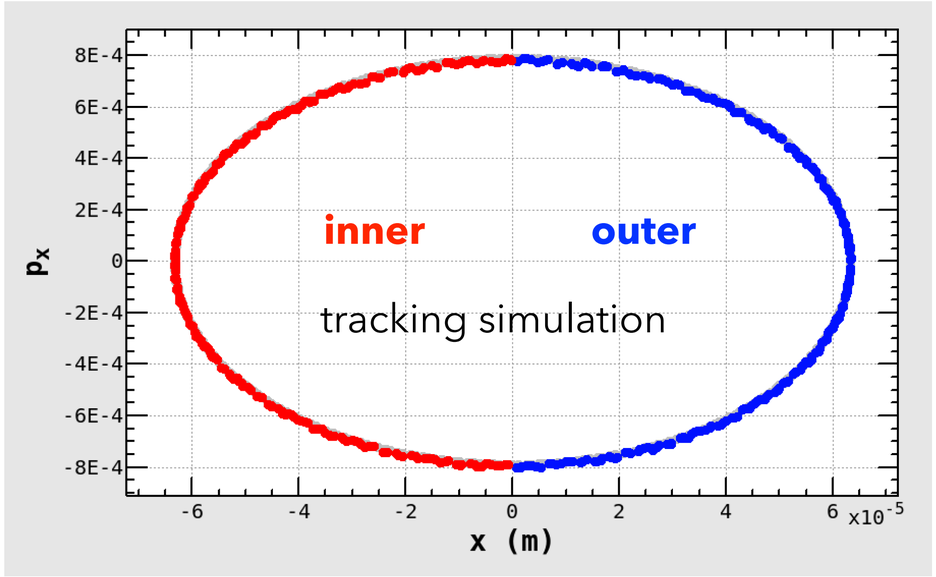
Crab Waist Lattice in LER

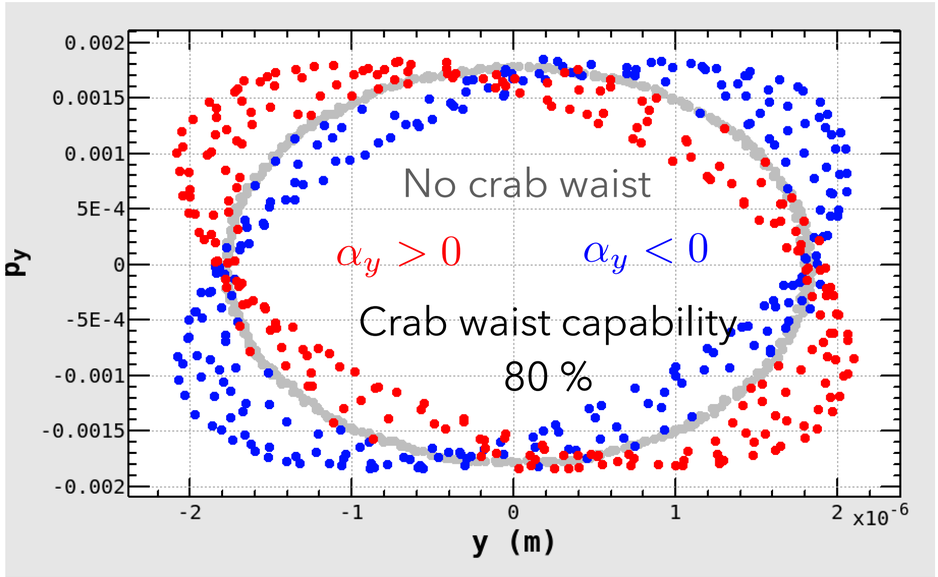
FCC-ee style
Crab Waist
(K. Oide)

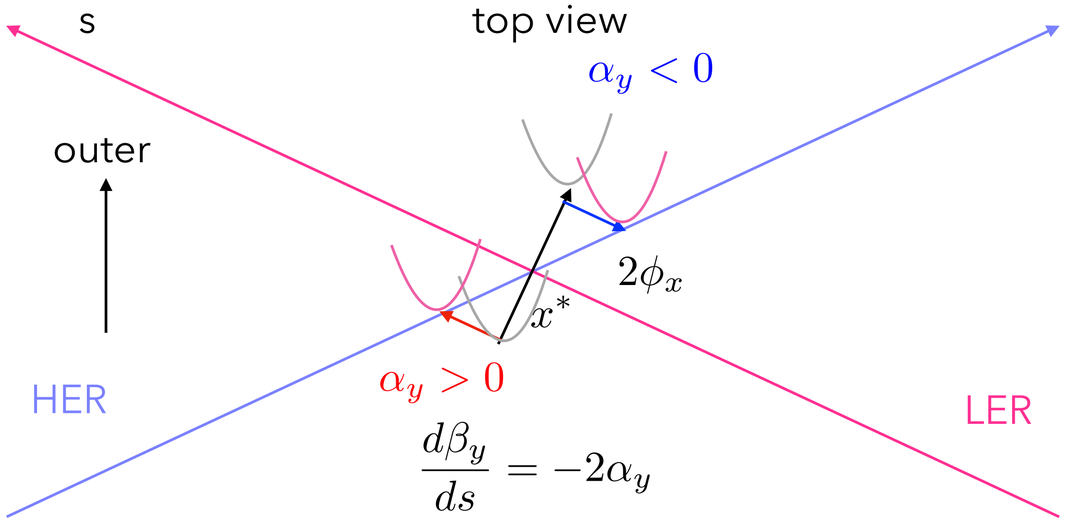


Phase Space at IP in LER

Interaction point (s = 0)







$$\beta_x^* = 80\ mm$$
$$\beta_y^* = 1\ mm$$

$$\frac{d\beta_y}{ds} = -2\alpha_y$$

$$\Delta s = -\frac{x^*}{\tan 2\phi_x}$$

1704_80_1_A_YO2

	L-side	R-side	Unit
β_x	5.66	5.52	m
β_y	525	521	m
$\cos\Delta\psi_x$	-0.992	-0.988	
$\sin^2\Delta\psi_y$	1.0	1.0	
$K_{2\ (SLYT\{LR\}1/2)}$	1.327 / 3.526	1.226 / 3.478	1/m^2

Crab waist capability 80 %

Machine Parameters (I)

	SuperKEKB : June 21, 2020		SuperKEKB : Dec. 8, 2019		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	2.0	4.6	nm
Beam Current	712	607	467	388	mA
Number of bunches	978		783		
Bunch current	0.728	0.621	0.597	0.496	mA
Lifetime	760	1270	522	1393	sec
Horizontal size σ_x^*	17.9	16.6	12.6	16.6	μm
Vertical cap sigma Σ_y^*	0.403		0.445		μm*1
Vertical size σ_y^*	0.285		0.315		μm*2
Betatron tunes ν_x / ν_y	44.523 / 46.581	45.531 / 43.577	44.525 / 46.590	45.534 / 43.567	
β_x^* / β_y^*	80 / 1.0	60 / 1.0	80 / 1.0	60 / 1.0	mm
Piwinski angle	10.7	12.7	15.1	12.7	
Crab waist ratio	80	40	0	0	%
Beam-Beam parameter ξ_y	0.0389	0.0261	0.0281	0.0193	
Specific luminosity	5.43×10^{31}		4.91×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	2.40×10^{34}		1.14×10^{34}		$cm^{-2}s^{-1}$

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

Machine Parameters (2)

	SuperKEKB : June 21, 2020		SuperKEKB : July 1, 2020		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	nm
Beam Current	712	607	536	530	mA
Number of bunches	978		978		
Bunch current	0.728	0.621	0.548	0.542	mA
Lifetime	760	1270	600	1177	sec
Horizontal size σ_x^*	17.9	16.6	15.5	16.6	μm
Vertical cap sigma Σ_y^*	0.403		0.317		μm*[1]
Vertical size σ_y^*	0.285		0.224		μm*[2]
Betatron tunes ν_x / ν_y	44.523 / 46.581	45.531 / 43.577	44.525 / 46.581	45.531 / 43.574	
β_x^* / β_y^*	80 / 1.0	60 / 1.0	60 / 0.8	60 / 0.8	mm
Piwinski angle	10.7	12.7	12.3	12.7	
Crab waist ratio	80	40	80	40	%
Beam-Beam parameter ξ_y	0.0389	0.0261	0.0345	0.0199	
Specific luminosity	5.43×10^{31}		6.90×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	2.40×10^{34}		2.00×10^{34}		$cm^{-2}s^{-1}$

*1) estimated by luminosity with assuming design bunch length
*2) divide *1 by $\sqrt{2}$

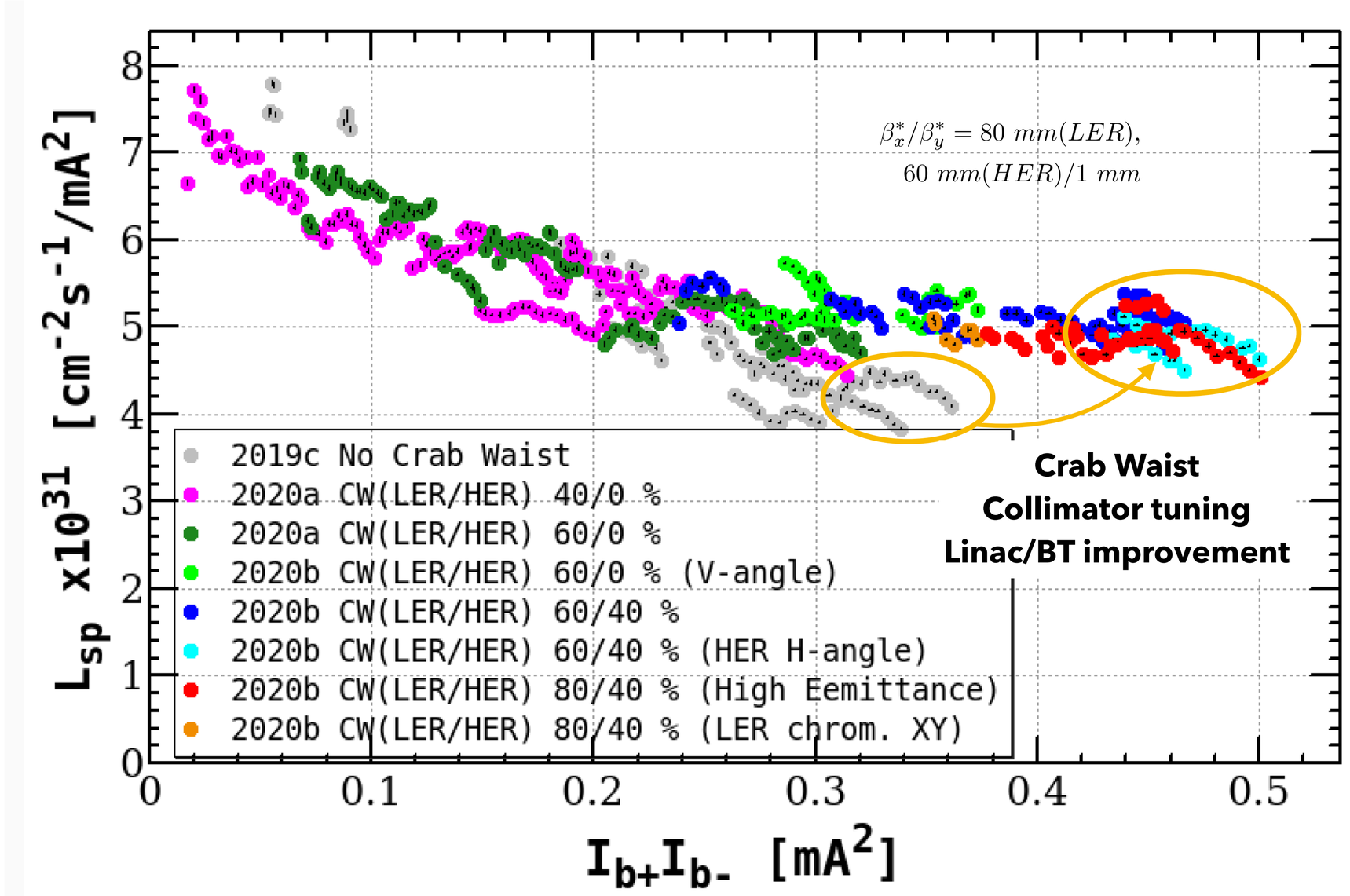
Beam size and Bunch Length

June 21, 2020	LER	HER	Unit	Remarks
Beam current	712	607	mA	
Bunch current	0.728	0.621	mA	
Vertical size σ_y^*	0.27	0.20	μm	XRM measurement
Cap sigma y Σ_y^*	0.336		μm	XRM meaurement
Cap sigma z Σ_z	8.24		mm	estimated by Luminosity
$\Sigma_z/\sqrt{2}$	5.8		mm	estimated by Luminosity
Bunch length σ_z	4.6	5.1	mm	design (zero current)
Σ_z	6.9		mm	design (zero current)

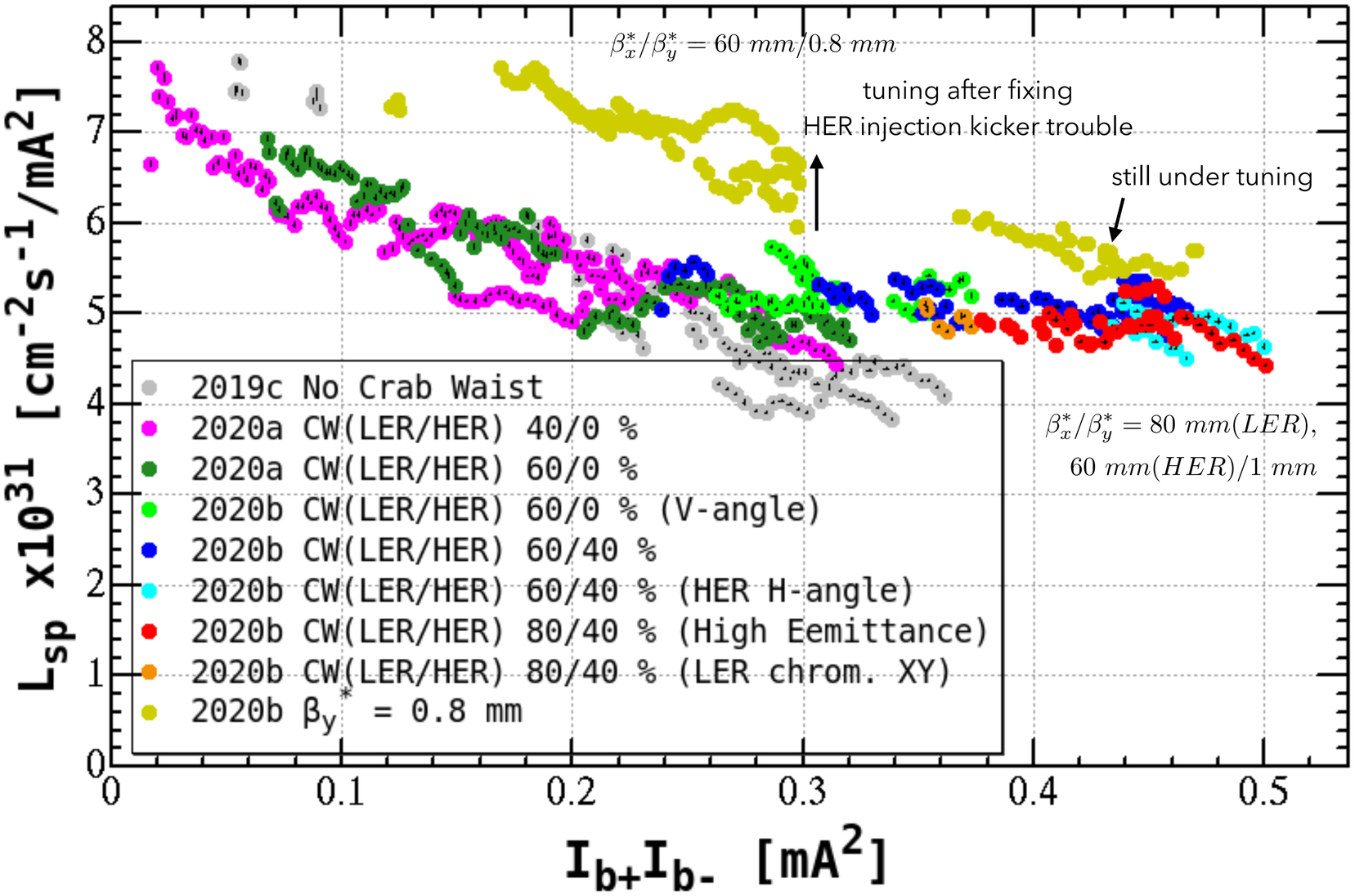
$$L \propto \frac{1}{\phi_x \Sigma_z \Sigma_y^*}$$

Measurement of σ_z is consistent with the value ?

Specific Luminosity

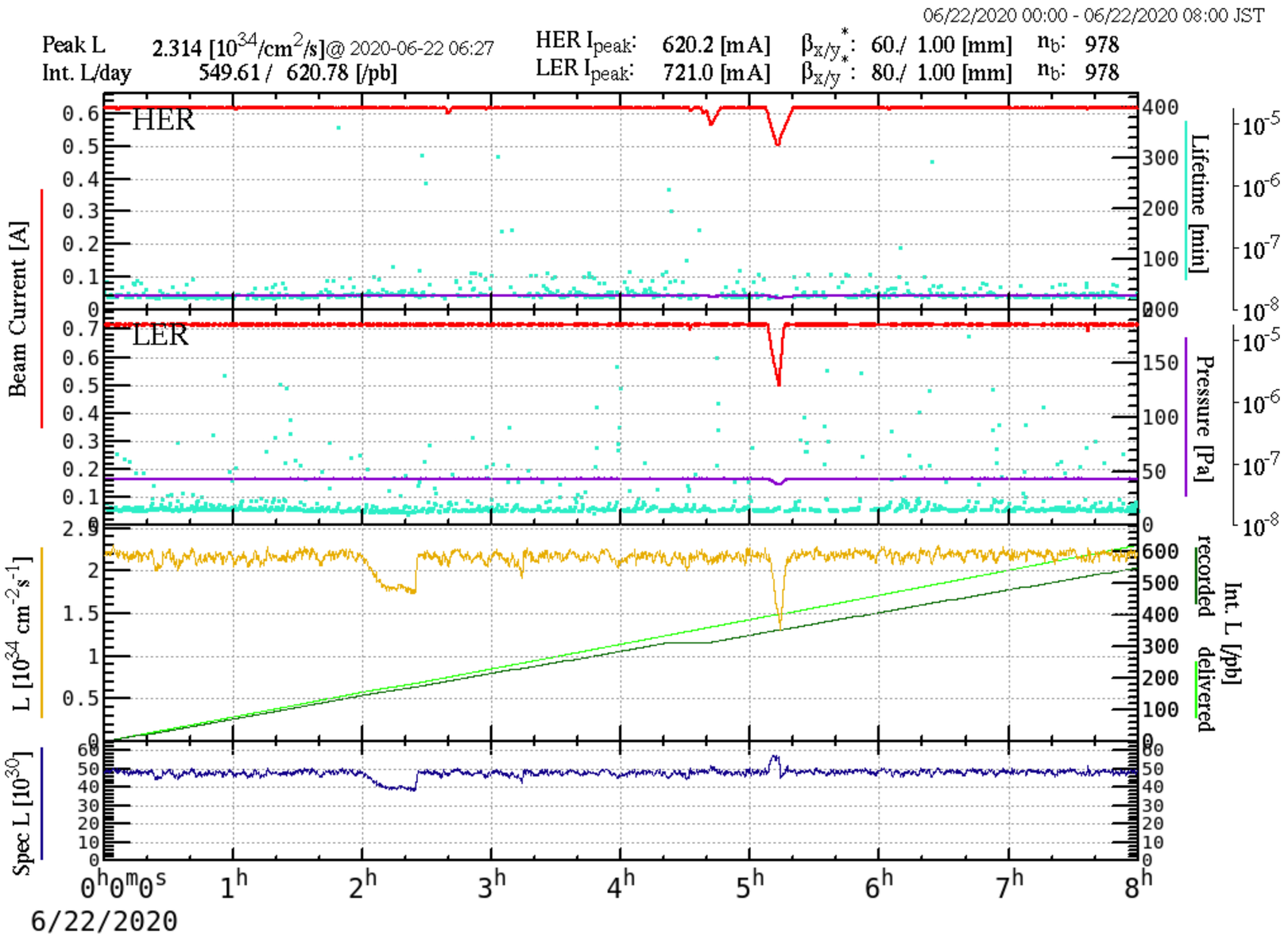


Specific Luminosity



Best Shift

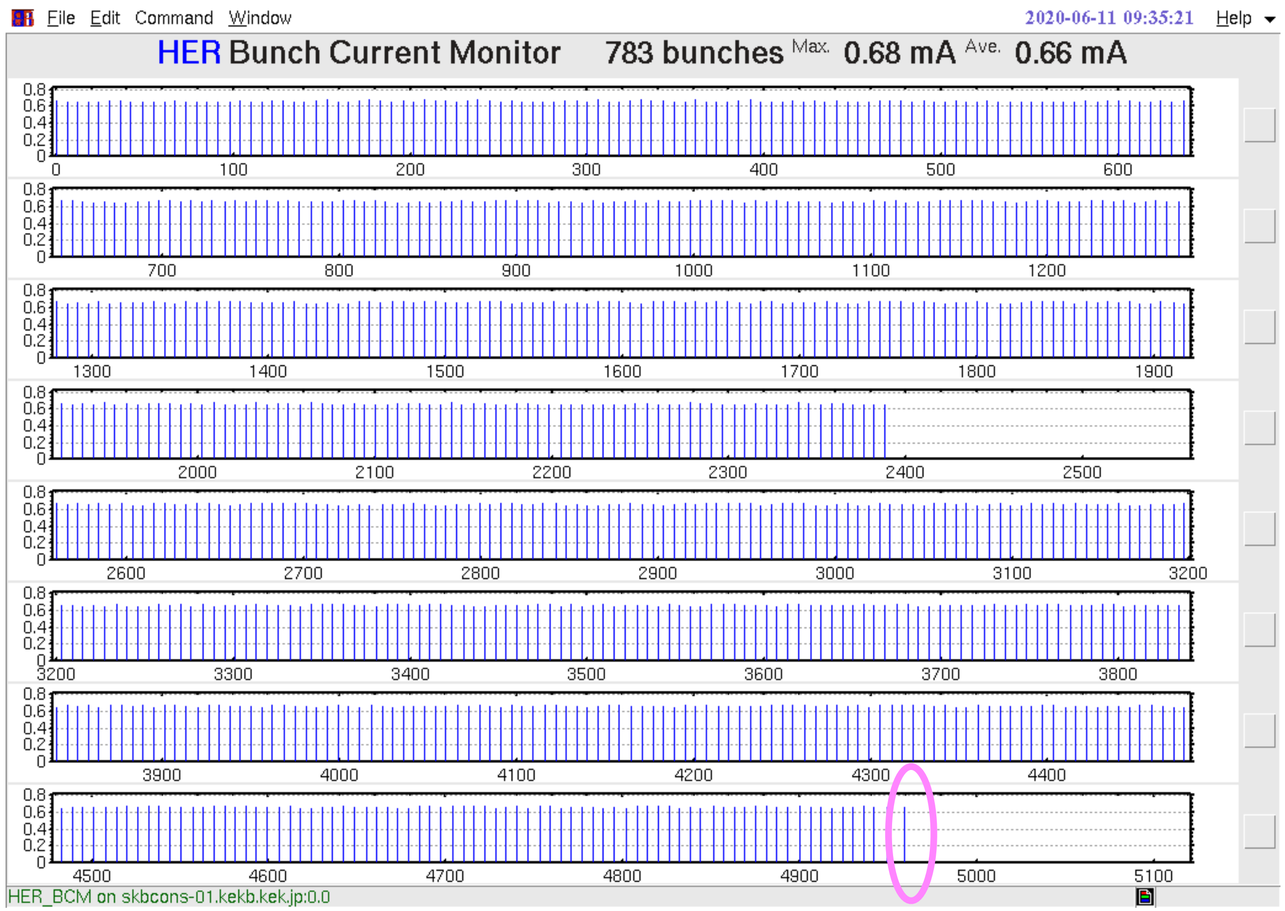
shift : M. Nishiwaki

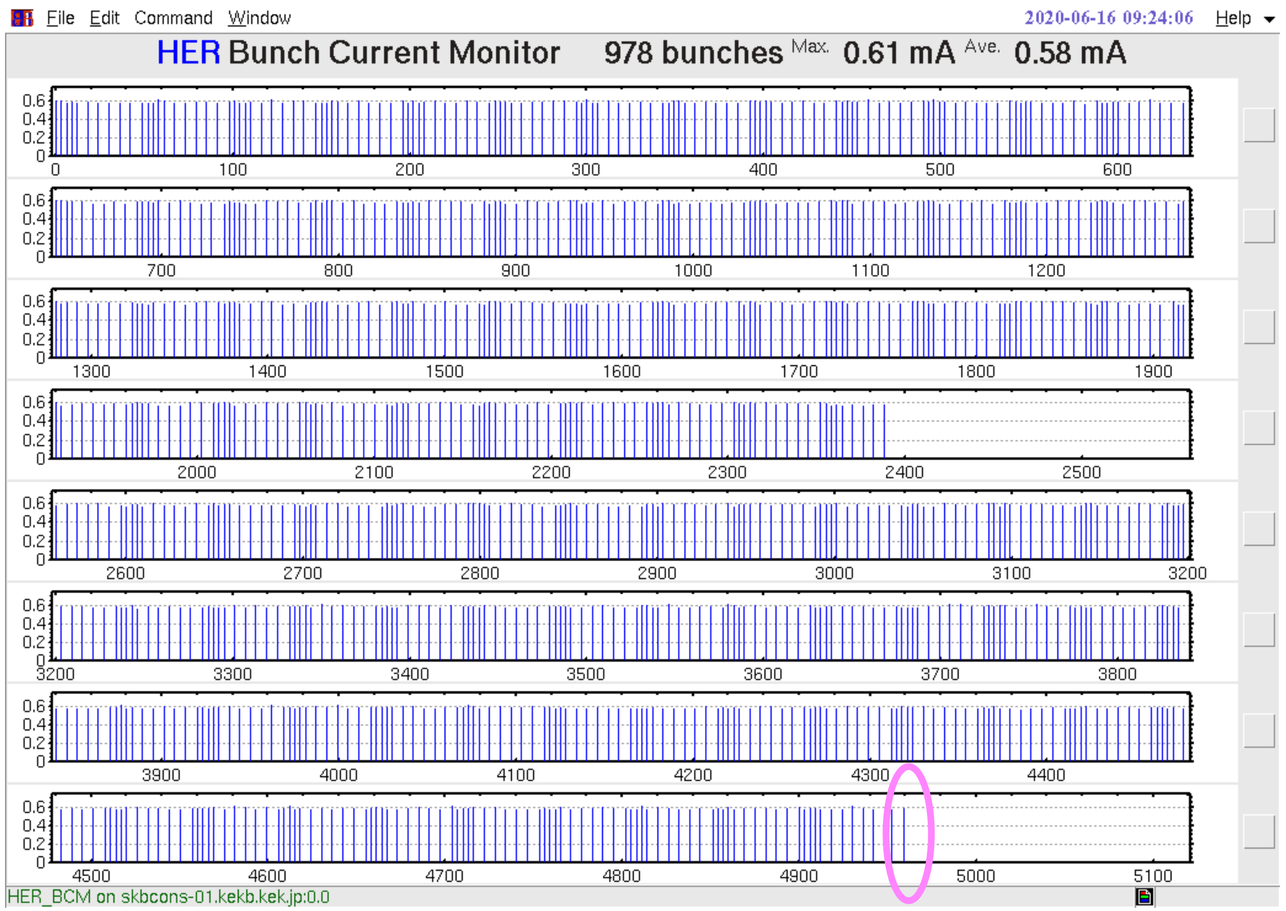


549.6 pb^{-1}/ 620.8 pb^{-1} (89 %)

Fill Pattern

Two abort gaps are prepared to make abort trigger fast.





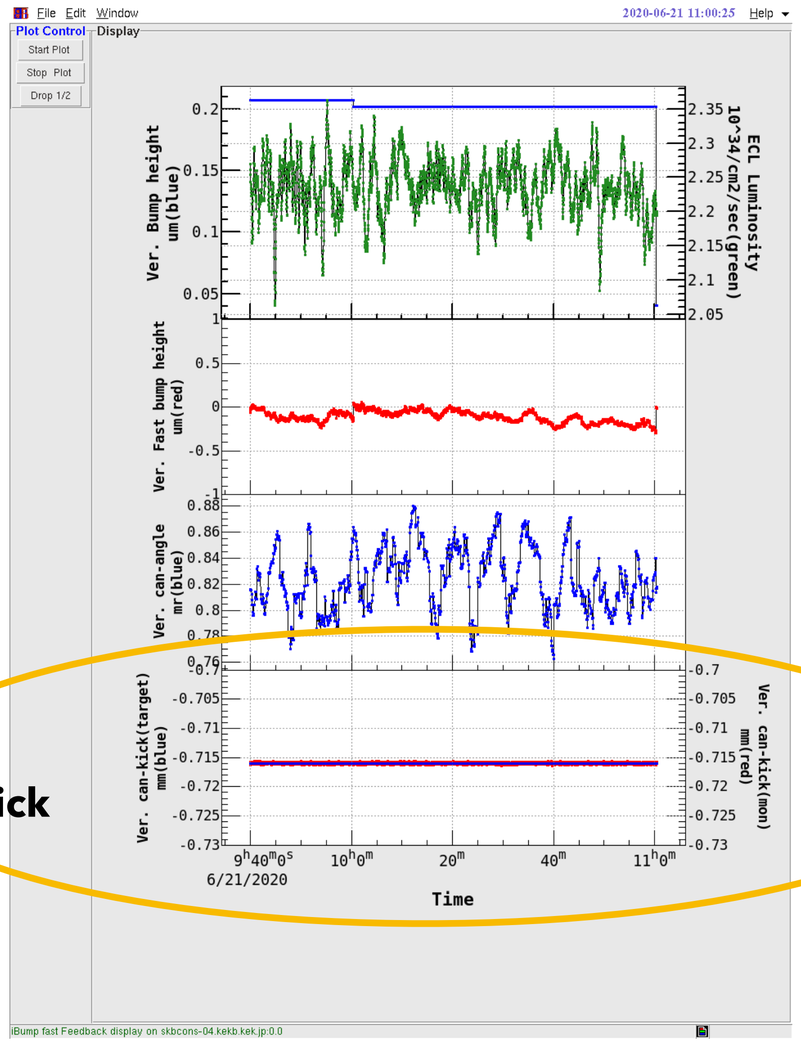
We switched 783 bunches to 978 bunches for physics run in June.

pilot bunch to measure tunes

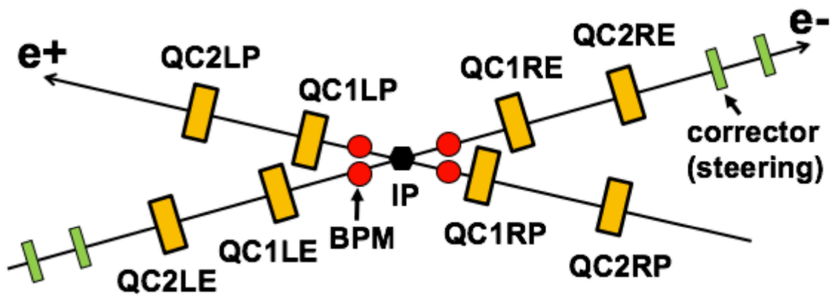
Fast iBump Feedback System

We have applied fast iBump feedback system for collision tuning since Spring run. **H. Fukuma**

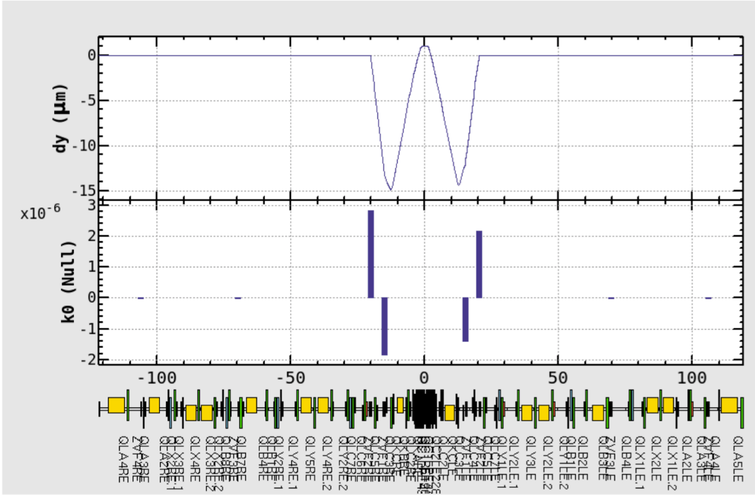
The repetition of the feedback is 33 kHz.



vertical beam-beam kick



Correctors in the HER



ZVF1LE -1.39urad

ZVF2LE 2.15urad

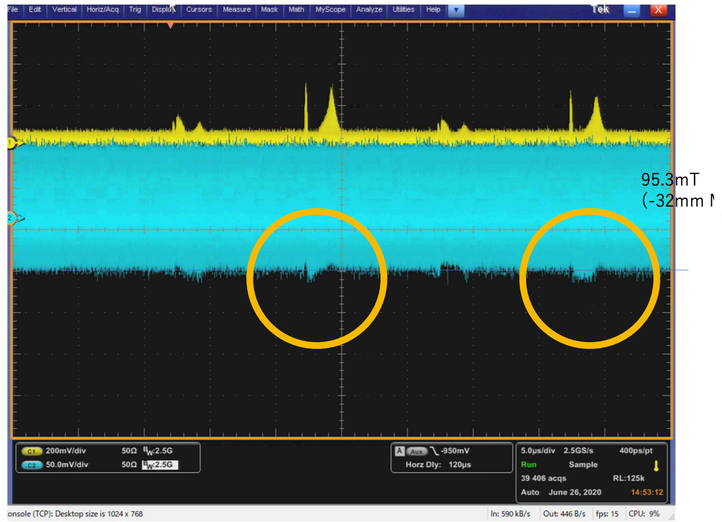
ZVF1RE -1.83urad

ZVF2RE 2.82urad

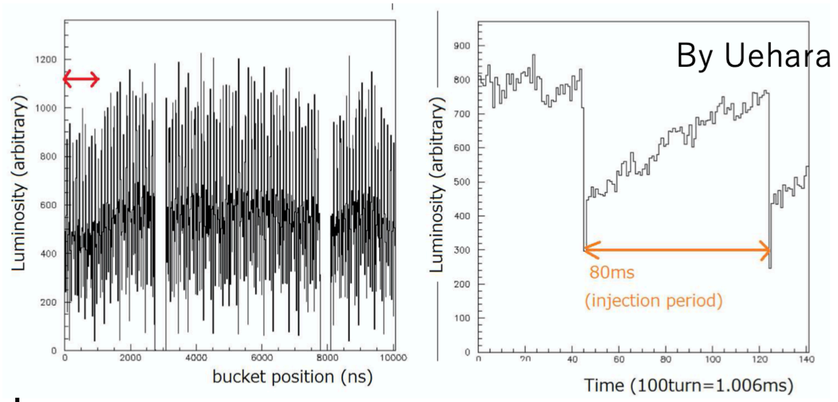
Transverse injection oscillation in the LER

Beams are oscillated due to the horizontal injection error.
If there is X-Y coupling at the injection kicker region, the vertical orbit oscillation can be induced. Then, luminosity degradation occurs for the injection intervals.

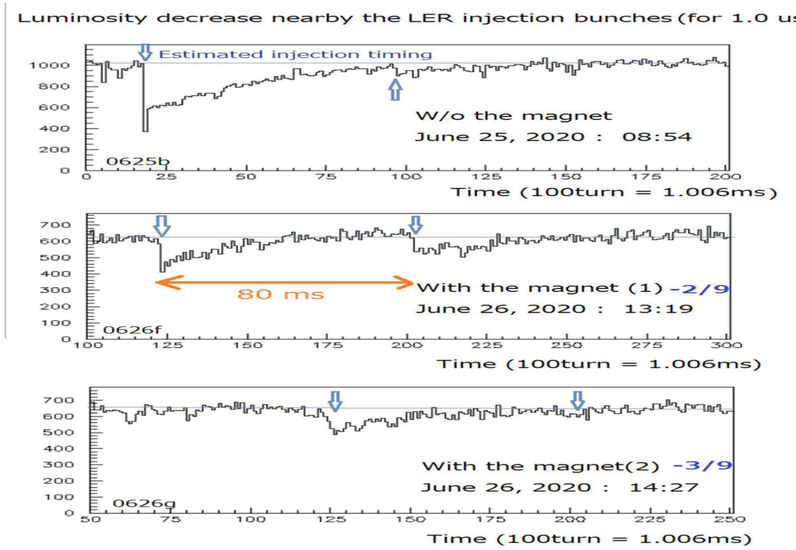
We installed skew quadrupole (permanent magnet) to correct local X-Y coupling in the vicinity of injection kickers.



T. Mimashi, S. Terui, T. Ueda



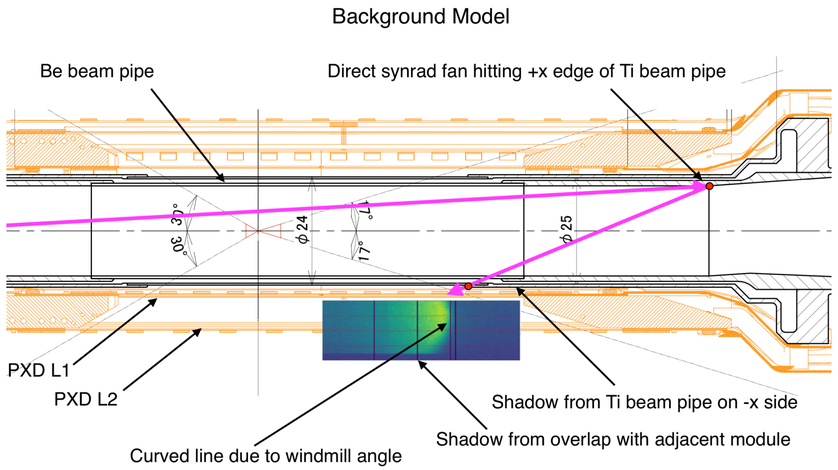
injection repetion rate : 12.5 Hz
80 msec interval

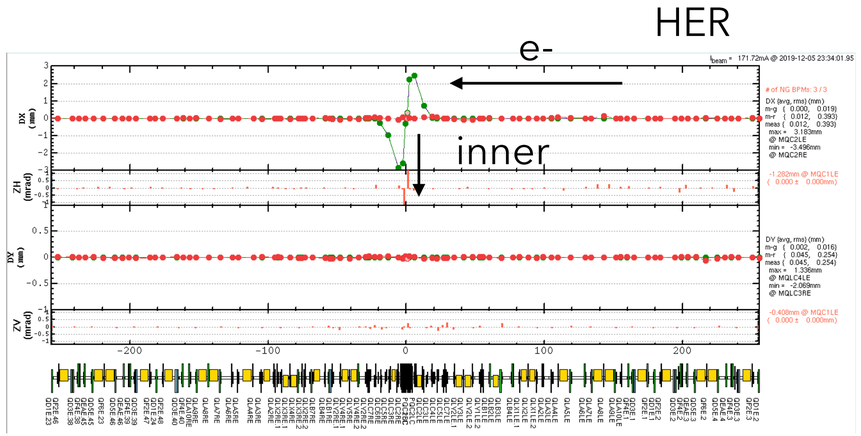


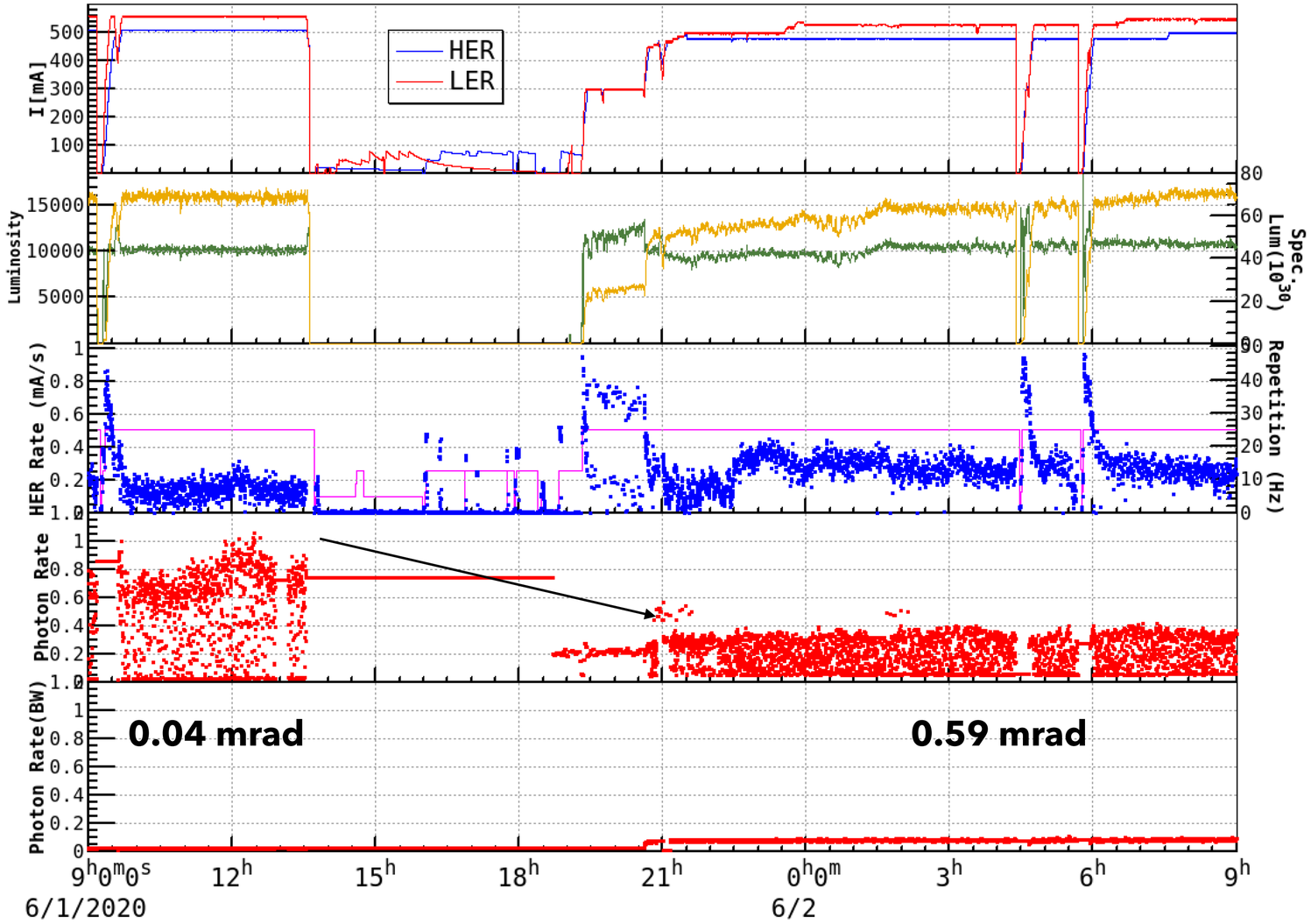
S. Uehara

Synchrotron Light on PXD in HER

Synchrotron light from Injected beam at QC2LE hits the chamber wall and reflected light hits the PXD.

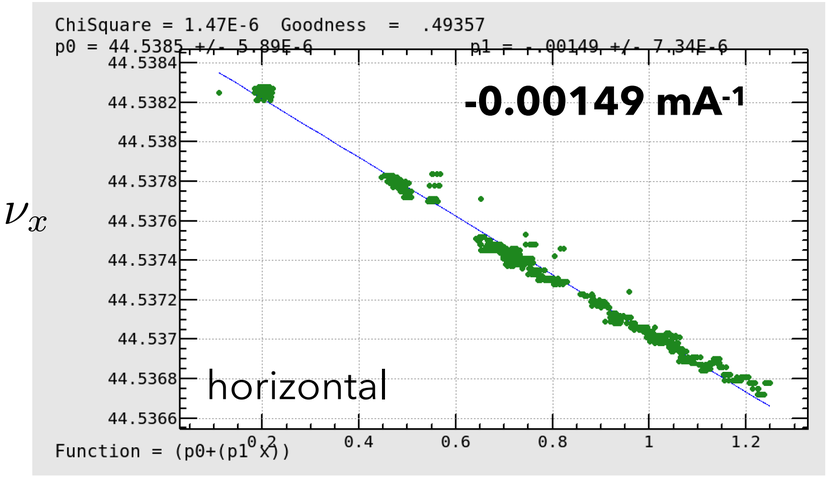






Single Bunch Tune Shift in LER

March 4, 2020 $\beta_x^*/\beta_y^* = 80\ mm/2\ mm$



ν_x

I (mA)

movable collimators

D02

H1IN(-9.0)
H1OUT(9.0)
H2IN(-11.)
H2OUT(11.5)

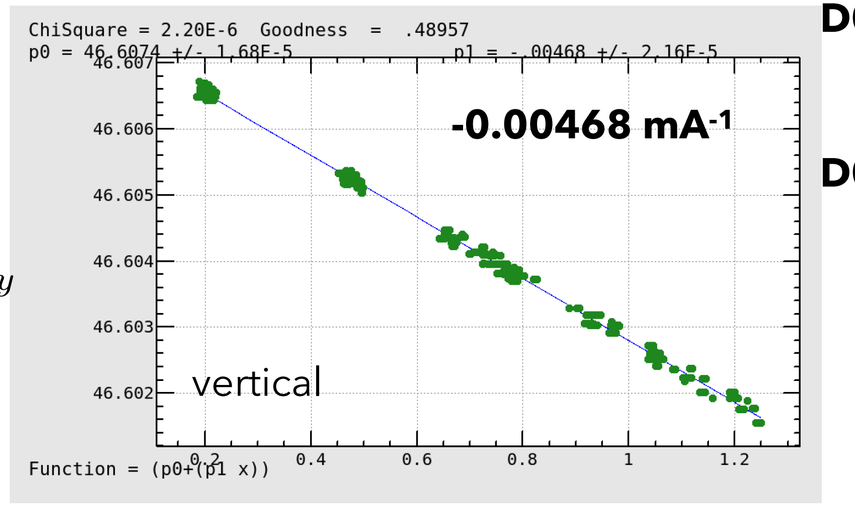
H3IN(-18.)
H3OUT(18.0)
H4IN(-10.)
H4OUT(10.5)
V1TOP(2.2)
V1BTM(-2.0)

D03

H1IN(-14.)
H1OUT(14.5)

D06

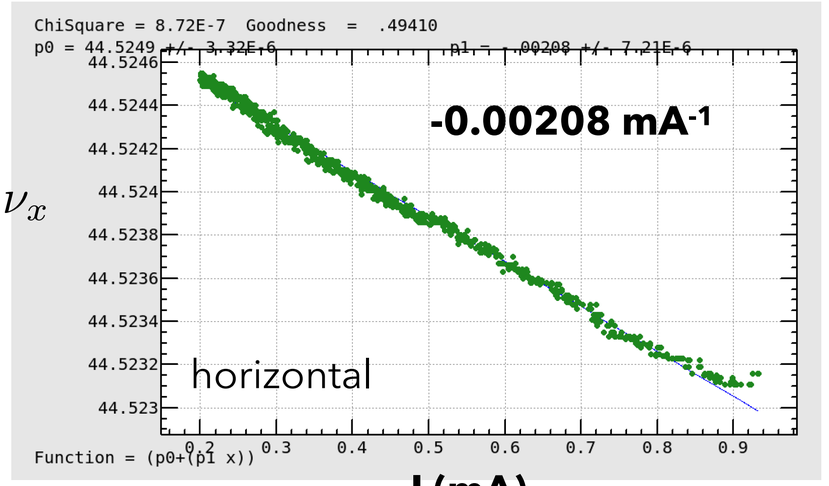
H1IN(-11.)
H1OUT(11.5)
H3IN(-12.)
H3OUT(12.0)
V1TOP(20.5)
V1BTM(-20.)
V2TOP(2.3)
V2BTM(-2.3)



ν_y

I (mA)

June 30, 2020 $\beta_x^*/\beta_y^* = 60\ mm/0.8\ mm$



ν_x

I (mA)

movable collimators

D02

H1IN(-8.0)
H1OUT(8.0)
H2IN(-10.)
H2OUT(10.5)

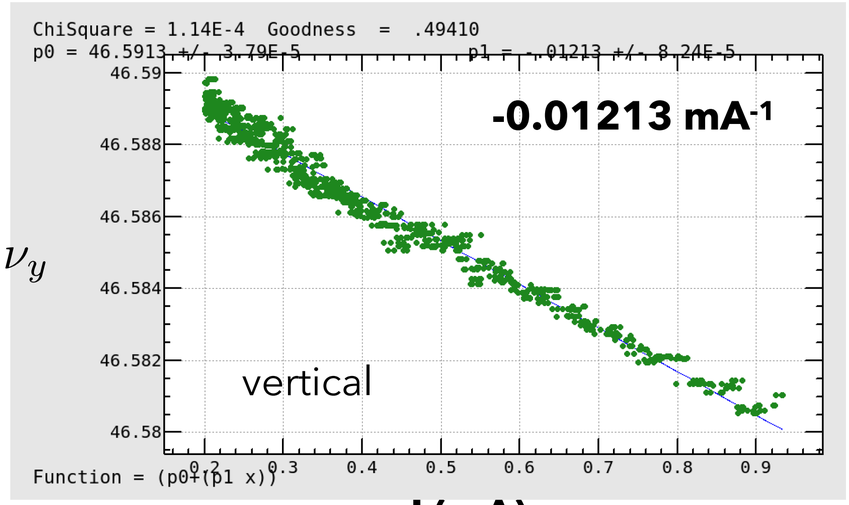
H3IN(-12.)
H3OUT(12.5)
H4IN(-8.3)
H4OUT(7.8)
V1TOP(1.7)
V1BTM(-1.4)

D03

H1IN(-11.)
H1OUT(11.0)

D06

H1IN(-10.)
H1OUT(10.5)
H3IN(-11.)
H3OUT(10.6)
V1TOP(2.6)
V1BTM(-1.9)
V2TOP(2.2)
V2BTM(-1.8)



ν_y

I (mA)

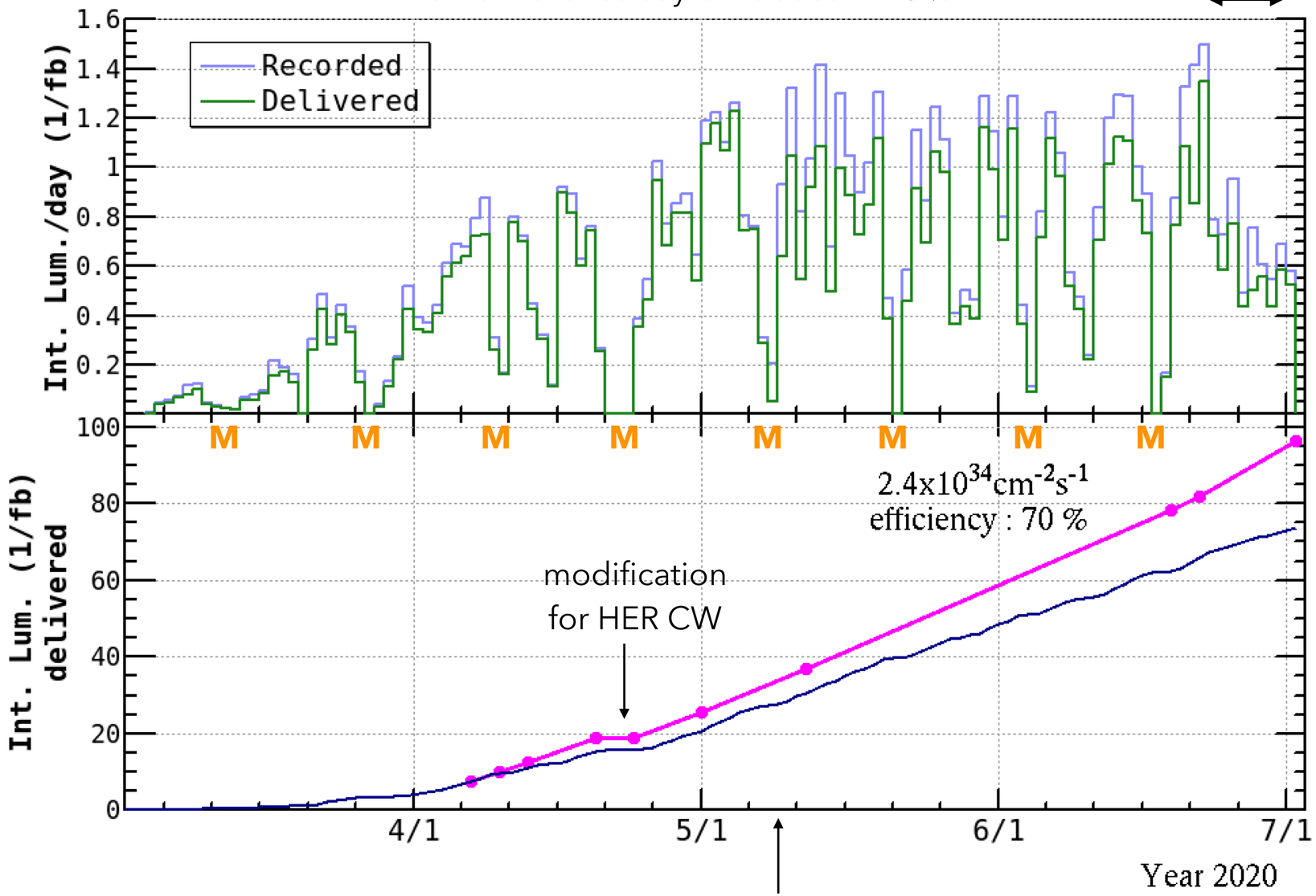
Large tune shift !

Guide Line for Integrated Luminosity

To keep 70 % efficiency is not so easy.

The maintenance day is included in 70 %.

almost machine study



More than 1 fb^{-1} per day is promising.

M : maintenance day (no beam for 25 hours)

Remarks : ECL online luminosity does not include trigger veto dead time before May 7.

Operation Statistics

2020	Physics run	Machine tuning	Machine study	Troubles	Maintenance and others	total (hours)
February	0.0	102.0	0.0	0.0	10.0	112.0
March	344.0	314.5	0.0	17.5	68.0	744.0
April	468.0	135.0	0.0	71.5	45.5	720.0
May	525.0	133.5	0.0	26.0	59.5	744.0
June	463.0	153.5	28.0	50.5	25.0	720.0
July	9.0	0.0	0.0	0.0	0.0	9.0
total (hours)	1809.0 59.3 %	838.5 27.5 %	28.0 0.9 %	165.5 5.4 %	208.0 6.8 %	3049.0

- Machine Tuning
  - NEG activation
  - vacuum scrubbing
  - magnet standardization,
  - RF conditioning
  - XRM calibration
  - bunch-by-bunch FB
  - change of beam energy
  - high current test
  - **injection tuning (includes after maintenance, short break, QCS down)**
  - **optics corrections**
  - iBump calibration
  - collimator tuning
  - BBA
  - **linac/BT beam tuning**, and so on.

Summary

- The peak luminosity of 2.4 x 10^{34} $cm^{-2}s^{-1}$ with Belle II data acquisition is the world record.
- The luminosity around 2.2 - 2.4 x 10^{34} $cm^{-2}s^{-1}$ can be operated with Belle II for the βy^* = 1 mm optics.
  In case of βy^* = 0. 8 mm, 1.8 - 1.9 x 10^{34} $cm^{-2}s^{-1}$ so far.
- The vertical beta at the IP, 0.8 mm is the smallest value in the world. Beam size at the IP is also smallest.
- The crab waist scheme seems to work successfully. Especially, it is effective at higher bunch current.
- SuperKEKB applies a really large Piwinski angle, O(10). The crab waist has been successfully working in the both rings together with the nano-beam scheme.
- The rotatable sextupoles have been utilized to correct chromatic X-Y couplings in the LER. The effort will be continued to the following operation. This may help to reduce beam-beam blowup.
- RF system works well and provides stable operation; LER max. current is 770 mA and 660 mA in HER.
- Collimators works well to reduce detector BG. More precise adjustment system will be necessary soon.

Summary (cont'd)

- However, difficulties arises significantly such as extremely short beam lifetime, stability of operations, and so on. Sextupole and octuple tunings have to be performed to improve lifetime issue if the dynamic aperture affects it. The linac performance will be a key issue for the next Autumn run to overcome one of the difficulties. Impedance issue ?
- Beam background (TOP counter) and injector performance limit the beam currents so far.
  - BG comes from stored (residual gas, Touschek) and injected beam.
- Recently, the deterioration of devices and facilities obstructs beam operations (as well as human resources). We have to endure the deterioration or aging ?

Appendix

23rd KEKB ARC : Recommendations and Conclusions

R2.1: The ARC endorses the proposed operational goals, toward β_y^* of 0.64 mm, 2 kAh, 200 fb^{-1}, $3x10^{34}cm^{-2}s^{-1}$ by summer 2020.

C2.1: 0.8 mm, 1.18 kAh, 63 fb^{-1}(73.5 fb^{-1}), $2.4x10^{34}$ $cm^{-2}s^{-1}$

R2.2: By autumn 2019, evaluate different operating scenarios, select the one with the best risk-reward ratio, and establish a detailed commissioning plan for accelerator and background studies.

C2.2: ---

R2.3: Do basic collision tuning around the energy-transparent condition.

C2.3: We have been able to perform IP knob tuning under stable physics run day by day. The continuous injection much helps the collision tuning.

R2.4: Develop a collimation scenario down to design β_y^*.

C2.4: We studied a part of collimators with changing aperture, reducing by 200-300 μm or enlargement from the reference for injection beams. Tune shift and bunch lengthening were also measured. D02V1 is 1.3 mm which is smaller than the design of 2.1 mm in the LER.

R2.5: The origin of the much larger than expected increases of bunch length with current should be investigated.

C2.5: Not yet done.

R2.6: Develop a Crab-Waist lattice to mitigate the beam-beam blowup, even if it may not work with the final design value of β_y^* .

C2.6: LER : 80 %, HER : 40 % for Crab-Waist ratio

R2.7: Develop a new nomenclature for the names of beam runs.

C2.7: We use 2020a and 2020b for Spring run, 2020c for Autumn run.

Collimator Aperture in LER

Assumption : ε_y = 60 pm (1.5 %) for collision (σ_y^* = 0.22 μm for 0.8 mm)

LER β_x^* / βy^* : 80 mm / 1.0 mm

June 21,2020	A_x (mm)	A_x/σ_x	A_y (mm)	A_y/σ_y
D06H1	10.25	16.8		
D06H3	10.75	17.6		
D03H1	11.25	16.8		
D02H1	8.0	24.8		
D02H2	10.25	17.2		
D02H3	13.0	16.1		
D02H4	8.25	18.8		
D06V1			**2.3**	**36.1**
D06V2			2.1	59.7
D02V1			1.3	44.9
QC1LP	13.0	41.7	13.5	62.8
QC2LP	35.0	43.3	35.0	289
QC2RP	35.0	43.3	35.0	289
QC1RP	13.0	42.6	13.5	63.0

LER β_x^* / βy^* : 60 mm / 0.8 mm

July 1,2020	A_x (mm)	A_x/σ_x	A_y (mm)	A_y/σ_y
D06H1	10.25	16.8		
D06H3	10.8	17.7		
D03H1	11.0	16.4		
D02H1	8.0	23.5		
D02H2	10.25	16.8		
D02H3	12.25	15.6		
D02H4	8.0	17.1		
D06V1			**2.2**	**34.3**
D06V2			2.0	56.3
D02V1			1.5	44.7
QC1LP	13.0	35.9	13.5	55.8
QC2LP	35.0	37.2	35.0	256
QC2RP	35.0	37.2	35.0	256
QC1RP	13.0	36.6	13.5	55.8

Collimator Aperture in HER

Assumption : ε_y = 60 pm (1.3 %) for collision (σ_y^* = 0.22 μm for 0.8 mm)

HER β_x^* / βy^* : 60 mm / 1.0 mm

June 21,2020	A_x (mm)	A_x/σ_x
D09H1	10.0	16.2
D09H2	10.0	16.2
D09H3	11.0	17.8
D09H4	12.0	19.4
D12H1	9.9	16.0
D12H2	9.8	15.9
D12H3	9.8	15.9
D12H4	9.8	15.9
D01H3	4.8	17.0
D01H4	8.0	25.0
D01H5	8.0	21.5
QC1LE	15	28.4
QC2LE	35	25.9
QC2RE	35	23.5
QC1RE	15	28.7

June 21,2020	A_y (mm)	A_y/σ_y
D09V1	1.6	52.5
D09V2	3.1	90.8
D09V3	1.3	42.7
D09V4	3.4	107.3
D12V1	3.3	104.1
D12V2	1.8	59.1
D12V3	2.2	72.1
D12V4	3.3	96.6
D01V1	1.9	36.0
QC1LE	15	46.5
QC2LE	35	196.6
QC2RE	35	198.8
QC1RE	15	46.4

HER β_x^* / βy^* : 60 mm / 0.8 mm

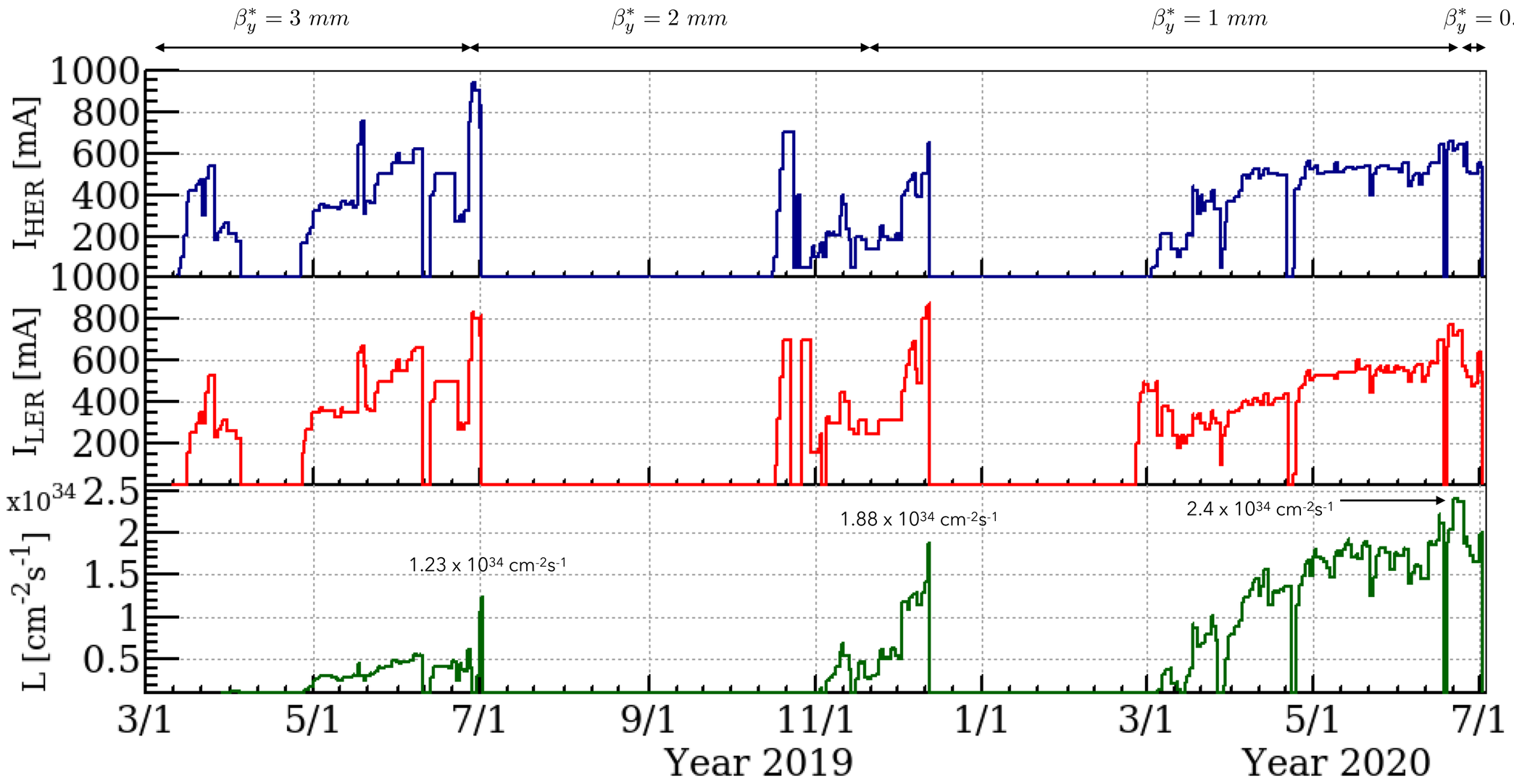
July 1,2020	A_x (mm)	A_x/σ_x
D09H1	10.0	16.2
D09H2	10.0	16.2
D09H3	11.0	17.8
D09H4	12.0	19.4
D12H1	8.9	14.4
D12H2	8.8	14.2
D12H3	8.8	14.2
D12H4	8.8	14.2
D01H3	4.8	17.0
D01H4	8.0	25.0
D01H5	8.0	21.5
QC1LE	15	28.4
QC2LE	35	25.9
QC2RE	35	24.0
QC1RE	15	28.6

July 1,2020	A_y (mm)	A_y/σ_y
D09V1	1.6	52.5
D09V2	3.1	90.8
D09V3	1.3	42.7
D09V4	3.3	104.1
D12V1	3.4	107.3
D12V2	1.9	62.4
D12V3	2.2	72.2
D12V4	3.3	96.6
D01V1	2.1	35.7
QC1LE	15	41.6
QC2LE	35	175.8
QC2RE	35	177.8
QC1RE	15	41.5

History from Phase 2 to Phase 3

	Phase 2 2018a/b	Phase 3.1 2019a/b	Phase 3.2 2019c	Phase 3.3 2020a/b	Remarks
Date	**March 19 - July 17 2018**	**March 11 - July 1 2019**	**Oct. 15 - Dec. 12 2019**	**Feb. 25 - July 1 2020**	
Operation time (days)	120	91 (fire : 21)	57	127	
Beta Function at IP (mm)	LER : 200 / 3 HER : 100 / 3	LER : 80 / 2 HER : 80 / 2	LER : 80 / 1 HER : 60 / 1	LER : 60 / 0.8 HER : 60 / 0.8	
Beam Currents (mA)	LER : 860 HER : 800	LER : 940 HER : 840	LER : 880 HER : 700	LER : 770 HER : 660	
Peak Luminosity ($cm^{-2}s^{-1}$)	2.62×10^{33}	5.50×10^{33}	1.14×10^{34}	2.40×10^{34}	w Belle II
	5.55×10^{33}	1.23×10^{34}	1.88×10^{34}	-	w/o Belle II

History of Phase 3



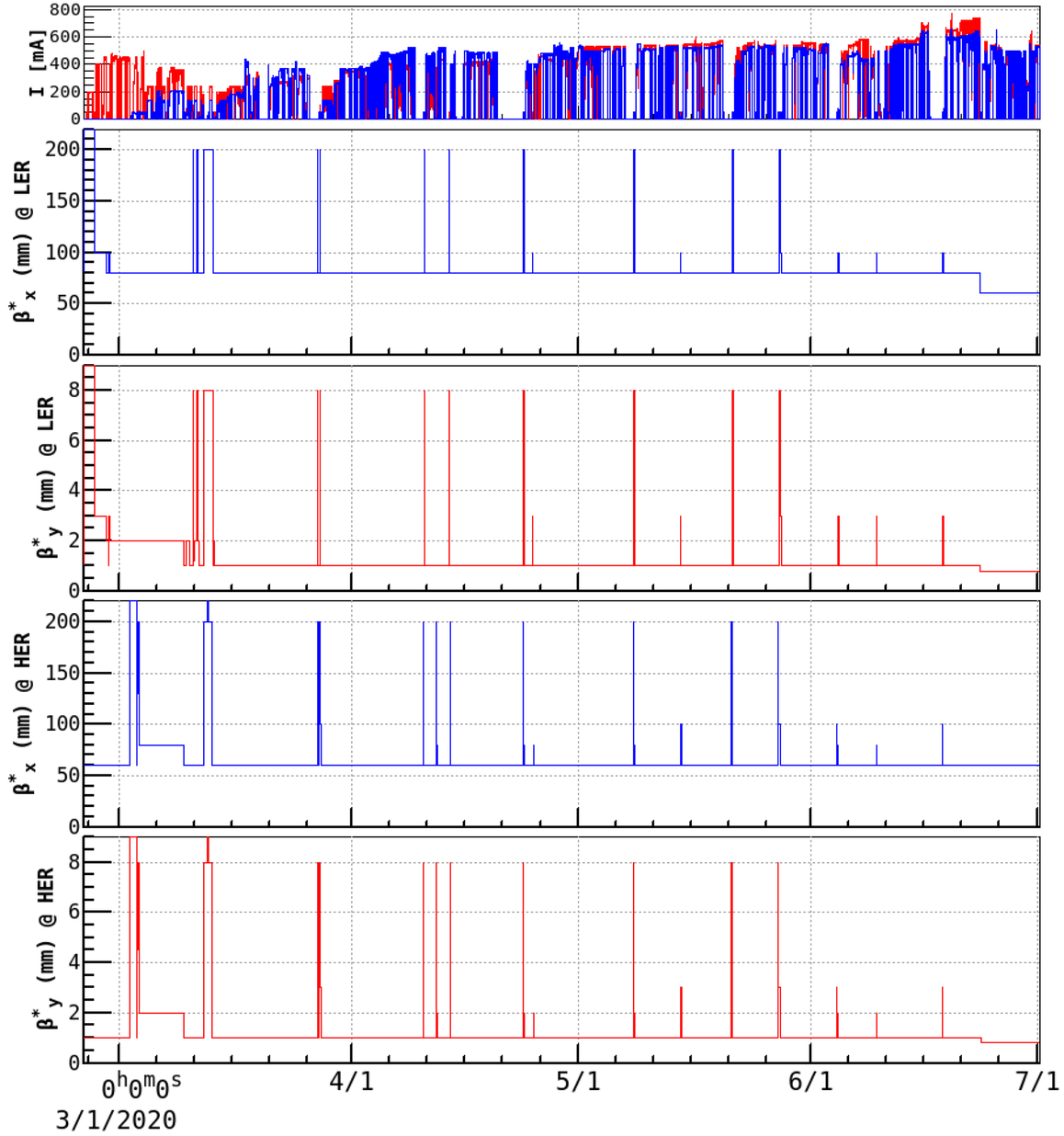
91 days

57 days

127 days

~ 9 months in total

Beta Squeezing in 2020a/b



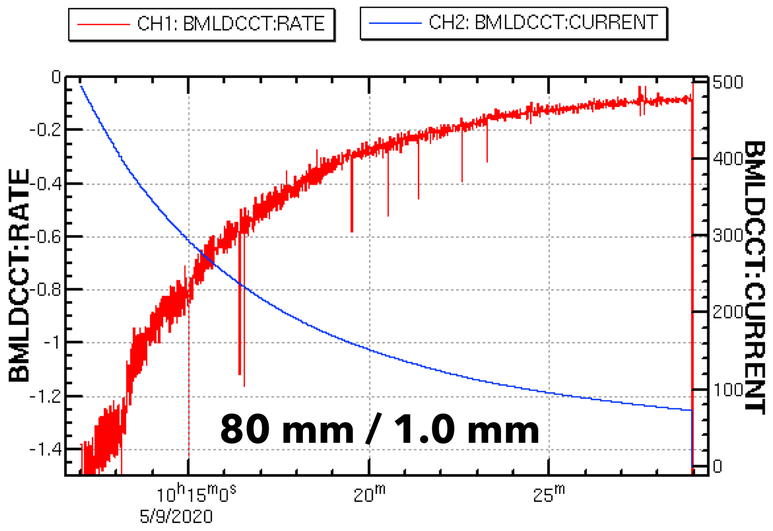
Machine Parameters (3)

	SuperKEKB : June 21, 2020		SuperKEKB : June 30, 2020		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	nm
Beam Current	712	607	270	269	mA
Number of bunches	978		393		
Bunch current	0.728	0.621	0.686	0.685	mA
Lifetime	760	1270	600	1173	sec
Horizontal size σ_x^*	17.9	16.6	15.5	16.6	μm
Vertical cap sigma Σ_y^*	0.403		0.374		μm*1
Vertical size σ_y^*	0.285		0.265		μm*2
Betatron tunes ν_x / ν_y	44.523 / 46.581	45.531 / 43.577	44.525 / 46.582	45.531 / 43.573	
β_x^* / β_y^*	80 / 1.0	60 / 1.0	60 / 0.8	60 / 0.8	mm
Piwinski angle	10.7	12.7	12.3	12.7	
Crab waist ratio	80	40	80	40	%
Beam-Beam parameter ξ_y	0.0389	0.0261	0.0370	0.0212	
Specific luminosity	5.43×10^{31}		5.85×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	2.40×10^{34}		1.08×10^{34} (w/o Belle II)		$cm^{-2}s^{-1}$

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

Lifetime of Single Beam

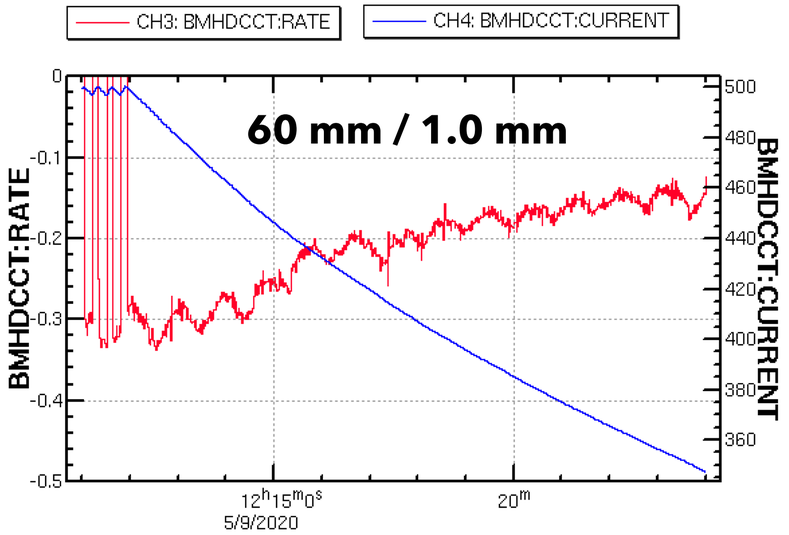
LER



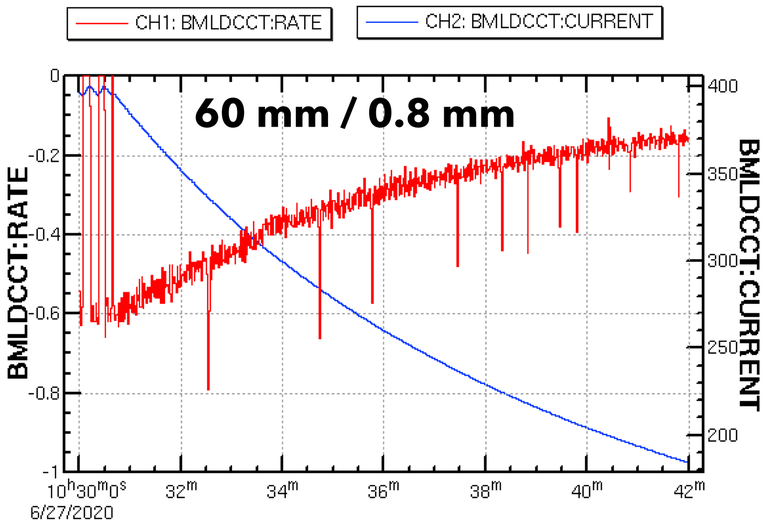
Low emittance (2 nm)

I = 400 mA(n_b = 783)
dI/dt = -1.2 mA/s
life = 333 sec

HER

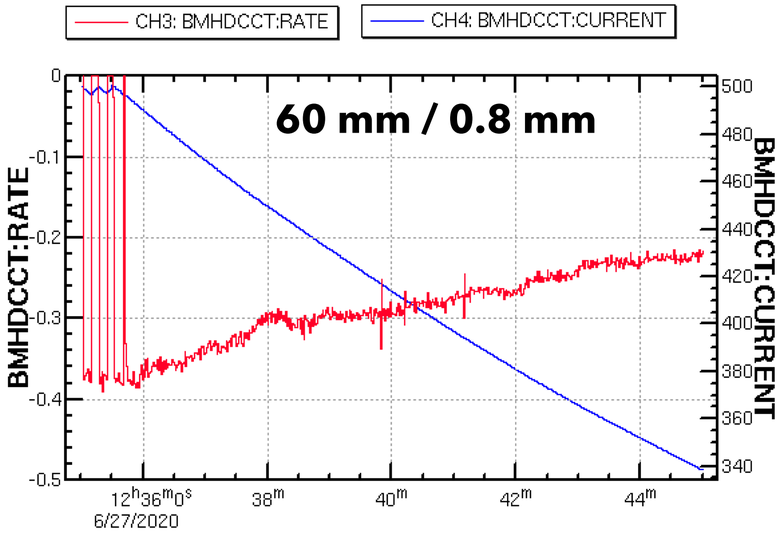


I = 500 mA(n_b= 783)
dI/dt = -0.30 mA/s
life = 1666 sec



High emittance (4 nm)

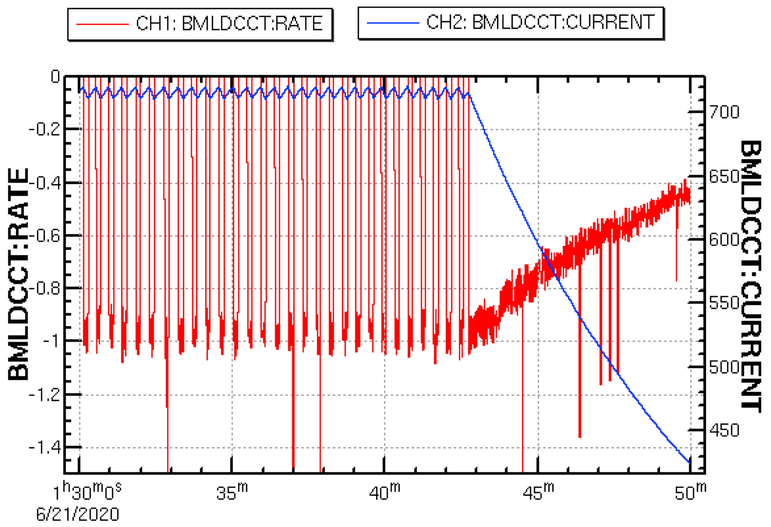
I = 400 mA(n_b = 783)
dI/dt = -0.6 mA/s
life = 666 sec



I = 500 mA(n_b= 783)
dI/dt = -0.38 mA/s
life = 1316 sec

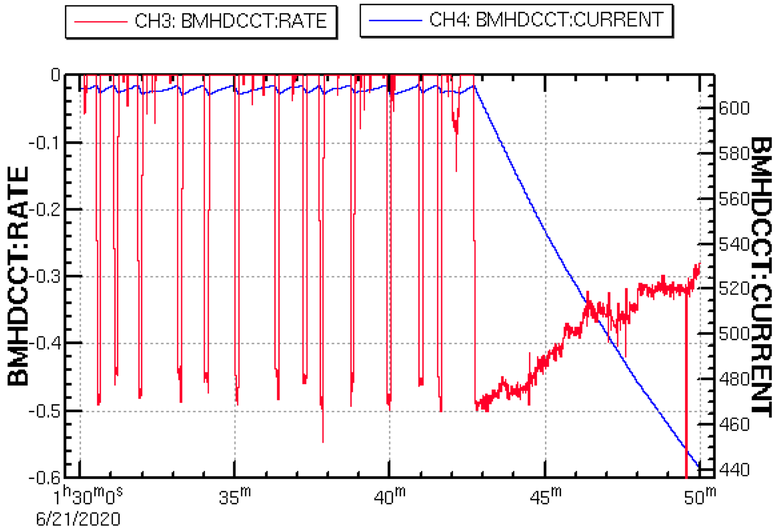
Lifetime for Collision

LER 80 mm / 1.0 mm



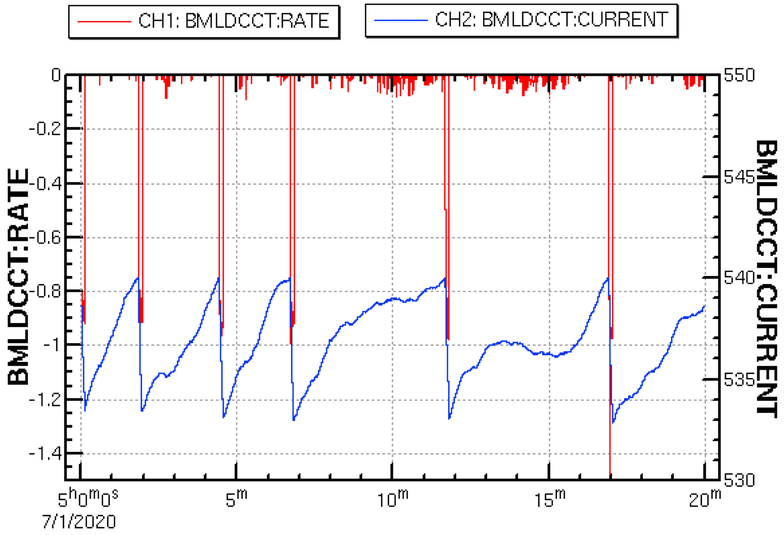
I = 720 mA(n_b = 978)
dI/dt = -0.95 mA/s
life = 760 sec
(High emittance)

HER 60 mm / 1.0 mm



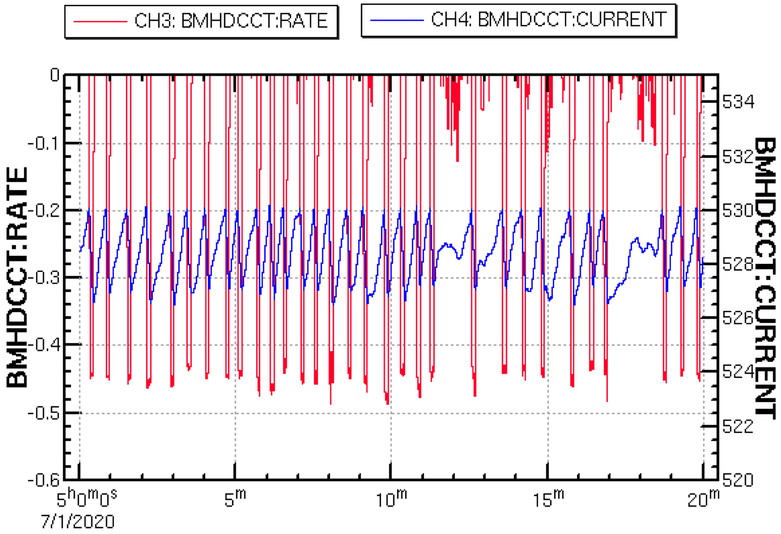
I = 610 mA(n_b = 978)
dI/dt = -0.48 mA/s
life = 1270 sec

60 mm / 0.8 mm



I = 540 mA(n_b = 978)
dI/dt = -0.90 mA/s
life = 600 sec
(High emittance)

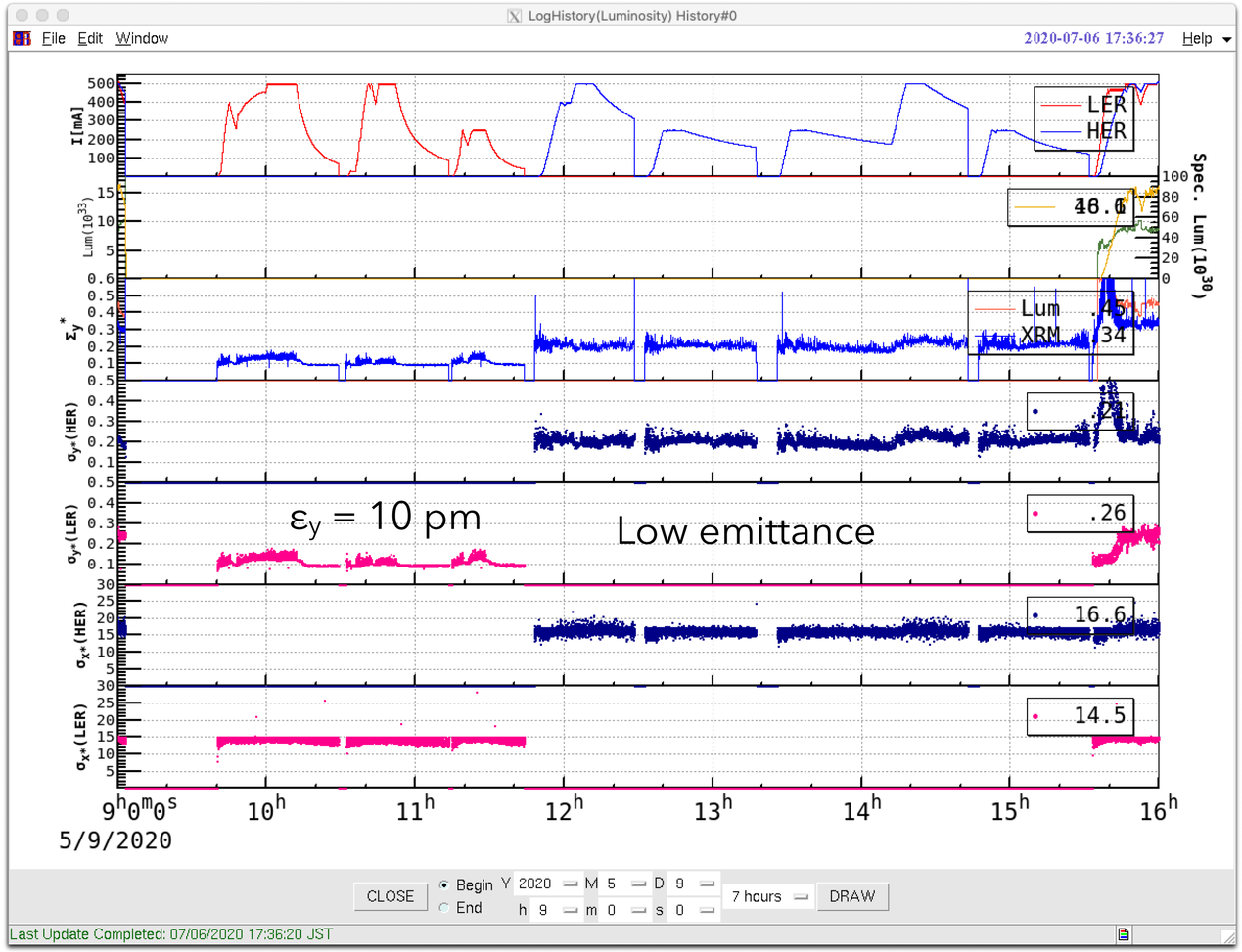
60 mm / 0.8 mm



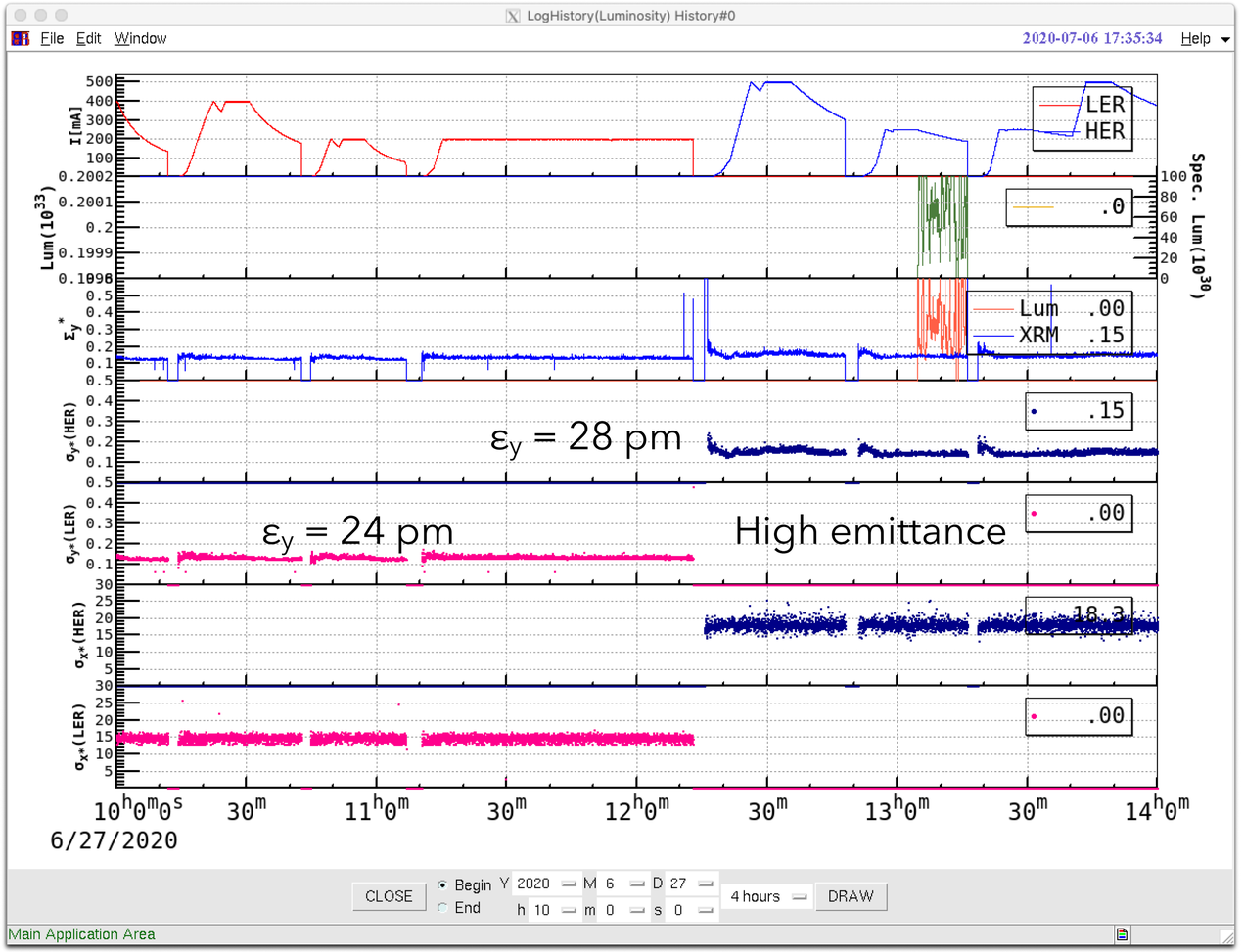
I = 530 mA(n_b = 978)
dI/dt = -0.45 mA/s
life = 1177 sec

Beam Size of Single Beam

LER : 80 mm / 1.0 mm, HER : 60 mm / 1.0 mm



LER, HER : 60 mm / 0.8 mm



Restart from Maintenance