Operation Status of SuperKEKB

B2GM

2022-01-24

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on behalf of SuperKEKB accelerator group

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Summary of 2021c run

[Y. Ohnishi]

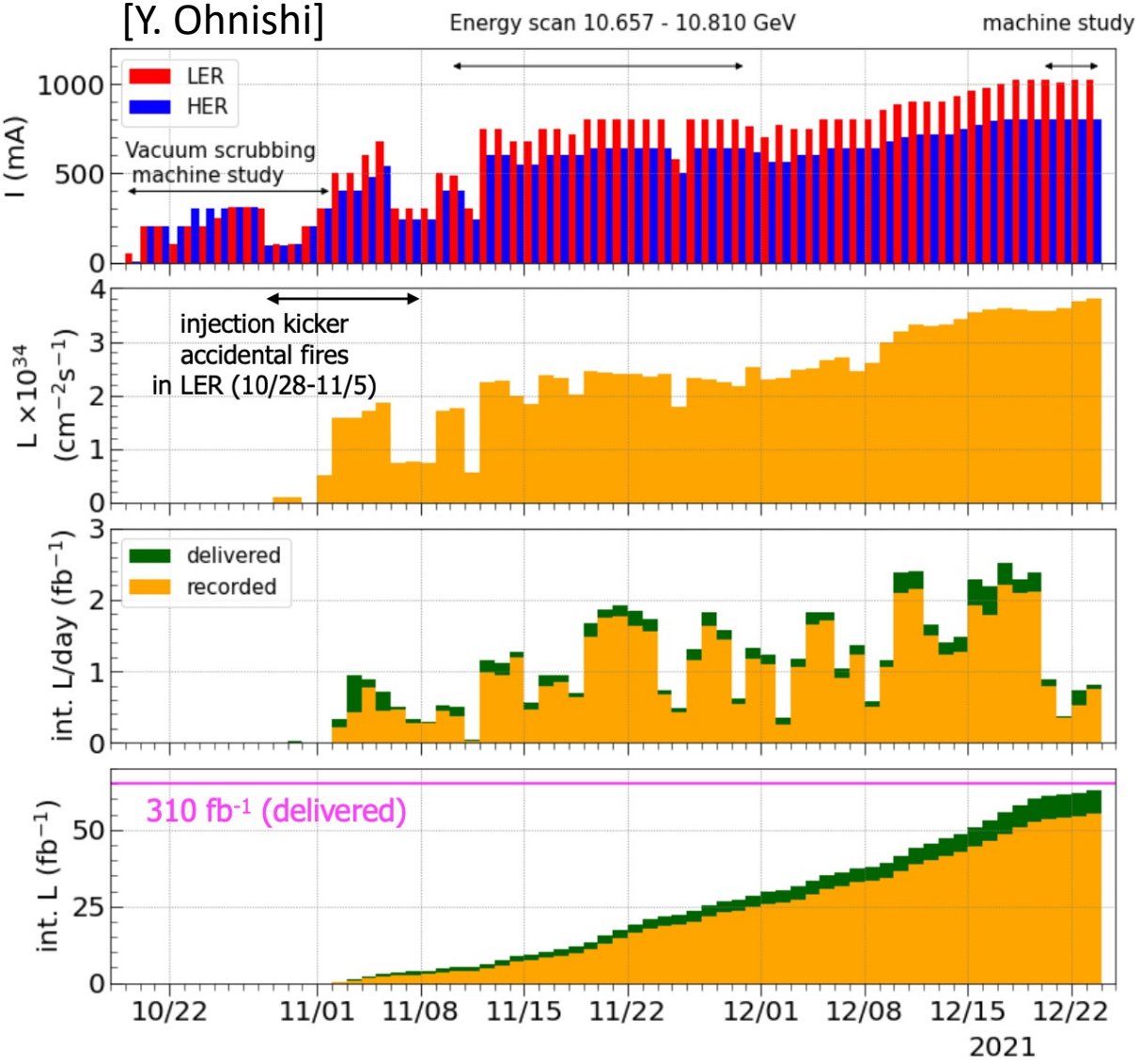
	SuperKEKB : Dec. 23, 2021		SuperKEKB : July 1, 2020		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	nm
Beam Current	1015	797	536	530	mA
Number of bunches	1370		978		
Bunch current	0.741	0.582	0.548	0.542	mA
Lifetime	600	1500	600	1177	sec
Horizontal size σ_x^*	17.9	16.6	15.5	16.6	μm
Vertical cap sigma Σ_y^*	0.339		0.317		μm*1
Vertical size σ_y^*	0.240		0.224		μm*2
Betatron tunes ν_x / ν_y	44.524 / 46.589	45.530 / 43.572	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	0.0433	0.0315	0.0345	0.0199	
Specific luminosity	6.45×10^{31}		6.90×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	3.81×10^{34}		2.00×10^{34}		$cm^{-2}s^{-1}$

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

- We had been able to operate with 1 A in the beam current of LER stably.
- We broke the luminosity record.

History of 2021c run

[Y. Ohnishi]

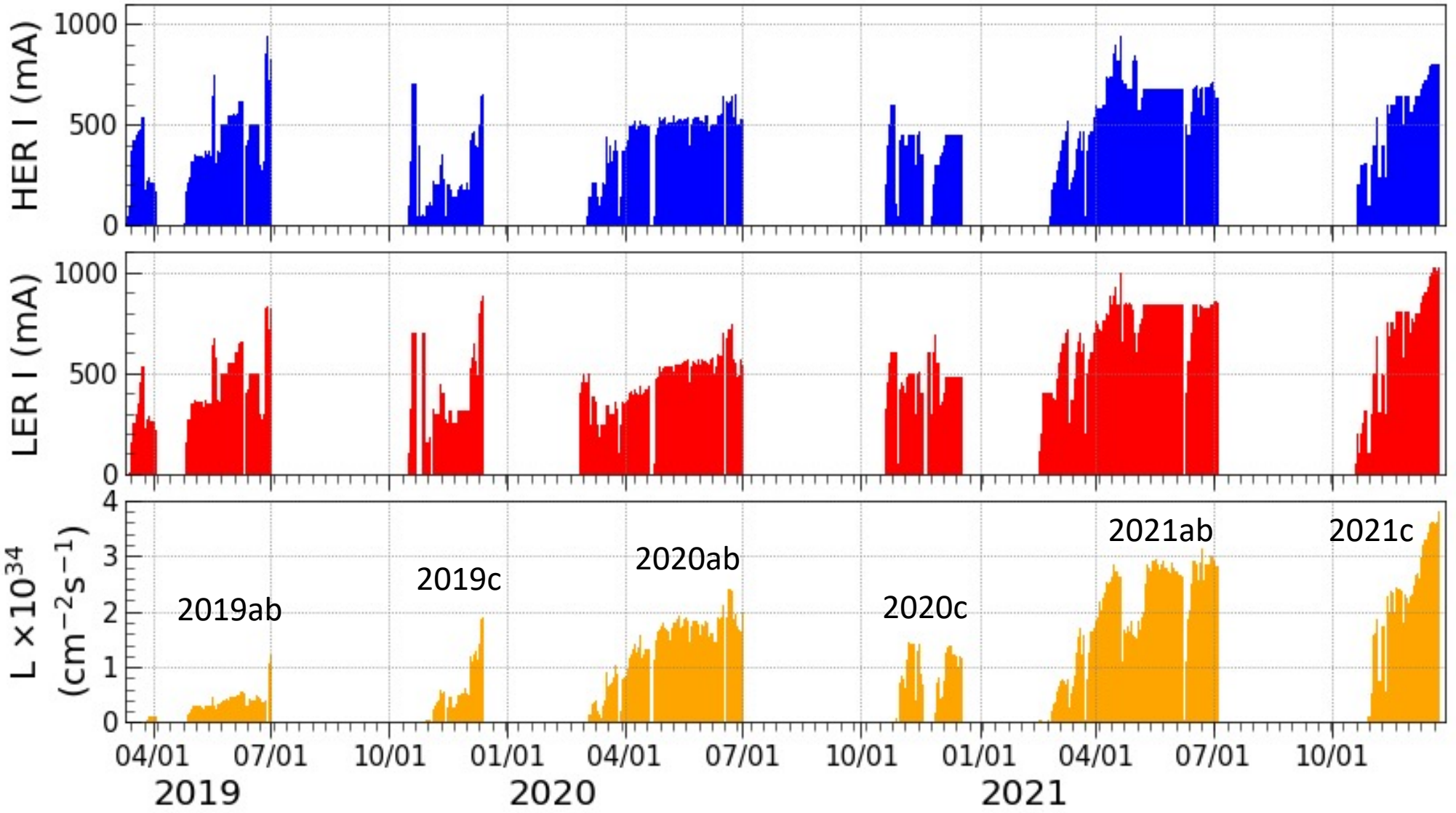


(We made a protocol of the baking run at the beginning of 2021c and it looks like it worked.)

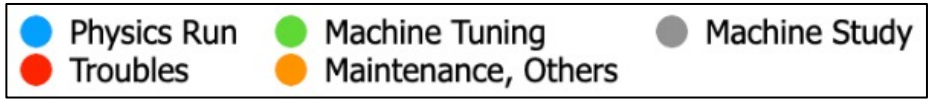
- Oct. 19th – Oct. 27th
  - Vacuum scrubbing and machine study for β_y^*=8 mm.
- Oct. 28th – Oct. 31st
  - Injection kicker accidental firings in LER. The beam current in LER had been limited to 200 mA or less.
- Nov. 1st – Nov. 10th
  - QCS quench due to earthquake
  - Injection kicker accidental firings in LER. Thyratrons replacement work on Nov. 8th.
- Nov. 11th – Nov. 29th
  - Energy scan: 10.657, 10.706, 10.751, 10.810 GeV
  - Thyratron replacement work on Nov. 24th.
- Nov. 30th – Nov. 8th
  - Increasing beam currents up to 800 mA/640 mA (LER/HER).
- Nov. 9th – Dec. 19th
  - Mini energy scan on Dec. 1. Changed +4 MeV.
  - QCS quench due to a human error on Dec. 6th
  - Increasing beam currents up to 1020 mA/820 mA (LER/HER, number of bunch: 1370).
- Dec. 10th – Dec. 23th
  - Machine studies

History of the luminosity

[Y. Ohnishi]

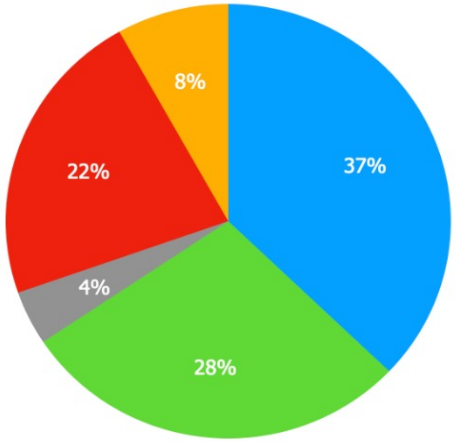


Operation Statistics for three years

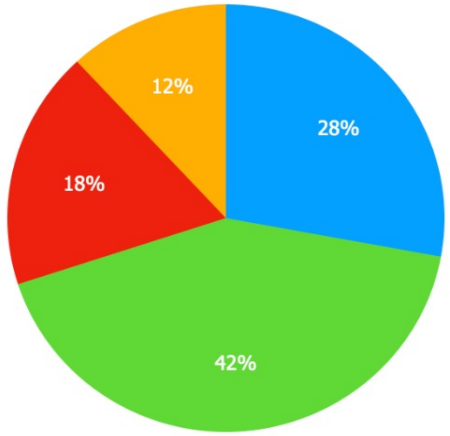


[Y. Ohnishi]

2019 a/b

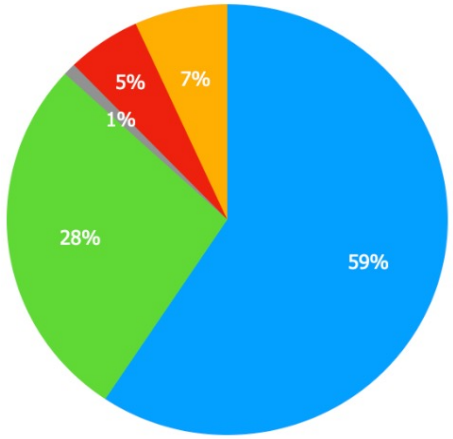


2019 c



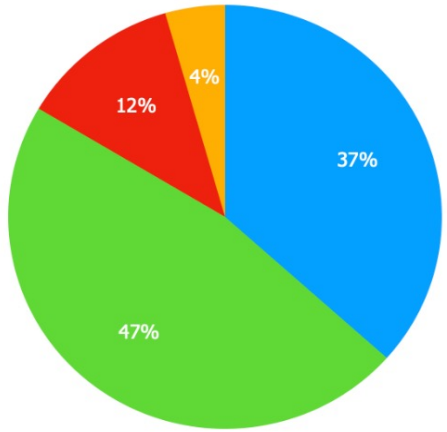
- β_y^* squeezing from 2 mm to 1 mm while taking steps of 1.5 mm and 1.2 mm

2020 a/b



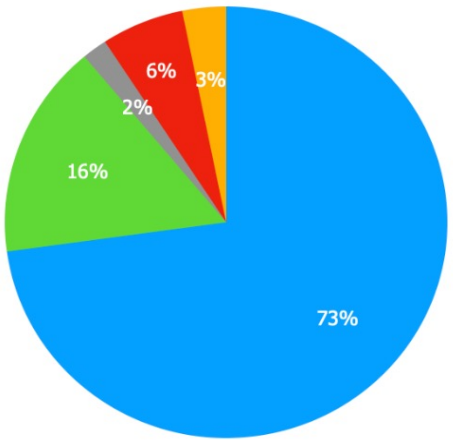
- Crab waist
- β_y^* squeezing from 1 mm to 0.8 mm

2020c



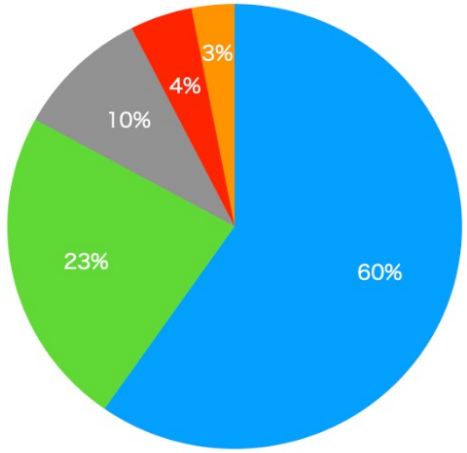
- Many optics trials
- Carbon jaw in D06V1 in LER
- Replaced damaged jaws of D02V1

2021a/b



- β_y^* = 1 mm
- Replaced damaged jaws of D02V1

2021 c



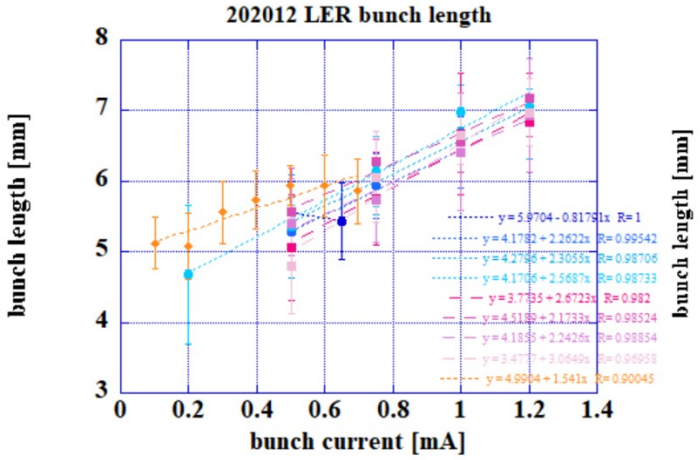
- β_y^* = 1 mm

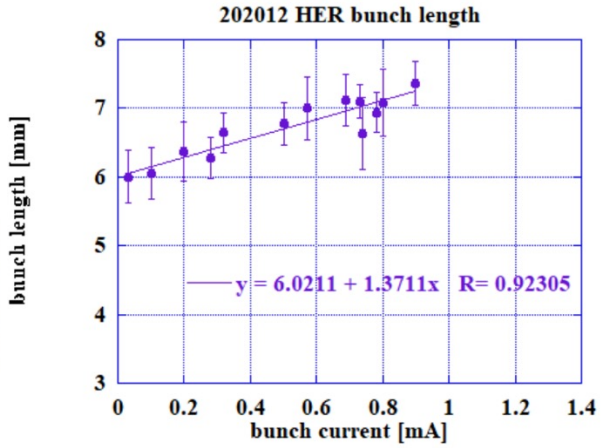
- The time to tune the machine increased because of the energy scans.
- No vertical collimator was damaged during 2021c.
  - ✓ Actually, this is the first time it didn't break during a run period.

Specific Luminosity

Bunch Length Measurement

Y. Ohnishi, Jan 21,2022

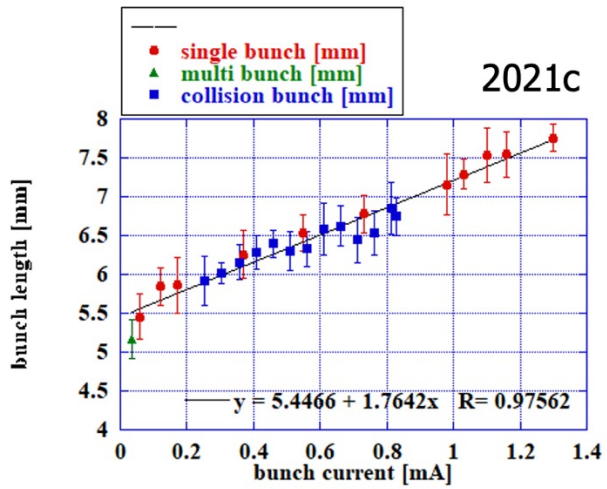




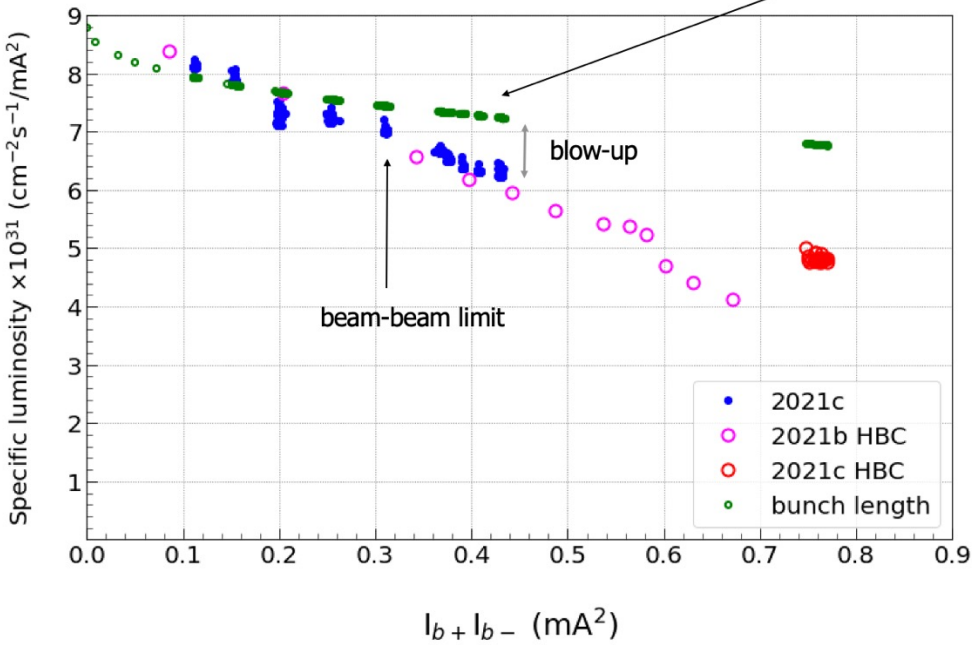
The design bunch length is used for zero bunch current instead of measured values.

$$\sigma_{z+}(I_{b+}) = 4.6 + 1.7642 \cdot I_{b+} \ (mm)$$
$$\sigma_{z-}(I_{b-}) = 5.1 + 1.3711 \cdot I_{b-} \ (mm)$$

$$L_{sp} = L_{sp}^{0} \frac{\sqrt{(\sigma_{z+}(0))^2 + (\sigma_{z-}(0))^2}}{\sqrt{(\sigma_{z+}(I_{b+}))^2 + (\sigma_{z-}(I_{b-}))^2}}$$



H. Ikeda



L_{sp}^{0} = 8.8 x 10^{31} $cm^{-2}s^{-1}/mA^2$

$$L_{sp} = \frac{1}{2\pi e^2 f_0 \phi_x} \frac{1}{\Sigma_z \Sigma_y^*}$$

(I) I_{b+} = 0 - 0.6 mA, I_{b-} = 0 - 0.48 mA, $I_{b+}I_{b-}$ = 0 - 0.32 mA^2
(II) I_{b+} = 0.6 - 0.9 mA, I_{b-} = 0.48 - 0.72 mA, $I_{b+}I_{b-}$ = 0.32 - 0.64 mA^2
(III) I_{b+} = 0.9 - 1.2 mA, I_{b-} = 0.72 - 0.76 mA, $I_{b+}I_{b-}$ = 0.64 - 0.92 mA^2

(I) The beam-beam blowup is small and the bunch lengthening can explain the drop of specific luminosity.
(II) The beam-beam limit appears. The drop of specific luminosity is explained by beam-beam effect instead of TMCI. The candidates are chromatic X-Y couplings, and so on.
(III) The head-tail instability or TMCI affect the drop of specific luminosity. The impedance in the interaction region (QCS) and the vertical collimators. The unstable mode is -1 mode. TMCI threshold is about 2 mA/bunch. Still need to study for head-tail of TMCI, no answer yet.

Status of Sub-systems – RF system

[K. Watanabe *et al*.]

- There had been no detuned stations, and they had been able to keep the total cavity voltage for 1020 mA in LER and 820 mA in HER.
- ARES cavity
  - Averaged trip ratio = 0.7 times/cavity/90 days
  - D05-A cavity: Added a digital camera during summer shutdown to observe abnormal emission, and this emission has been observed when the break downs occur frequently.
  - D04-A: Abnormal emissions with pressure rises had occurred, so we decreased the cavity voltage temporally. After that, the emissions hadn't occurred, so we set it the default value on Dec. 8th.
- LLRF (Low Level RF)
  - A master oscillator for DR broke and was replaced on Dec. 2nd.
  - Beam aborts by μ=-1 mode excitations in HER on Nov. 5th and Dec. 8th.
- High Power RF
  - Number of beam aborts caused by the high power systems: total 22
    - Crowbar: 10 times, microwave transmission circuits: 11, steam cooling system: 1, infrastructure: 1

Status of Sub-systems – Magnet system

QCS

[S. Nakamura *et al*.]

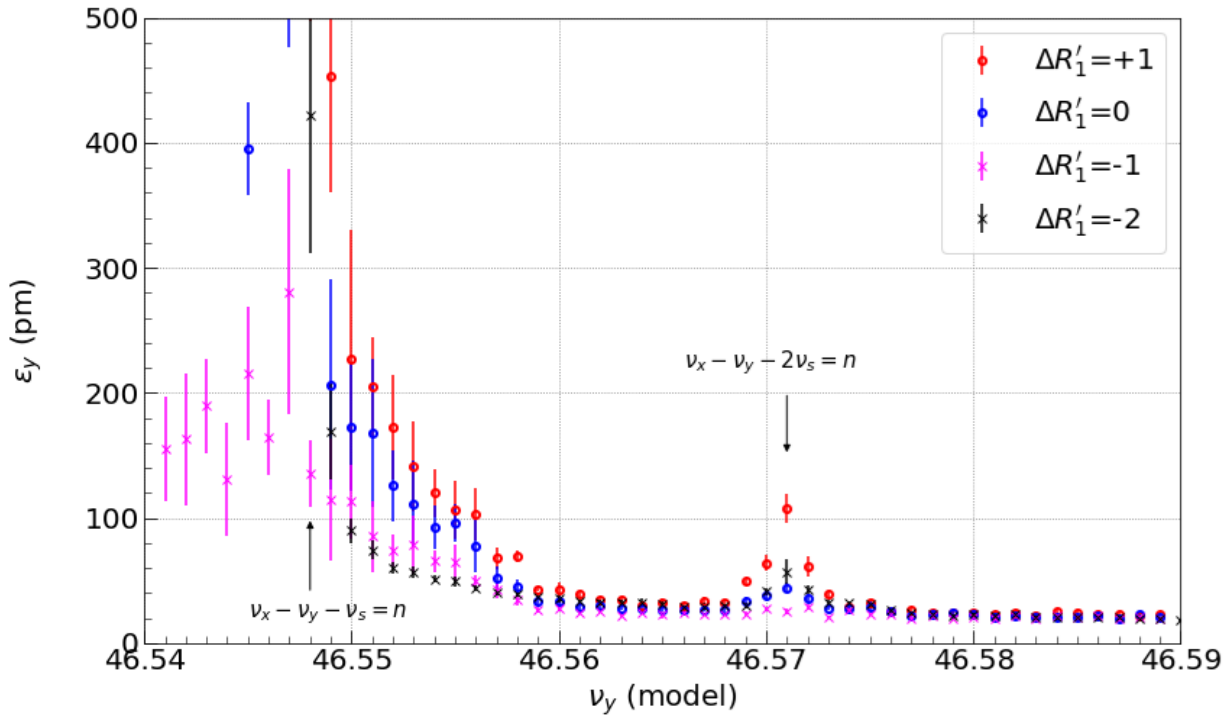
- power supply
  - Minor failure on the digital feedback system.
- Quench
  - Caused by earthquake on 2021-11-01 06:14. After that, a threshold of the quench detectors has increased.
  - Caused by mis-operation for the cryogenic system on 2021-12-06 17:07.
  - There was no quench derived from beam loss.

Normal conducting

- power supply
  - Communication failure in D09. Inserted a hub in the middle of the ARCNET chain.
  - Major failure on a small size power supply named ZVQLY2RE_1. A circuit board broke, and we were not able to inject the beam. It was replaced immediately.
  - Minor failure issued by cooling fans on a small size power supply named ZVQR3OLE.
  - Oscillation phenomenon in small size power supplies manufactured by a maker.
  - Operation of a synchronous setting system has started [A. Morita].
- magnets
  - No operation stop due to the troubles by the magnets.
  - A downward trend of flow rate in HER-QA type magnets.
  - Operation of rotatable sextuple magnets has started to suppress the chromatic coupling. We have been able to rotate them with holding the beam in the ring.

Status of Sub-systems – Magnet system

- Suppression of synchro-beta resonance by changing the rotation angle of the rotatable sextuple magnets.
- The degradation of the linear optics by this change is small.
- We can rotate with holding the beam.
- $\Delta R_1'$ = -1 has been adopted.

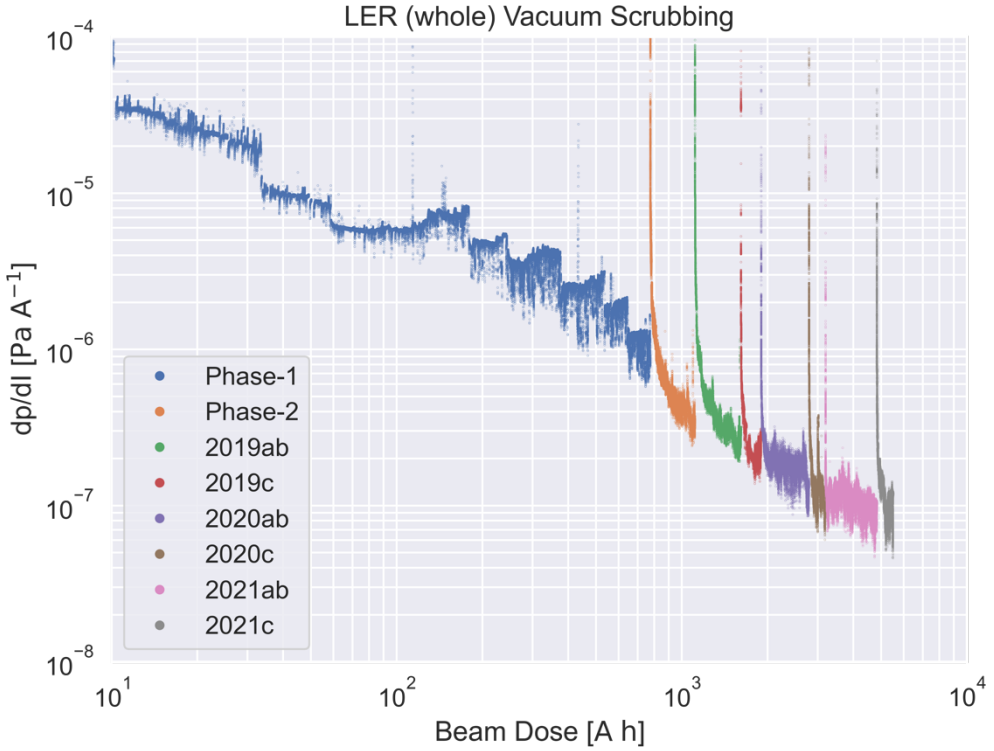


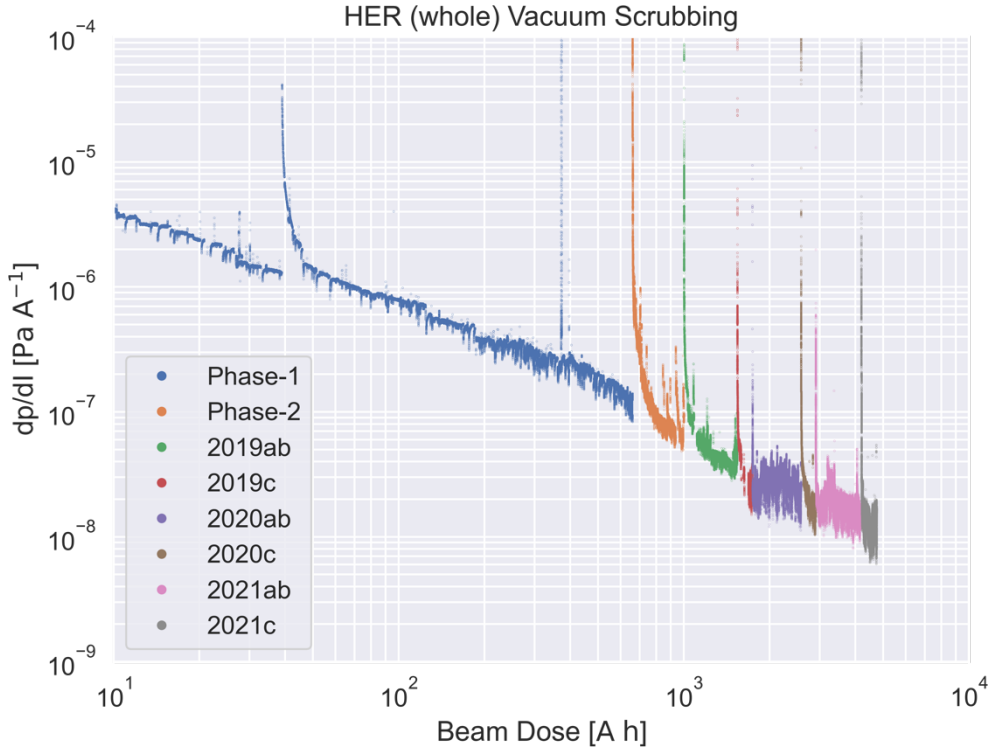
[Y. Ohnishi]

Status of Sub-systems – Vacuum system

[K. Shibata *et al*.]

- Beam dose during 2021c (HER: 553.1 Ah, LER: 678.4 Ah)





- Troubles
  - D06H3 collimator was damaged by the accidental firings of the injection kickers in LER. →We replaced them with new ones during this shutdown.
  - A chiller, which was used for the QCS beam-pipes and so on, on IR D02 side stopped twice by the overload on Nov. 13th and Dec. 14th. → We have plans to install an additional chiller on IR D02 side during this shutdown.
  - An abnormal pressure rise at an arc section in LER D04 (CCG D04_L09D, L10). The cause is still unknown, but the pressure has decreased and kept the lower level (~2×10^{-8} Pa).

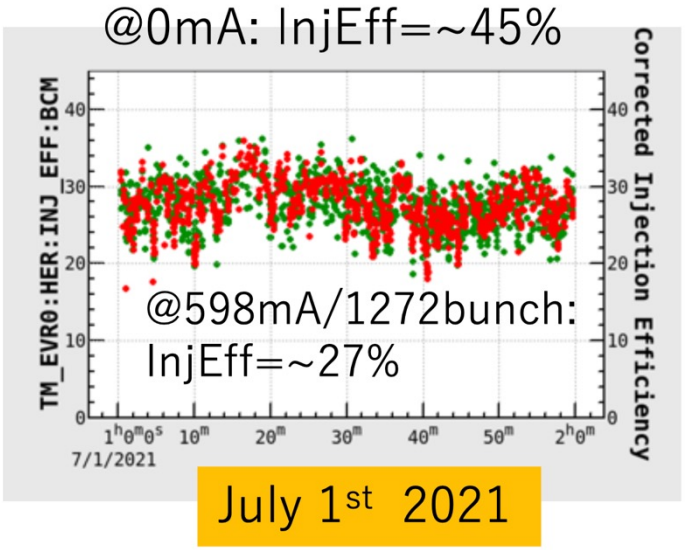
Status of Injection

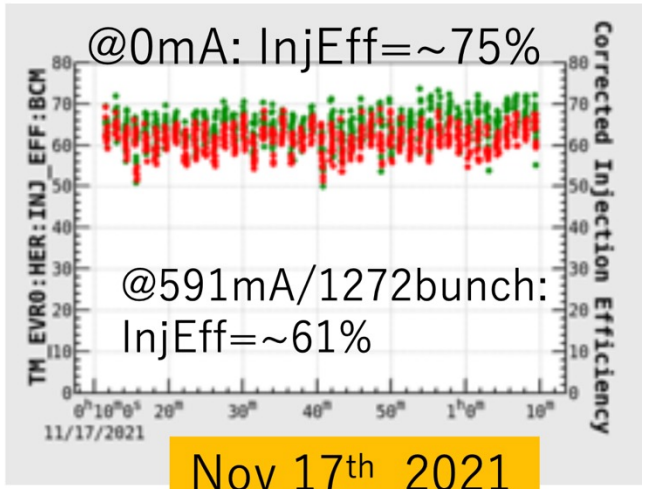
[N. Iida *et al.*]

- Injection efficiency in HER has been improved from 60% to 80% in maximum for β_y^*=1 mm.
  - The horizontal orbit from the septum magnets to the injection point has been closer to the design orbit.
  - A BPM named “injection-BPM” to monitor the injection beam has been started to use in the operations and very useful for the injection tunings.
- Beam clearance in the injection beam channel is very tight.

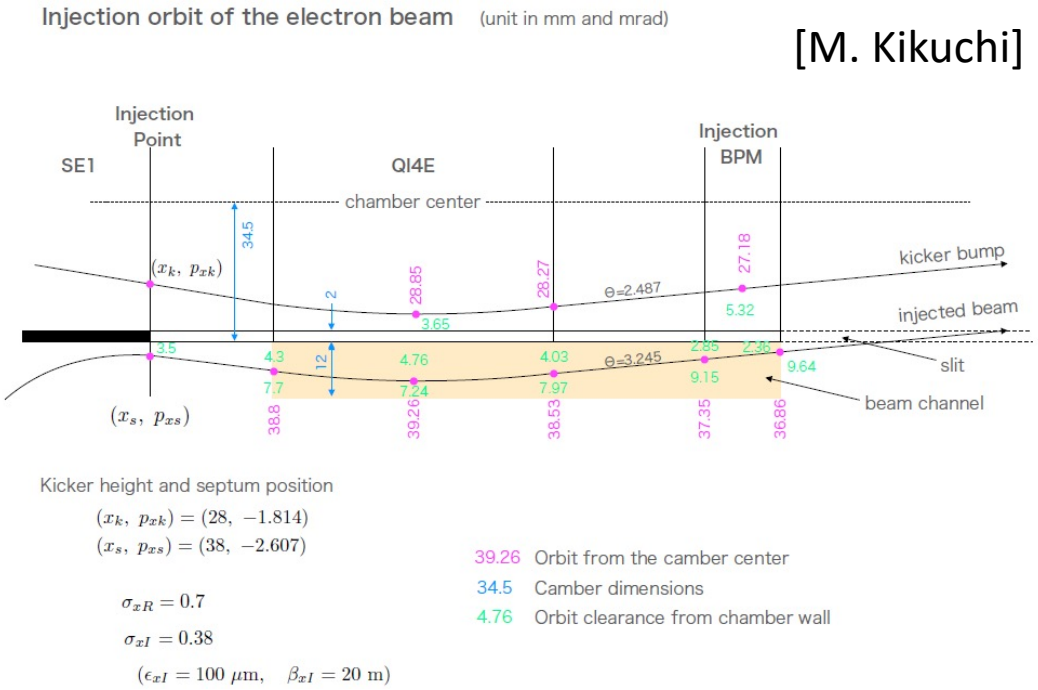
  →We have plans to widen an aperture of the injection beam channel at the injection point during LS1 (Long Shutdown-1), and this could improve the injection efficiency further.
- Emittance blow-ups in the beam transport lines have still occurred.
  - The horizontal emittance blowups may be caused by radiation excitation and CSR (Coherent Synchrotron Radiation). Some simulation works are on going in order to understand this.

[Y. Funakoshi]

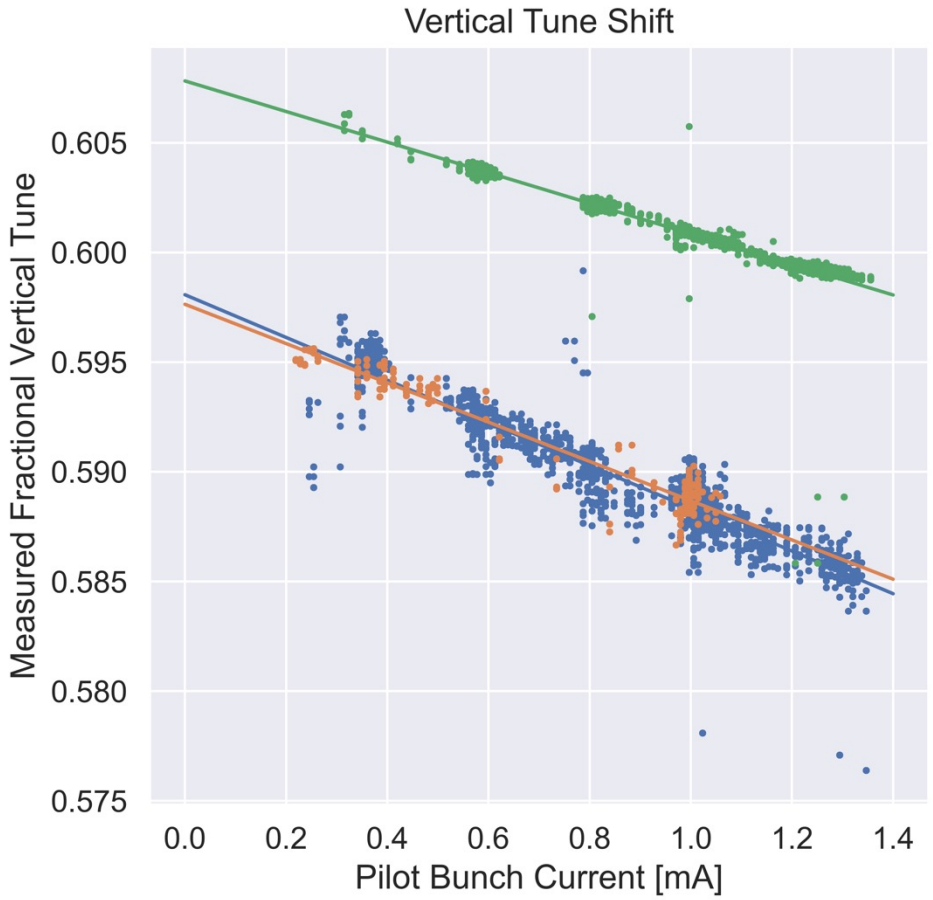




[M. Kikuchi]



Impedance Issues in LER



ν_y = 0.5950 (model), $\Sigma\beta_y k_y$=3.41e+16 V/C (calc), β_y^* = 1 mm, 2021-12-22
fit: y=(-9.74e-03)x + (0.598), $\Sigma\beta_y k_y$=4.86e+16 V/C
ν_y = 0.5950 (model), $\Sigma\beta_y k_y$=2.62e+16 V/C (calc), β_y^* = 1 mm, 2021-12-22
fit: y=(-8.95e-03)x + (0.598), $\Sigma\beta_y k_y$=4.47e+16 V/C
ν_y = 0.6050 (model), $\Sigma\beta_y k_y$=3.47e+16 V/C (calc), β_y^* = 8 mm, 2021-10-26
fit: y=(-6.97e-03)x + (0.608), $\Sigma\beta_y k_y$=3.48e+16 V/C

$$\Delta\nu_{x/y} = \frac{I_b T_0}{4\pi(E/e)} \Sigma\beta_{x/y} k_{x/y}$$

T_0 = circ./c ~1e-5 s
E/e = 4 GV

- The $\Sigma\beta_y k_y$ on this study (β_y^*=1 mm) is almost same as that on Oct. 26th (β_y^*=8 mm), however the tune shift on this study in β_y^*=1 mm is somehow larger.
- During this study, we had opened apertures of some vertical collimators to reduce the $\Sigma\beta_y k_y$ by ~20%, but the measured tune shift didn't change much.

Impedance Issues in LER

Assuming σ_z = 6 mm

βy* = 1 mm

	β_y [m]	$\beta_y k_{y,D}$ [V/C]	$\beta_y k_{y,Q}$ [V/C]
QCSR	402.76	5.96e15	9.91e10
QCSL	431.74	5.43e15	4.54e10

$\Sigma\beta_y k_y$ on Dec. 22nd

	Narrow setting [V/C]	Wide setting [V/C]
v. collimator	3.41e16	2.62e16
QCS + v. collimator	4.65e+16	3.80e16
Measured	4.86e16	4.47e16

βy* = 8 mm

	β_y [m]	$\beta_y k_{y,D}$ [V/C]	$\beta_y k_{y,Q}$ [V/C]
QCSR	49.73	7.36e14	1.22e10
QCSL	49.89	6.71e14	5.60e10

$\Sigma\beta_y k_y$ on Oct. 26th

	[V/C]
v. collimator	3.47e16
QCS + v. collimator	3.55e+16
Measured	3.48e+16

- The $\Sigma\beta_y k_y$ becomes comparable between the calculated and measured one by adding the wake in QCS beam-pipes.
- However, there is still a discrepancy between them when we opened the apertures on Dec. 22nd.

✓ Note: The βy in the QCS beam-pipes is averaged value between QC1LP515 and QC2LP2475 or QC2RP2715 and QC1RP485.

- The detail was presented on the MDI parallel session on Jan. 20th (https://kds.kek.jp/event/40691/).

Future plans (2022ab)

- Scenario to increase beam currents [Y. Ohnishi, Y. Funakoshi].
  - We're going to gradually increase the total beam currents with increasing the number of bunches and keeping the bunch current.
  - At some point, we're going to squeeze the βy^* to 0.8 mm.
  - Periodic machine studies are planed (once a month, for example).

	Dec. 23, 2021		HC1		HC2		Unit
Ring	LER	HER	LER	HER	LER	HER	
Beam Current	1015	797	1159	910	1783	1365	mA
Number of bunches	1370		1565		2346		
Bunch current	0.741	0.582	←	←	←	←	mA
Bunch current product	0.431		←		←		mA^2
Lifetime	600	1500	←	←	←	←	sec
Necessary injection charge (100 % eff.)	17.0	5.35	19.4	6.10	29.9	9.16	nC
β_x^* / β_y^*	80 / 1.0	60 / 1.0	←	←	←	←	mm
Specific luminosity	6.45×10^{31}		←		←		$cm^{-2}s^{-1}/mA^2$
Luminosity	3.81×10^{34}		4.35×10^{34}		6.52×10^{34}		$cm^{-2}s^{-1}$

βy^*=0.8 mm: 5.44×10^{34} 8.16×10^{34}

Future plans (2022ab)

[Y. Ohnishi, 2021c summary meeting]

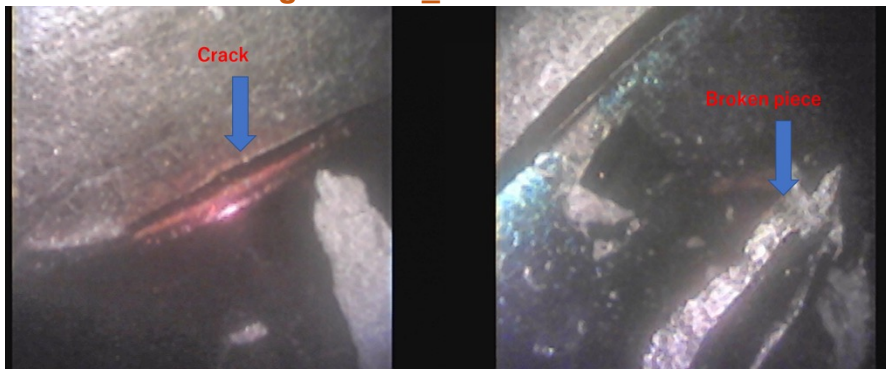
Target of 2022ab

Base Plan	Aggressive Plan	
Target 1 of 2022ab I_{LER} > 1.35 A	Target 1 of 2022ab I_{LER} > 2.0 A	← Bunch current, number of bunches, and beta at IP affect the total beam currents.
Target 2 of 2022ab Lp = 5 x 10^{34}	Target 2 of 2022ab Lp = 7.5 x 10^{34}	Beta at IP : 80 mm / 1 mm (LER), 60 mm / 1 mm (HER) and try 60 mm / 0.8 mm (LER, HER)
Target 3 of 2022ab int. L > 480 fb^{-1}	Target 3 of 2022ab int. L > 620 fb^{-1}	Issues: injection, lifetime, background, collimator damage beam-beam, head-tail instability(?) and machine stabilities

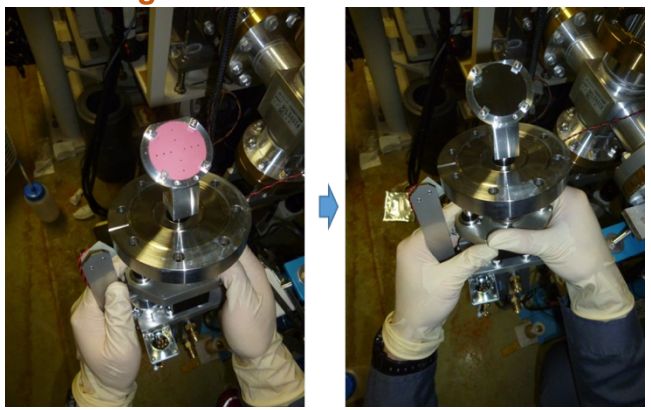
Maintenance works during winter shutdown

- Replacement of LER D06H3 collimator jaws.
  - The jaws were found to be heavily damaged by steered abnormal beam due to accidental firings of injection kickers.
- Exchange of screen monitors in beam transport lines
  - Some alumina-fluorescence-type screen monitors were exchanged to OTR (Optical Transition Radiation)-type ones for improving the sensitivity.
- Replacement of primary transformer of DR bending magnet power supply
  - The problem was found in the last summer shutdown and the rental trance had been used since then.
- Other usual maintenance, including periodic inspection of refrigerator system.
- Measures against aging facilities
  - Replacement of pure water pumps for vacuum chamber lines at Tsukuba.
    - We had no spears up to now since 2021a run.
  - Repairment of untreated water pumps for RF dummy loads lines at Fuji.
    - It was failed during 2021c run.
  - Roof waterproofing work at Fuji power-supply building.

Damage of D06_H3 collimator heads



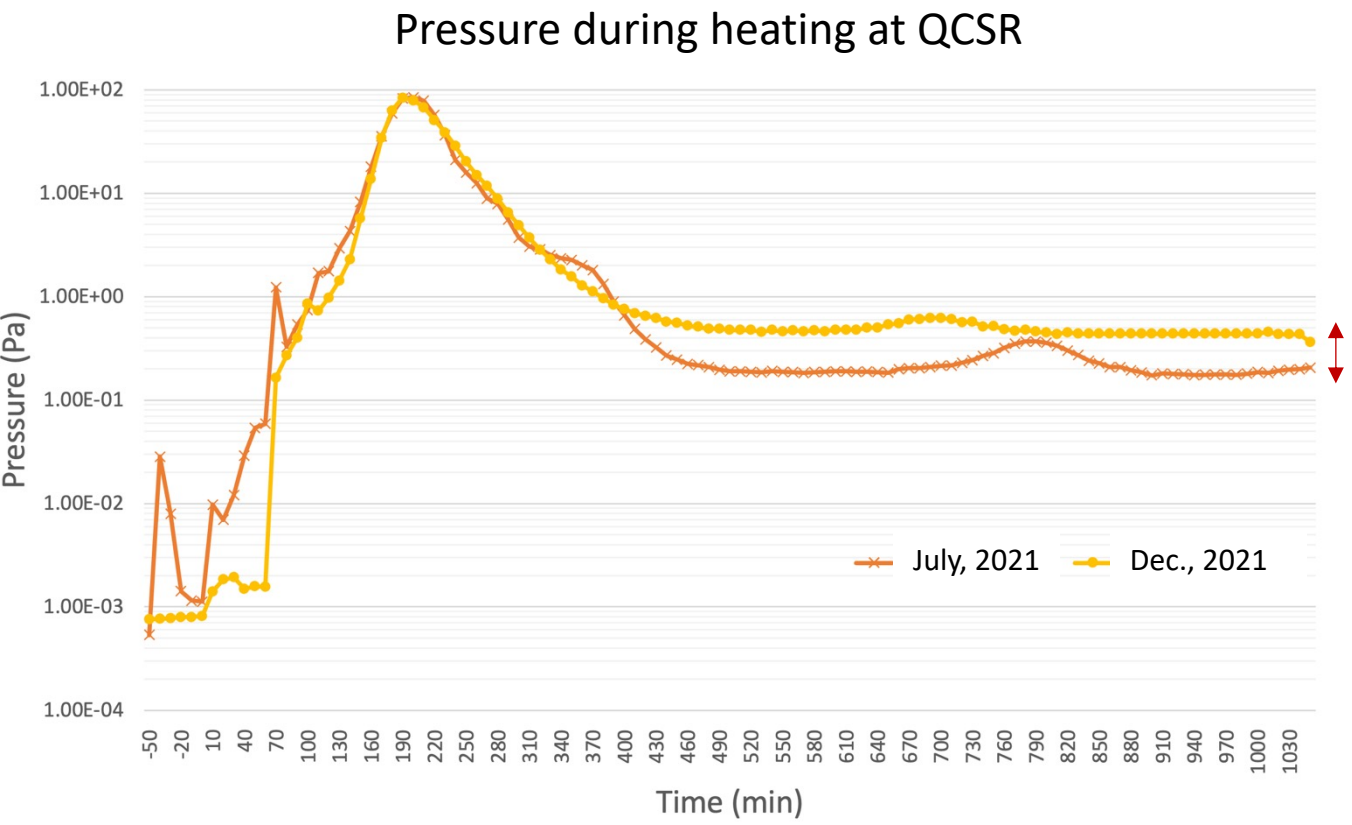
Exchange of screen monitors in BT lines



Water pumps at Fuji

Water leak of MR power supply building

Leakage of vacuum insulation tank of QCSR



[N. Ohuchi]

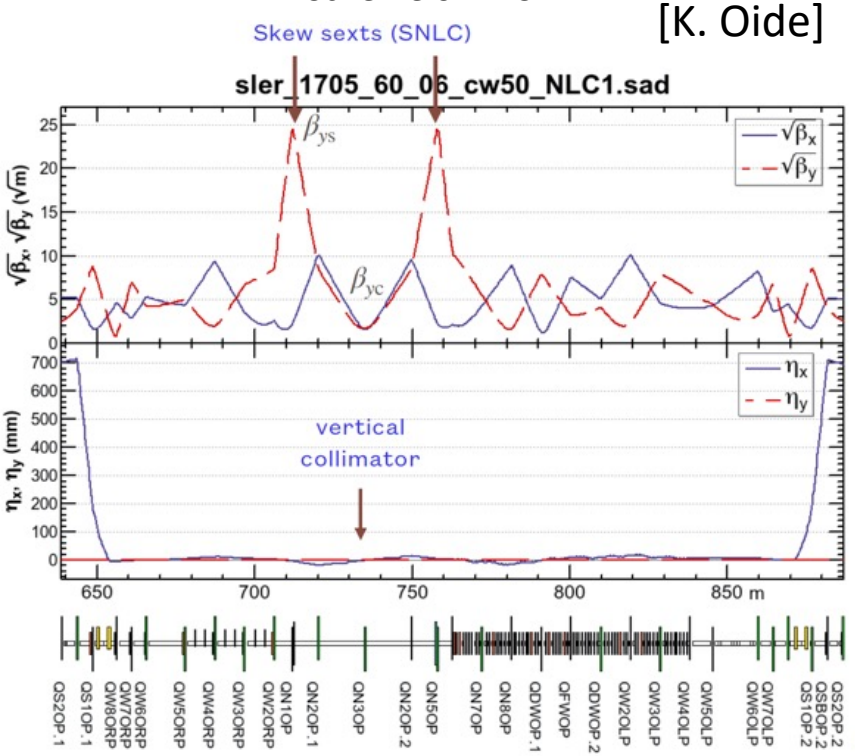
- QCS refrigerator stopped on Dec. 24th, 2021.
- The increase of vacuum pressure (peak value) in the insulation tank was almost the same to that after 2021b.
- July, 2021: The existing vacuum pump had driven.
- Summer shutdown: a turbo molecular pump was added and directly connected to the tank.
- Dec, 2021:The existing pump was stopped during the heating, and only an additional pump had driven.

→This may indicate that the leak rate gets larger because the effective pumping speed of the additional pump is higher than that of the existing one.

Future plans (LS1)

- A biggest task planned in LS1 is Non Linear Collimator (NLC) at LER OHO straight section.
  - NLC could fully work instead of D06V1 collimator and reduce the impedance by opening the aperture of D06V1.
  - However, the impedance around IR could be dominant with squeezing the β_y^*.
  - On the other hand, there are some mitigation schemes that we've found, which are BxB FB, chromaticity, tune and so on, to suppress the vertical beam size blow-up.
  - We need to discuss carefully whether NLC is really needed.

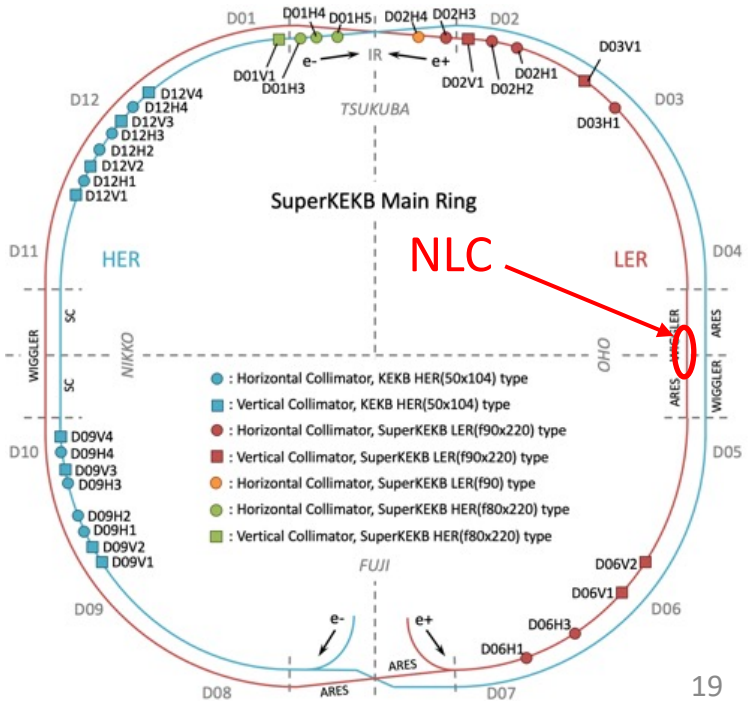
Scheme of NLC [K. Oide]



βy and aperture of vertical collimators

	β_y [m]	2021-06-30 [mm]	2021-07-02 [mm]
D06V1 top	67.3	3.06	3.84
D06V1 bottom		-2.65	-2.65
D06V2 top	20.6	2.27	2.25
D06V2 bottom		-2.26	-2.24
D03V1 top	17.0	8.00	7.99
D03V1 bottom		-8.00	-7.99
D02V1 top	13.9	1.30	1.71
D02V1 bottom		-1.14	-1.35
NLC@OHO	2.9	5.7	5.7

Collimator Location



Activities of International Task Force (ITF)

- Optics sub-group (A. Morita, H. Koiso)
  - 3rd meeting on 2021-11-17 (https://kds.kek.jp/event/40129/)
    - Dynamic Aperture in the Low Energy Ring of SuperKEKB, Yunhai Cai

- Beam-beam sub-group (D. Zhou, K. Ohmi)
  - 6th meeting will be hold on 2022-01-25 4:30pm JST (https://kds.kek.jp/event/40786/)
    - Preliminary Simulation Study with 'realistic' Crab Sextupoles, Yuan Zhang
    - Analysis of beam-beam instability with longitudinal impedance for SuperKEKB, Chuntao Lin
    - Updates on beam-beam simulations and results of recent beam-beam machine study, Demin ZHOU
  - 5th meeting on 2021-12-15 4:30pm JST (https://kds.kek.jp/event/40470/)
    - Beam-beam performance in the presence of lattice resonances in SuperKEKB, Kazuhito Ohmi
    - Analysis of coherent beam-beam instability, Chuntao Lin

    and so on

- TMCI sub-group (M. Migliorati, T. Ishibashi)
  - 5th meeting will be hold on 2022-01-27 5pm JST (https://kds.kek.jp/event/40778/)
    - Machine study report, Takuya Ishibashi

    and so on
  - 4th meeting on 2021-12-16
    - ECHO3D and its application, Igor Zagorodnov
    - Computation of the impedance of collimators in the LHC, Mounet Nicolas

    and so on

- Linac sub-group (M. Sato, S. Matsumoto)
  - Organization is in progress.

Activities of ITF

- Anyone can join the group-mail-list by sending an email to {group-name}-request AT ml.post.kek.jp with a subject of “subscribe”

- Mailing list of the sub-groups
  - skb-itf-bb AT ml.post.kek.jp: for Beam-beam
  - skb-itf-opt AT ml.post.kek.jp: for Optics
  - skb-itf-tmci AT ml.post.kek.jp: for TMCI
  - skb-itf-linac AT ml.post.kek.jp: for Injector Linac

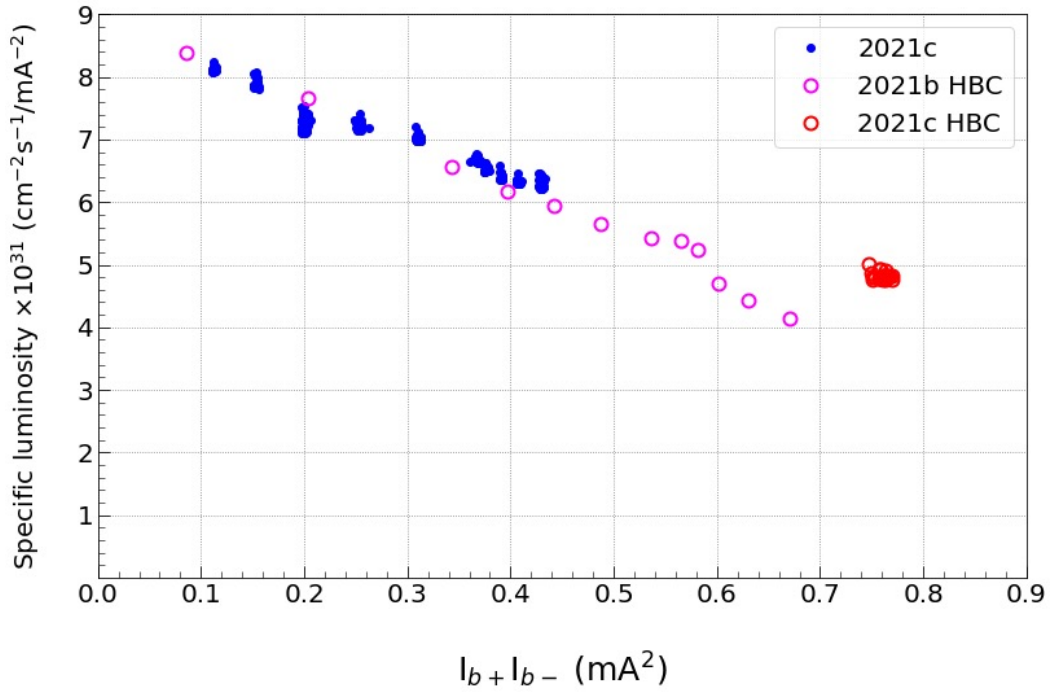
Thank you for your attention.

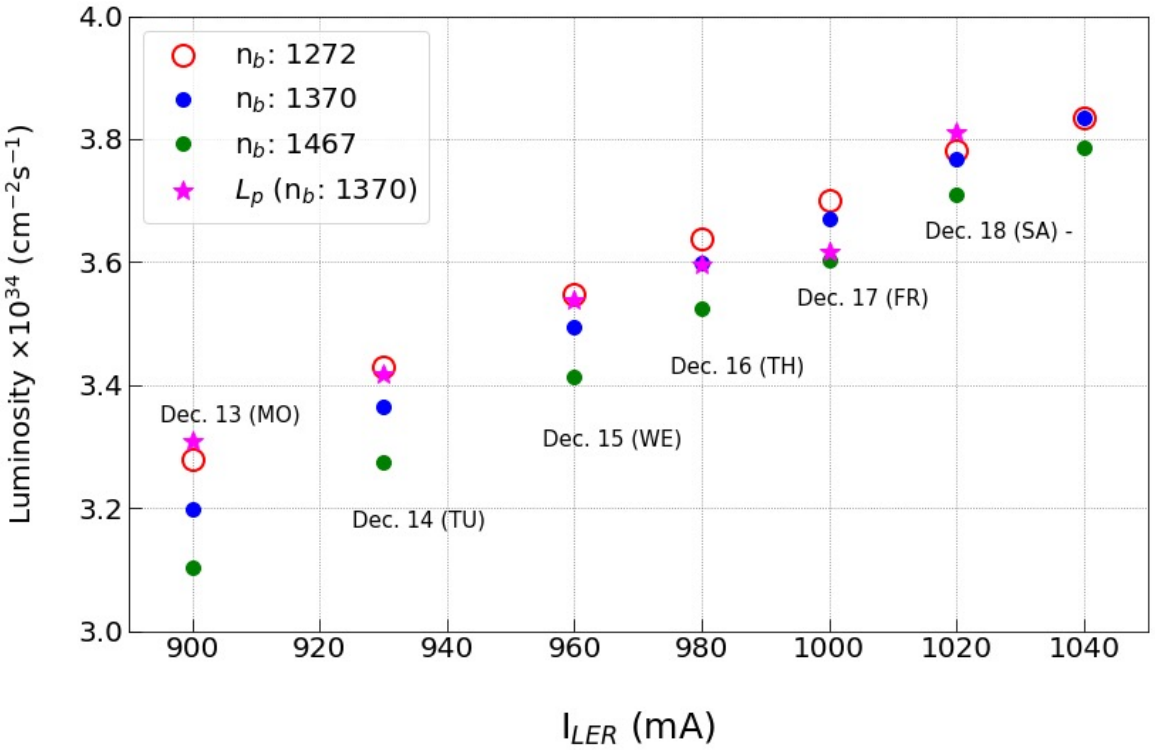
backup

Specific Luminosity

[Y. Ohnishi]

(HBC: High Bunch Current study)





Future plans (2022ab)

- Attainable luminosity scaled from high bunch current study [Y. Funakoshi].

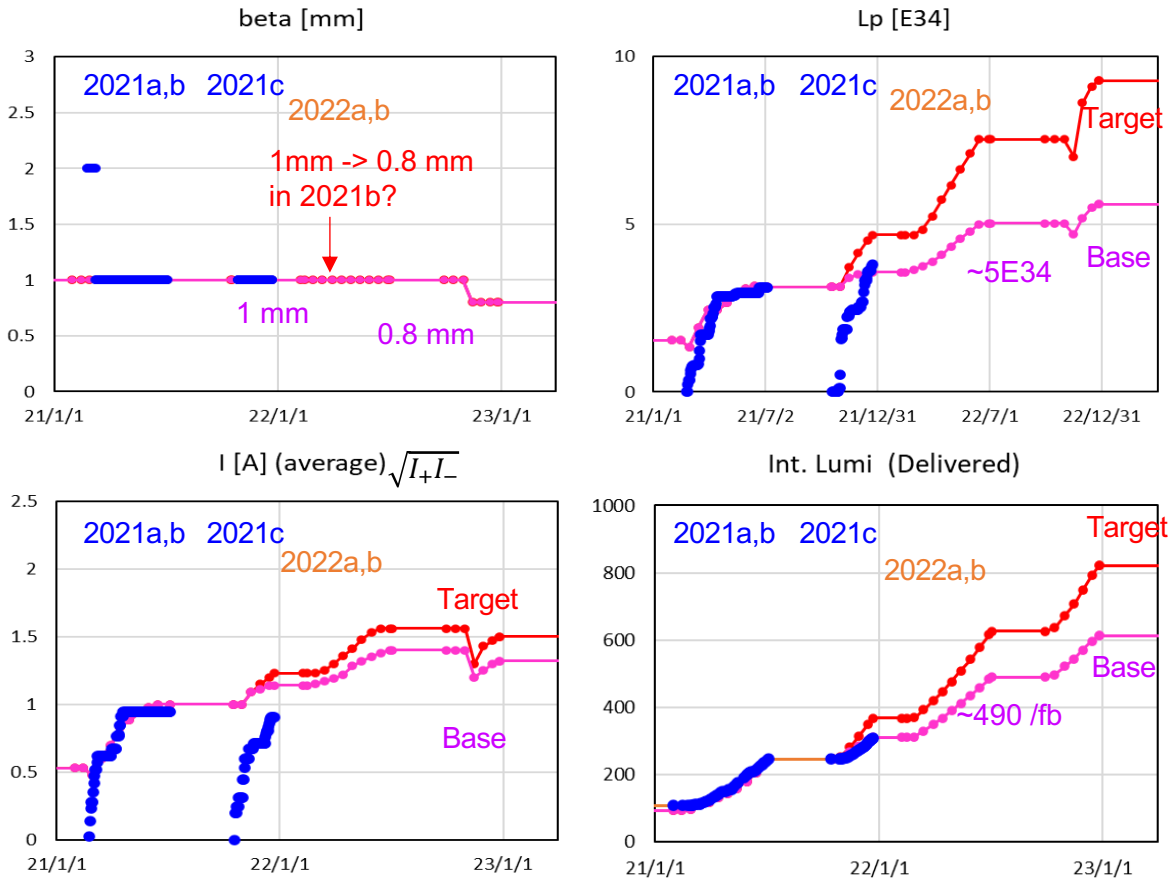
	LER	HER		LER	HER	LER	HER
# of bunches	392+1			1564+1		2345+1	
Luminosity	1.49×10^{34} cm^{-2}s^{-1}		scaling	5.94×10^{34} cm^{-2}s^{-1}		8.91×10^{34} cm^{-2}s^{-1}	
I_total	0.4349 A	0.2694 A		1.73A	1.07 A	2.60 A	1.61 A
I_bunch	1.11mA	0.685mA			β_y^*=0.8mm		
σ_x^*							
σ_y^*	0.225μm	0.256μm		7.43×10^{34} cm^{-2}s^{-1}			
ν_x							
ν_y			$I_{b(LER)} \times I_{b(HER)} = 0.758mA^2$ Ratio = 1.61 =0.92 x (7/4)				
ξ_y	0.0394	0.0364				1×10^{35} cm^{-2}s^{-1}	
				1mm/0.6mm = 1.67 5.94/0.6 = 9.9		1mm/0.8mm = 1.25 8.91 /0.8 = 11.1	

As beam currents increase, optimum current ratio seems to approach the inverse of beam energy ratio.

[Y. Suetsugu]

2022a and b run plan

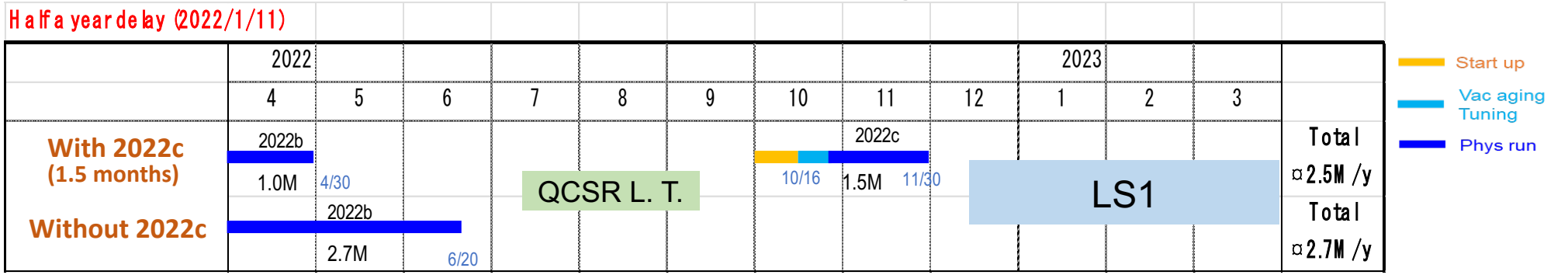
- 2022a run will start from 21st, February, as scheduled.
  - The electricity charge is rising abnormally, as you know.
  - The budget is already short, but KEK will make up for it.
- In 2022a and b runs, we will continue physics run aiming higher luminosity and stable data taking, in parallel with necessary beam studies for improving luminosities, for investigating various challenges, and for finding effective upgrade plans in the future (LS1 and LS2).
  - Luminosity ~5E34 $cm^{-2}s^{-1}$ (Base)
  - Integrated luminosity ~490 fb^{-1} (Base)
    - Assumed Operation efficiency ~0.4
  - Beam currents ~1.4 A (Base)
  - β_y^* squeezing down to 0.8 mm, and 0.6 mm if possible.
  - Try new sextupole magnet setting to improve dynamic aperture.
  - Practical use of rotatable sextupole magnets during collision
  - Try new tune and/or chromaticity values
  - Change crab-waist ratio and beam current ratio.
  - Note: For some studies, we will perform them in proper timing during physics run, and need some period (~one week?) to see the effect of the settings on the luminosity.



[Y. Suetsugu]

FY2022 operation plan

- Budget
  - KEK requested the operation budget to MEXT expecting approximately 6 months operation for FY2022, based on an electric-power unit price at that time (anticipating some increase in the price, of course).
  - The budget assessed by MEXT was found to be somewhat low, and was enable approximately 4.8 months operation with the assumed unit price.
  - However, as you know, the unit price has been rising abnormally, and further shorter operation time is forecasted now.
- Operation plan
  - Case study: if we assume a unit price at this March (no increase after that)
  - If the unit price continue to increase, the situation will get worse.



≤ 3 months!

- We are now under negotiation with KEK to find the best plan.
- Discussion on the FY2022 operation plan will be necessary including the start time of LS1 (before May).