Status of SuperKEKB Ring

Contents

- Brief review of 2021a/b runs
- Works during summer shut down
- Status of 2021c run
- Near-term operation plan
- Long-term operation plan and
  International task force for SuperKEKB upgrade
- ARC report
- Summaries

Y. Suetsugu
KEK

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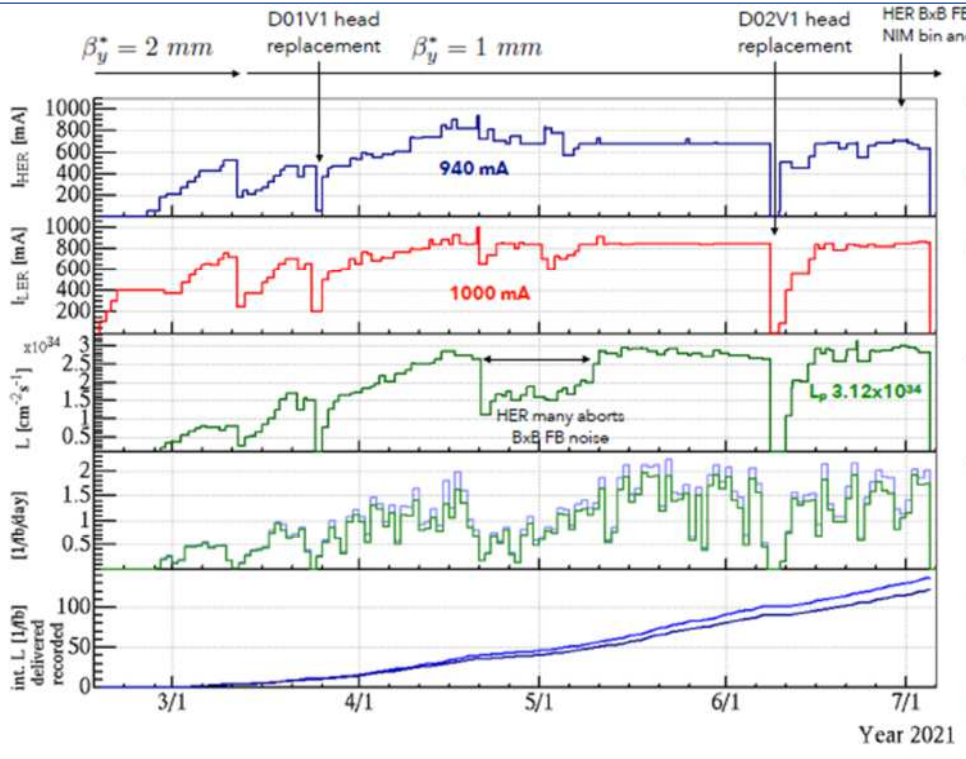
Brief review of 2021a/b runs

- 2021ab operation summary

Y. Ohnishi, ARC, 2021



- The 2021a/b run started on 16th February and operated for 140 days.
- The maximum beam currents were 940 mA and 1000 mA for HER and LER, respectively. (during baking runs)
- The peak luminosity was 3.12x10^{34} cm^{-2}s^{-1}.
- HER D01V1 jaw was replaced since wrong type had been used in May.
- LER D02V1 jaw was replaced due to damage in June.
- Many aborts occurred from 20th April to 3rd May due to noises in BxB FB system, which was fixed finally.

Brief review of 2021a/b runs

- Machine parameters (2020b and 2021b)

Y. Ohnishi, ARC, 2021

	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

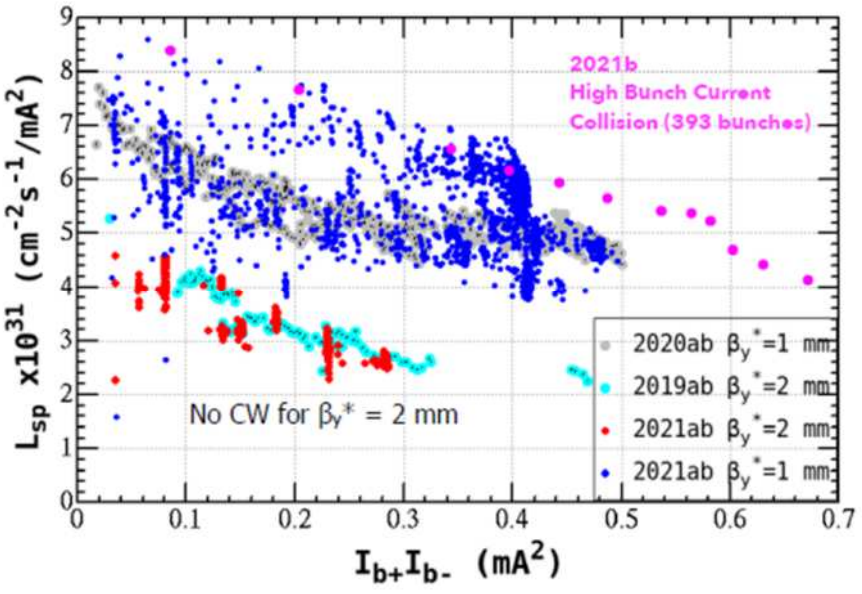
Brief review of 2021a/b runs

- Specific luminosity
  - 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.

Y. Ohnishi, ARC, 2021



Brief review of 2021a/b runs

- Major challenges in 2021a/b runs

Y. Ohnishi, ARC, 2021

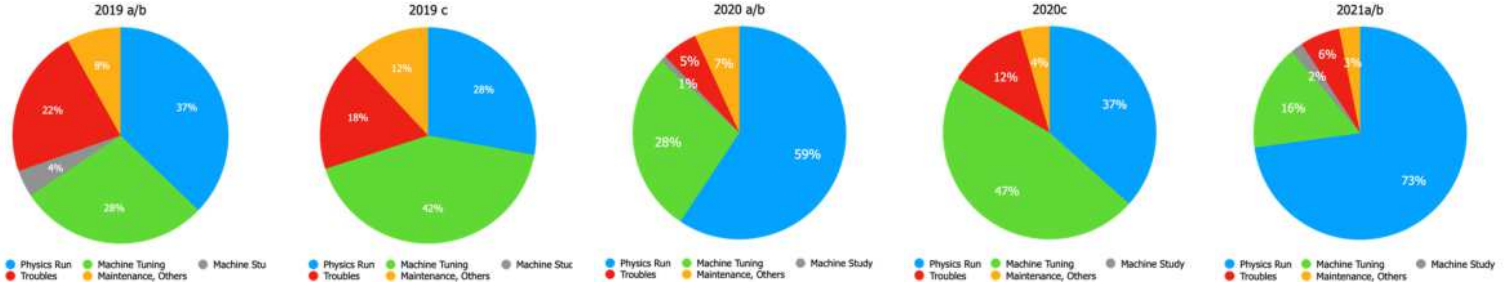
  - Beam background and beam aborts due to beam loss
    - Caused by stored beam and injection beam
    - Resulted in high radiation dose (serious) at collimators, collimator damage, Belle II detector damage

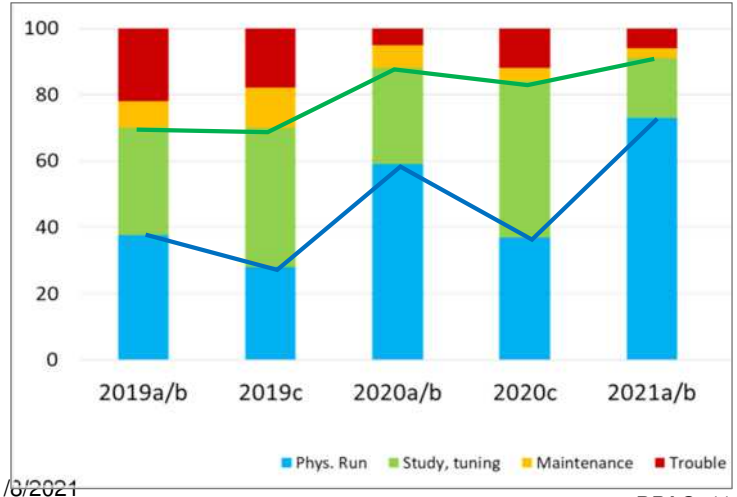
    → Risks for increasing beam currents
  - Collimator impedance : TMCI threshold
    - High impedance due to narrow collimator aperture (physical aperture)
    - The lower threshold limits of bunch current than expected.
  - Short lifetime
    - Due to mall dynamic aperture and/or small physical aperture (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 understanding of injection beam
    - Emittance, orbit fluctuation, energy spread, stability of injector linac

Brief review of 2021a/b runs

- Operation statistics





- The ratio of “Physics run” reached 60~70%.
  - The percentage is increasing gradually.
  - 2020c run had a problem of heavy TMCI etc..
- “Troubles” + “Maintenance” ~ 10 %
- “Machine tuning” 20 ~ 30 %
  - Reducing these percentage is a key to improve efficiency.

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Works during summer shutdown

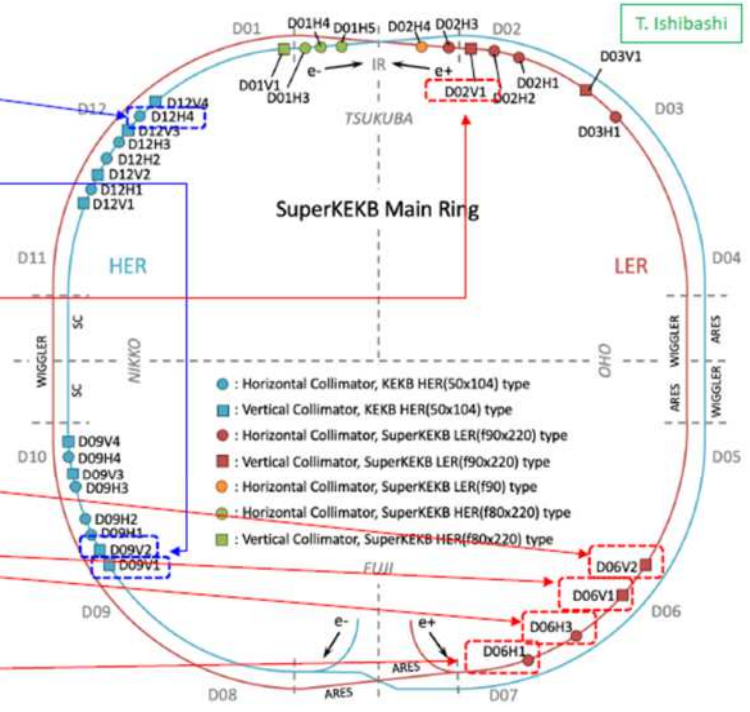
- Regular maintenance (Water flow meters, Power supplies for RF and magnets, etc.
- Collimators (see also next page)
  - Installation of new collimator heads with 3 mm Tantalum and graphite (at LER arc).
    - Robust against damages from beam.
  - Relocation of LER D02V1 collimators
  - Replacement of 2 collimator heads (HER).
  - Upgrade of driving device of 2 collimators (HER)
- LER injection kicker
  - Exchange of all thyratrons to those with higher withstanding voltage to avoid unexpected-firing.
  - Rewiring of trigger cables to control each kicker timing separately.
- Exchange of the mirror and its folder of SR beam size monitor for LER.
- Installation of a HOM absorber at RF section (HER Nikko).
- BT
  - Installation of beam profile monitors with OTR screen.
  - Installation of a beam shutter in LER injection line.
- Installation of a strip-line kicker into RTL line at DR
- Anti-aging measures
  - Replacement of HV (66 kV and 6.6 kV) power cables.
  - Repair of water leak from roof of some power stations.

Works during summer shutdown

- Works for beam collimators

K. Shibata

- HER
  - Upgrade of D12V4 driver unit
    - Not vacuum work. For precise jaw position control.
  - Damaged jaw replacement;
    - D09V2 : replaced with new jaws
    - D09V1 : Replaced with new jaws
- LER
  - Relocation of D02V1
    - In order to match the betatron phase at D02V1 and QC1RP (superconducting final focusing magnet)
    - We will be able to open D02V1 wider and suppress TMCI.
  - Damaged jaw replacement;
    - D06V2 :Replaced with new hybrid-type jaws
      Robustness of hybrid-type jaws will be tested.
    - D06V1 :Replaced with new jaws
    - D06H3 : Damaged due to accidental kicker-pulser misfiring.
      Since we have no spare jaws, damaged jaws were replaced with healthy D06H1 jaws.
    - D06H1 :Replaced with short-stroke jaws.
      Minimum aperture is limited to ±14 mm.



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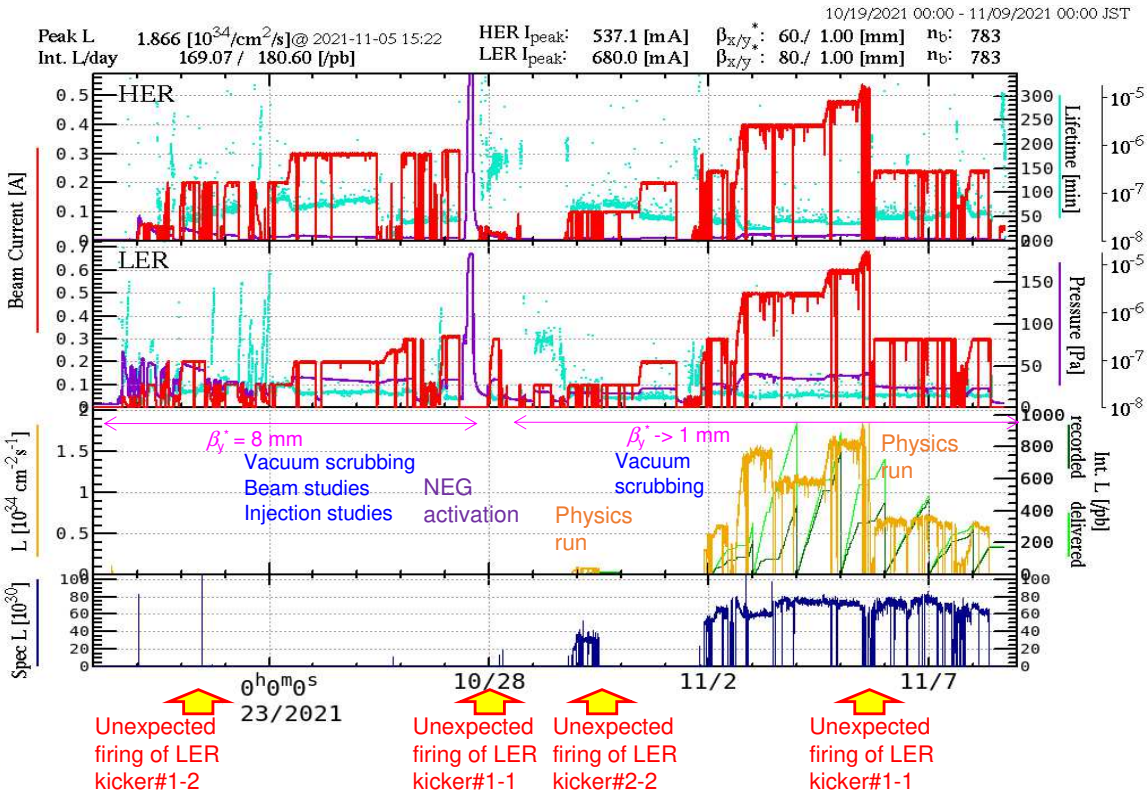
Status of 2021c run

- 2021c run has started as scheduled from 19th October.



As of 8th November

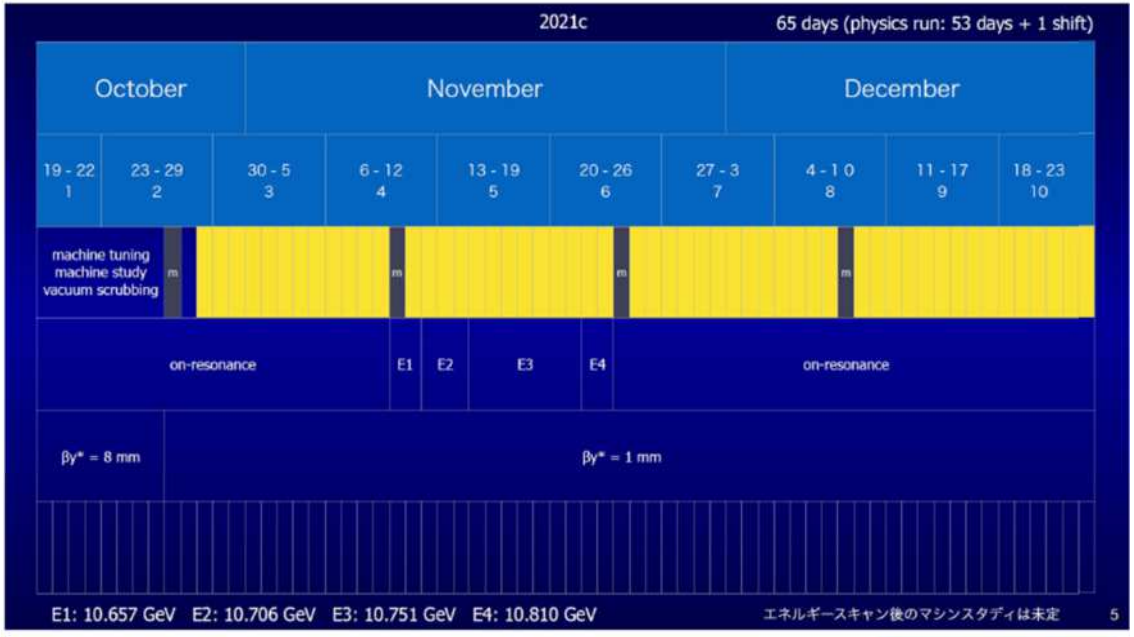
- 2021c run has started on 19th October.
- Vacuum scrubbing was performed until 27th at with β_y^* = 8 mm.
- Unexpected firing of LER injection kickers occurred on 21st.
- Various beam studies, such as on TMCI, beam injection, were carried out during this period.
- β_y^* was squeezed to 1 mm after regular maintenance on 27th.
- Unexpected firing of the LER injection kickers recurred on 28th.
- Physics run started once from 29th, but stopped next day since unexpected firing of the LER injection kickers has occurred again and moved to vacuum scrubbing.
- QCS power supply turned off due to an earthquake on 1st November.
- Physics run restarted on 2nd, the beam currents were increased gradually. But the beam currents were again decreased on 5th due to unexpected firing of the LER injection kickers.

Status of 2021c run

- 2021c run has started as scheduled from 19th October.

Y. Ohnishi, Commissioning meeting

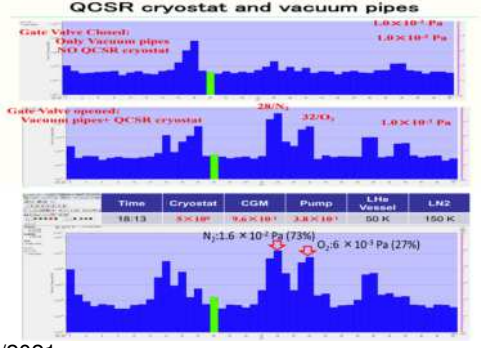
- First half;
  - Machine tuning & study:
    - HER beam injection
    - TMCI
    - Beam-beam effect
    - LER crab waist
  - On-resonance run
  - Energy scan:
    - 10.657 GeV
    - 10.706 GeV
    - 10.751 GeV
    - 10.810 GeV
  - β_y^* squeezing:
    - β_y^* = 1mm
- Second half;
  - On-resonance run with 1mm-β_y^*
  - Machine study plan is under consideration.

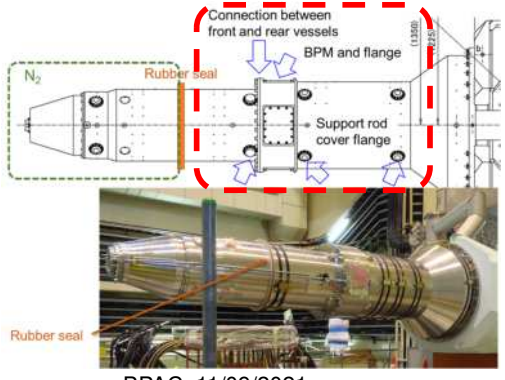


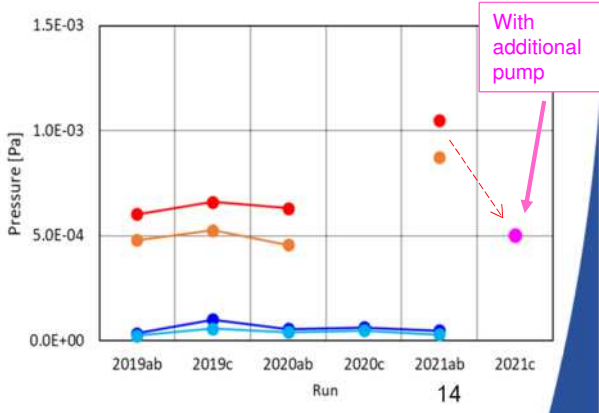
Y. Ohnishi (2021.10.8)
KCG meeting

Status of 2021c run

- Troubles - Leak at QCSR insulation vacuum tank -
  - In the examination of the QCS system in the summer shut-down, the degradation of the vacuum condition for the thermal insulation in the QCSR cryostat was found.
  - The residual gas indicated a clear air leak. The leak rate was 3.8 $\times 10^{-4}$ Pa m^3 s^{-1}.
  - Helium leak test of the accessible cryostat parts was performed, but no detection.
    - The most suspicious part is red squares in the bottom figure.
  - In October, the temperature successfully reached to 4 K in approximately 1.5 days.
  - The cooling down succeeded this time, but the risk would remain until LS1. We hope the leak do not get worse….
    - Heat load with the leak after cooling the magnets at 4 K for the He refrigerator < 1 W @4 K, while the margin of He ref. cooling capacity = 40 W @ 4 K. We have still enough margin.
  - We will perform a detailed leak check next summer, by opening End yoke and (if necessary) End cap.







Status of 2021c run

- Troubles - unexpected-firing of LER injection kicker
  - On 21st October, unexpected-firing occurred at LER injection kicker #1-2
    - Pressure burst at D06_H3 was observed at the same time. Damaged?
  - Since we have exchanged all of thyratrons of the kicker PSs to those with a higher withstand voltage during the last summer shutdown, noises to the trigger cables are suspected as a possible cause at first.
  - We have configured a "coincident circuit" to avoid fake trigger signal on 22nd.
  - However, the unexpected-firing again occurred at the kicker #1-1 and #1-2 on 28th.
  - The thyratron of kicker #1-2 was replaced with that had been used in #2-2. A thyratron stored at 30 years at PF was used to #2-2 instead. Furthermore, the running voltage was lowered for kickers #1.
  - The unexpected-firing occurred at kicker #2-2 on 30th. The kicker #2-2 was turned off.
    - Kicker #2 is available with two kicker magnets.
  - The unexpected-firing occurred at kicker #1-1 on 5th November.

Kicker- Thyratron	Before 2021c	10/21	10/22	10/28	10/30	11/5	11/8
#1 - 1	30y (unused)		Coincident circuit	X -> V↘		X -> V↘	-> Used (~2021b)
#1 – 2	30y (unused)	X		X -> 1y V↘			
#1 – 3	30y (unused)			-> V↘			
#2 – 1	Spare (new)						
#2 – 2	1y (unused)			->30y(unused)	X -> OFF		
#2 - 3	Spare (new)						

Status of 2021c run

- Troubles - unexpected-firing of LER injection kicker
  - Considering these situation, it seems that the thyratrons stored for 30 years unused were deteriorated, although the reason is unknown.
  - Then the thyratron of kicker #1-1 was replaced with used one which had been used until 2021b on 8th.
  - Short-term countermeasures
    - Select available thyratrons among those we have now, in any way.
    - Install new two thyratrons that we are now manufacturing as soon as we received.
    - Order more spares.
  - Mid-term, Long-term countermeasures
    - Set up a real test stand to check the property of thyratron before installing into the ring.
    - Rewire the system to use a common power supply for #1 and #2 kickers, as recommended in the last ARC. Need correction kickers and some tests.
    - Develop a semiconductor switch to replace with a thyratron. Need extensive R&D.

Kicker- Thyratron	Before 2021c	10/21	10/22	10/28	10/30	11/5	11/8
#1 - 1	30y (unused)		Coincident circuit	X -> V↘		X -> V↘	-> Used (~2021b)
#1 – 2	30y (unused)	X		X -> 1y V↘			
#1 – 3	30y (unused)			-> V↘			
#2 – 1	Spare (new)						
#2 – 2	1y (unused)			-> 30y(unused)	X -> OFF		
#2 - 3	Spare (new)						

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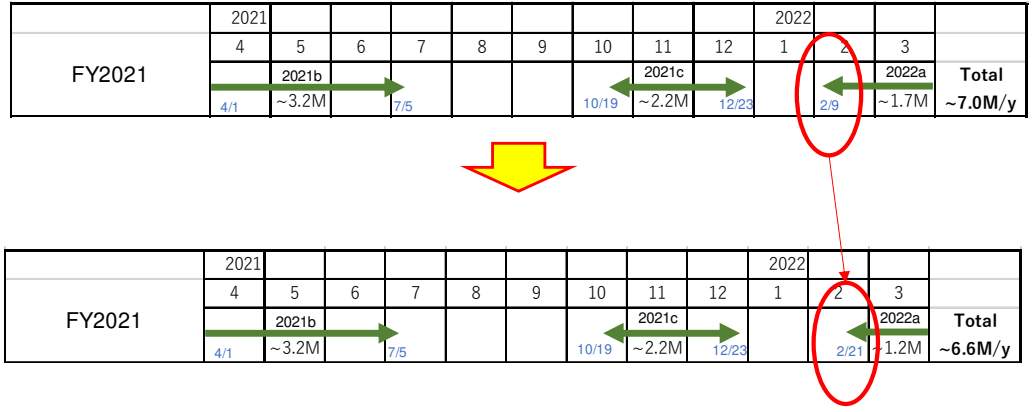
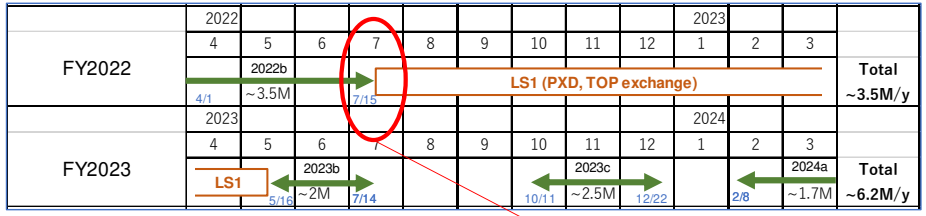
Near-term operation plan ~2024

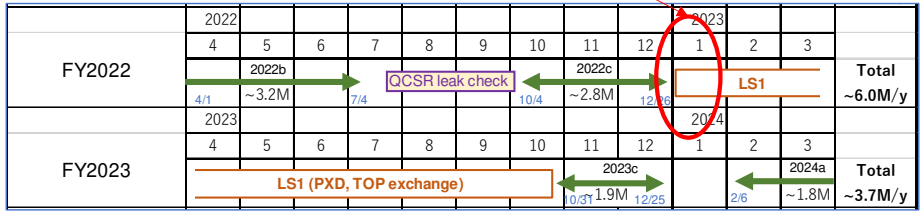
- Near-term operation plan was re-considered.
  - Considering the recent rise of electricity charge, the starting time of 2022a was postponed from 9th to 21st February.
    - Total operation period in this fiscal year will be approximately 6.6 months.
    - The period depends on the increase rate of electric charge in the future.



Near-term operation plan ~2024

- We decided to postpone the LS1 by a half year.
  - The LS1 will start from January, 2023.
  - A detailed leak check of QCSR cryostat vacuum tank is scheduled in summer shutdown 2022.

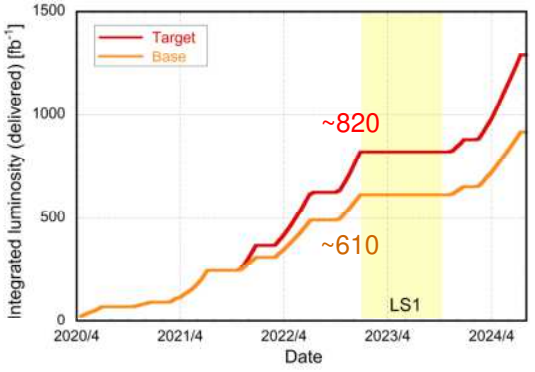


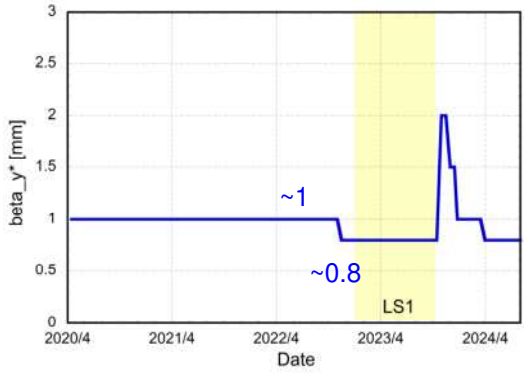


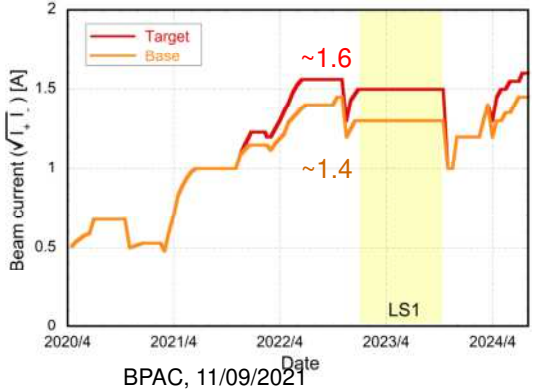
- Items to be considered
  - Influence of Covid-19
  - Fabrication of a new IP chamber
  - Integrated luminosity until LS1
  - QCSR leak
  - Availability of expertise especially in PXD.
- Requested budget is compatible with 6 months operation.
- The schedule will be discussed again in May 2022, considering the situation at that time.

Near-term Luminosity profile ~2024

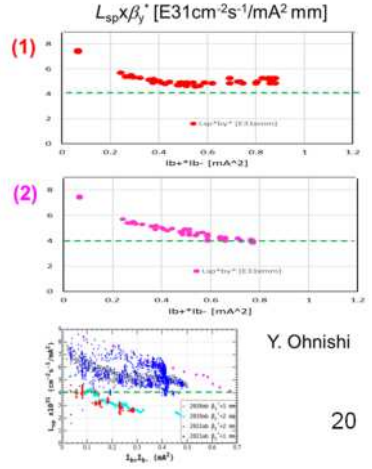
- Luminosity profile







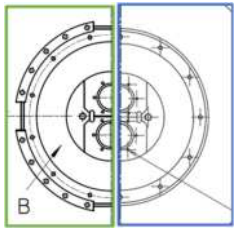
	Target profile*	Base profile
Profile until 2022b	Same profile as previous one	Modified from 2021c
Operation efficiency	~2021c: 0.65, 2022a~: 0.4	2021c~: 0.4
Bunch current	≤ 0.95 mA	≤ 0.9 mA
Total current	≤ 1.6 A	≤ 1.5A
Specific luminosity	Fig. (1)	Fig. (2)
Squeeze β_y^*	Squeeze to 0.8 mm at a proper timing after 2022c.	
After LS1	Need ~4 months' operation to fully recover the previous luminosity	

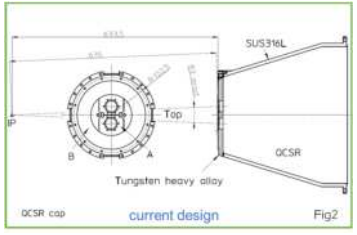


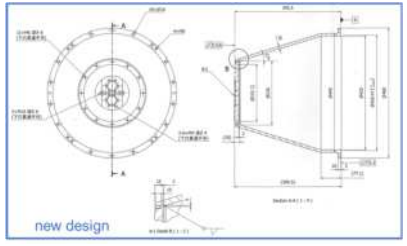
Works planed during LS1

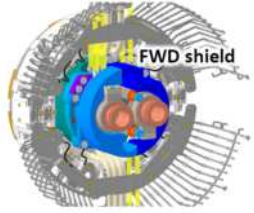
- QCS cryostat front panel modification and additional shield to IP bellows
  - Make rooms for cables of Belle II detectors.
  - Exchange plate material from tungsten to stainless-steel to reduce the beam background.
  - Add new radiation shield inside the cryostat.
  - FWD and BWD bellows shields were also developed. In the current mechanics, there is no beam BG shield around the bellows pipes and a fraction of BG go into CDC and TOP from these regions.
  - The preparation for LS1 is on going together with Belle II group.

K. Nakamura









Single-beam BG (SAD input with βy*=1mm)

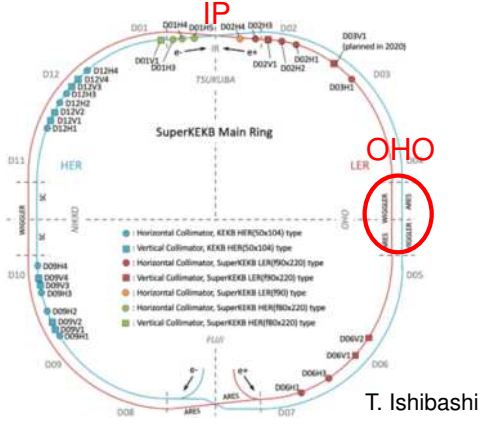
	LER Coulomb	LER Touschek	HER Coulomb	HER Touschek
CDC	27.77 ± 0.06%	13.00 ± 0.05%	29.03 ± 0.13%	24.50 ± 0.04%
TOP	23.43 ± 0.20%	9.93 ± 0.16%	19.70 ± 0.50%	20.74 ± 0.15%

Luminosity BG

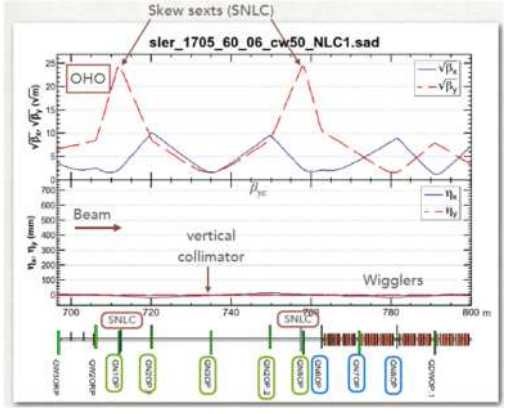
	TwoPhoton	BBBrem	BHWide	BHWide_LA
CDC	29.15 ± 0.04%	50.44 ± 0.16%	29.98 ± 0.03%	-1.55 ± 0.17%
TOP	15.61 ± 0.18%	25.29 ± 0.91%	13.47 ± 0.14%	-3.33 ± 0.65%

Works planed during LS1

- Non-linear collimator
  - A vertical-type collimator, called “non-linear collimator”, is located between a pair of specified skew-sextupole magnets. The non-linear vertical kicks by the magnet are utilized to enlarge the vertical displacement of particles at small β_y section, which will reduce the collimator impedance and mitigate TMCI (K. Oide).
  - Vertical phase advance of 0.25 between the sextupole magnets and the IP is possible, which reduces beam background (A. Natochii).
  - It can be uses as a primary collimator instead of D06_V1 at present.
  - The dynamic aperture looks fine so far by simulation.
  - The preparation has started to install the non-linear collimator during LS1.

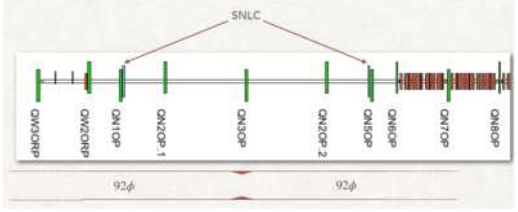


T. Ishibashi



K. Oide

	y_c (mm)	β_{yc} (m)
D06V1	2.03	67.3
D06V2	2.42	20.6
D03V1	8.02	17.0
D02V1	1.27	13.9
NLC @ OHO	8.5	2.9



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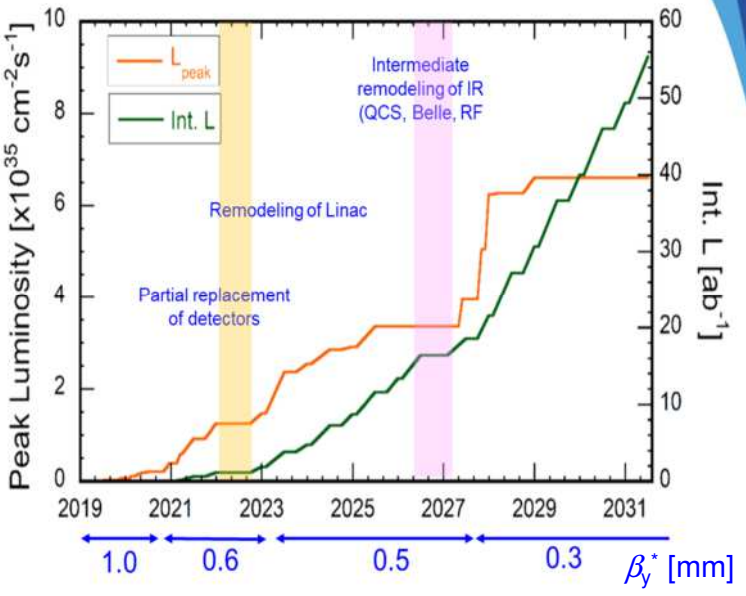
Long-term operation plan

- Current operation plan (luminosity profile)
  - The current goal is to achieve
    $L \sim 6 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and
    $\int L = 50\ \mathrm{ab}^{-1}$ by around 2031,
    which requires an intermediate machine upgrade around 2026 (LS2) that improves the luminosity by a factor of 2-3.
  - The plan was adopted in the MEXT roadmap 2020.
  - The plan and profiles were assessed by the external review committees (Accelerator Review Committee (ARC and BPAC)

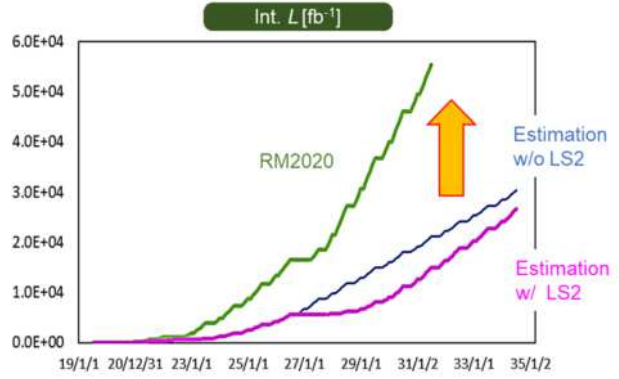


  - Recommendation in the last ARC, 2020
    - Over the next year or so, perform beam measurements to determine if the proposed upgrades are absolutely necessary to get to the design luminosity.
    - Determine which technical studies need to be carried out now, before a decision can be made, within about 2 years.

Long-term operation plan

- To solve the confronting challenges and to realize the plan, a variety of countermeasures have been proposed and discussed over the last year in various meetings, such as "Long-term operation plan meeting" (internal), MDI (Machine Detector Interface) meeting, BITF (Beam Injection Task Force) meeting and IR technical meeting, and so on.
- Although various kind of measures have been proposed to improve beam lifetime, relax TMCI, improve dynamic aperture, etc., no effective method to boost up the luminosity by LS2 has not been found so far.

- An international task force was created under the management of the KEK Accelerator Lab. and B promotion office (BPO) to pursue effective measures for recovering the luminosity profile and reaching target luminosity.
  - Find more effective (x2~3) measures, not limited to the IR but also to other parts of the MR and Linac, Ideas of a more revolutionary upgrade including some modification of Belle II should be considered to reach even higher luminosity; this may require a longer time for R&D (~203x).



International task force for SuperKEKB upgrade

- ITF members

International Task Force members

2021/7/27

International members

Maria Enrica Biagini	INFN
Georg Hoffstaetter	Cornell
Evgeny Levichev	BINP
Mark Palmer	BNL
Yunhai Cai	SLAC
Rogelio Tomas	CERN
Pantaleo Raimondi	ESRF
Katsunobu Oide	CERN/KEK

KEK ACCL members

Mika Maszawa (Chair)	SKEKB
Yukiyoshi Ohnishi	SKEKB
Akio Morita	SKEKB
Hiroshi Sugimoto	SKEKB
Renjun Yang	SKEKB
Haruyo Koiso	SKEKB
Yoshihiro Funakoshi	SKEKB
Tsukasa Miyajima	SKEKB
Kazuhito Ohmi	SKEKB
Demin Zhou	SKEKB
Kentaro Harada	KEK-PF

Belle II members

Hiroyuki Nakayama	Belle II
Francesco Forti	Belle II

BPO members

Masanori Yamauchi	KEK		
Tadashi Koseki	ACCL	Naohito Saito	IPNS
Makoto Tobiyama	SKEKB	Shoji Uno	Belle II
Kazuro Furukawa	SKEKB	Yutaka Ushiroda	Belle II
Kyo Shibata	SKEKB	Toru Iijima	Belle II
Yusuke Suetsugu	SKEKB	Kodai Matsuoka	Belle II

- Three ITF meeting were held so far, 28th July (kick off), 2nd September (Joint with ARC) and 16th October.
- Four working groups (sub-groups) were organized and their indico sites were created.
  - Optics (Contact person: Akio Morita & Sub: Haruyo Koiso)
  - Beam-beam (Contact person: Demin Zhou & Sub: Kazuhito Ohmi)
  - TMCI and impedance matters (Contact person: Mauro Migliorati & Sub: Takuya Ishibashi)
  - Linac (Contact person: Masanori Satoh & Sub: Shuji Matsumoto
- Indico site https://kds.kek.jp/category/2242/

International task force for SuperKEKB upgrade

- Recent activities and topics
- Beam-beam sub-group
  - Meetings: 24th August, 28th September, 28th October
  - Some observed properties of the beam-size blow up could be explained by the beam-beam head tail instability (BBHTI), but not satisfactory. A consistent and predictable model for beam-beam simulation is necessary.
  - Luminosity predicted by the strong-weak simulation with beam-beam effects agrees well with the present situation.
  - Proposals to move the working point to a higher point in the betatron tune diagram. It will be tried during 2021c run.
  - Re-evaluation of beam impedances for various vacuum components are on going for more precise simulations, together with TMCI sub-group.
- TMCI sub-group
  - Meetings: 27th August, 2nd September, 1st October, 9th November (scheduled),
  - Mystery of the lower bunch current threshold of TMCI than that expected by the simple formula. Localized impedance? Mode coupling between higher modes?
  - Need to develop an impedance model which can reproduce the observations. Re-evaluation of beam impedances for collimators is on going.
  - Machine studies, such as betatron tune scan, chromaticity, etc., are proposed, and partially already done during 2021c run.

International task force for SuperKEKB upgrade

- Recent activities and topics
- Optics sub-group
  - 22nd September, 13th October
  - Comprehensive summaries about optics measurement so far was presented.
  - Limitations of the optics correction using the present tools were pointed out.
  - It was reported that elaborate optics matching (“semi-perfect matching”) using existing magnets will give a comparable improvement in dynamic aperture with “perfect matching” proposed before.
  - It was also reported that additional sextupole magnets at IR was effective to improve the dynamic aperture for SuperB in a simulation. The effectiveness is under investigation using SuperKEKB lattice.
  - The conversion of lattice formats, that is, from SAD to MAD8, LEGO, etc., are on going. Some basic reproducibility will be reported soon.
- Linac sub-group
  - Just started.
  - First meeting will be held soon, where the upgrade plan was explained first of all.

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ARC report

- The 25th KEKB Accelerator Review Committee (ARC) meeting was held remotely on 1-2 September 2021.
- Slides of the presentations and the report are available at https://superkekb.kek.jp/event/131/

		KEKB_Review_Online_Meeting_program_2021_23.xlsx	
Ver. 2020/8/25		KEKB Review on line meeting Program (Draft)	
Sept. 1 (Wednesday)			
19:50-20:00		Committee zoom meeting (Closed session)	
20:00-20:07		Welcome address	M. Yamauchi
20:07-20:10		Welcome address	T. Koseki
20:10-20:40		Overview of 2020c, 2021a and b run	Y. Ohnishi
20:40-21:00		Injector (Linac) status (e-/e+ sources)	M. Satoh
21:00-21:20		Belle II status	K. Matsuoka
21:20-21:30		Break	
21:30-21:50		Beam injection	N. Iida
21:50-22:10		Beam Background and MDI	H. Nakayama
22:10-22:30		Bunch feedback system and luminosity	M. Tobiyama
22:30-22:50		Beam collimators (TMCI, damage, plan)	T. Ishibashi
22:50-24:00?		Committee zoom meeting (Closed session)	
(Tokyo time)			
Sept. 2 (Thursday)			
19:50-20:00		Committee zoom meeting (Closed session)	
20:00-20:20		Discussions on the long-term operation plan in the last year	Y. Suetsugu
20:20-20:30		Kickoff of International Task Force for SuperKEKB upgrade	M. Masuzawa
20:30-21:20		International Task Force Joint Meeting :Discussion on beam-beam	D. Zhou
21:20-21:30		Break	
21:30-22:10		International Task Force Joint Meeting :Discussion on optics	A. Morita
22:10-22:50		International Task Force Joint Meeting :Discussion on TMCI and impedance matters	M. Migliorati
22:50-24:00		Committee zoom meeting (Closed session)	
(Tokyo time)			
Sept. 6 (Monday)			
-20:00		Committee zoom meetings (Closed session)	
20:00-21:00		Review close-out, comments and suggestions	ARC members

KEKB Accelerator Review Committee

Frank Zimmermann, Chair	CERN
Ralph Assmann	DESY
Paolo Chiggiato	CERN
John Fox	Stanford University
Andrew Hutton	JLab
In Soo Ko (absence)	POSTECH
Catia Milardi	INFN-LNF
Katsunobu Oide	CERN and KEK (ret.)
Evgeny Perevedentsev	BINP
Matt Poelker (absence)	JLab
Qing Qin	ESRF
Bob Rimmer	JLab
John Seeman	SLAC
Michael Sullivan	SLAC
Tom Taylor	CERN (ret.)
Rogelio Tomas	CERN
Tadashi Koseki	KEK, Director of Acc. Laboratory, Ex Officio Member
Yusuke Suetsugu	KEK, Head of Acc. Division III, Ex Officio Member
Makoto Tobiyama	KEK, Head of Acc. Division IV, Ex Officio Member
Kazuro Furukawa	KEK, Head of Acc. Division V, Ex Officio Member

ARC report

- General comments
  - Remarkably, this progress was achieved with a limited, and shrinking, number of staff members, and during the covid-19 pandemic.
  - The important advances accomplished, the remaining large challenges and the noticeable task-force support from the international accelerator community underline that SuperKEKB is a highly innovative facility, of critical importance for particle physics and for the world-wide progress in colliders.
  - We support the KEK management in making every possible effort to ensure a highest priority for SuperKEKB and to maximize available staff support, such that the required substantial workload can be accomplished.
- The most important challenges at present
  - The top-up injection efficiency and injection stability, including HER beam blow up in the transfer line, mitigating the consequences of accidental kicker-pulser misfiring, problematic HER two-bunch injection, septum drifts, etc.
  - Collimation and machine protection strategy, including overcoming the present bunch intensity limitations due to TMCI; developing a strategy for safe beam current increase; and understanding and avoiding yet unexplained sudden large beam losses in the LER
  - Medium and long-term plan including possible upgrade paths.

ARC report

- Most significant recommendations and our actions - 1
  - Sufficient beam time should be allocated for beam studies (other than routine tuning) to better understand and characterize the machines and their limitations, and to develop solutions or mitigation measures. More beam diagnostics would be helpful. Planned, dedicated machine study periods would also enable remote participation by Task Force members and other foreign experts.
    →We are now discussing with Belle II group to increase the machine study time. We are also considering possible measure to participate the studies remotely.
  - Check the RF gun timing and perform careful RF conditioning of the QTW RF gun to recover the RF pulse width and, possibly, to improve the 2ndbunch emittance.
    → The timing has been checked. We succeeded in securing enough pulse width by careful conditioning.
  - Develop refined procedures including triggers so that Belle II can operate closer to the background limits of its sub-detectors.
  - The six LER kickers should be rewired to use a common power supply, or three power supplies each of which feeds a pair of upstream and downstream magnets, to avoid problems related to thyratron misfiring and injection impact on circulating bunches.
    → The reconfiguration of the kicker system is quite difficult. We replaced all thyratrons of LER to other ones with higher withstand voltage. The new circuit to avoid mis-firing by noise was also introduced.
  - Localize, identify and eliminate the source of vertical coupling in the HER injection line.
    → Various studies and analysis are on going.
  - Develop a safe plan for increasing beam intensity in documented phases/machine states, that are each formally verified for optimized performance, background and adequate machine protection.
    → We are working on a plan with the cooperation of the commission group and Belle II group.

ARC report

- Most significant recommendations and our actions - 2
  - Establish a realistic model of the transverse impedance including accurate collimator wake fields and correct weighting with local beta functions; assess TMCI threshold for this model.
  - Measure the single-bunch tune shift created by each collimator as a function of its gap, compare with theoretical expectation and verify that collimator contributions to the impedance are correctly understood.
    → We are planning to investigate in detail the difference between the results of the current model and the measurement through machine studies, and build a more realistic model.
  - Further develop and study the non-linear collimation scheme (including the removal of some wiggler sections) and quantify its implications on beam optics and beam dynamics.
    → Detailed studies are underway on both beam optics and hardware aiming to install it during LS1.
  - Carry out more comprehensive beam-beam simulations, incl. crab waist, impedance, lattice errors, etc., to guide the upgrade path.
    → Detailed discussion has started in the beam-beam sub-group of ITF.
  - Consider increasing the number of focused task-force groups to other key areas such as linac, injection, collimation and machine protection.
  - Invite external international task-force members to share organization efforts for the ITF sub-task groups.
    → Linac sub-group has been established. We would like to search for various ways to make the task force work effectively including the above plan.

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Summaries

- The performance of SuperKEKB has been steadily improving.
  - Peak luminosity : $3.12 \times 10^{34} cm^{-2} s^{-1}$, with $\beta y^* = 1mm$, Beam current [mA]= 790 (LER)/687(HER)
  - Total integrated luminosity : 213.5 fb^{-1}, Maximum Daily integrated luminosity (delivered) = 2.233 fb^{-1}
- Various challenges, however, still remained, and should be solved to further improve the machine to achieve the goal.
  - Vertical beam size blow-up, short beam lifetime, TMCI, low machine stability, aging of hardware and facilities, low injection efficiency (HER), etc.
- The near-term operation plan was reconsidered recently considering recent situations.
  - LS1 will start from January, 2023.
- Various countermeasures have been discussed in various meetings to solve lots of challenges facing us to realize the current Long-term operation plan.
- International Task Force to address the challenges and find ways to boost up the luminosity using LS2 was organized this summer.
  - Enthusiastic discussion is taking place in four sub-groups : Optics, Beam-beam, TMCI, and Linac
  - Some proposed beam studies will be performed in 2021c run.
- Lots of useful comments and recommendation was reported from ARC. The action plan is now under discussion.

We greatly appreciate your corporation!

End

Backup

Major results of 2021ab run

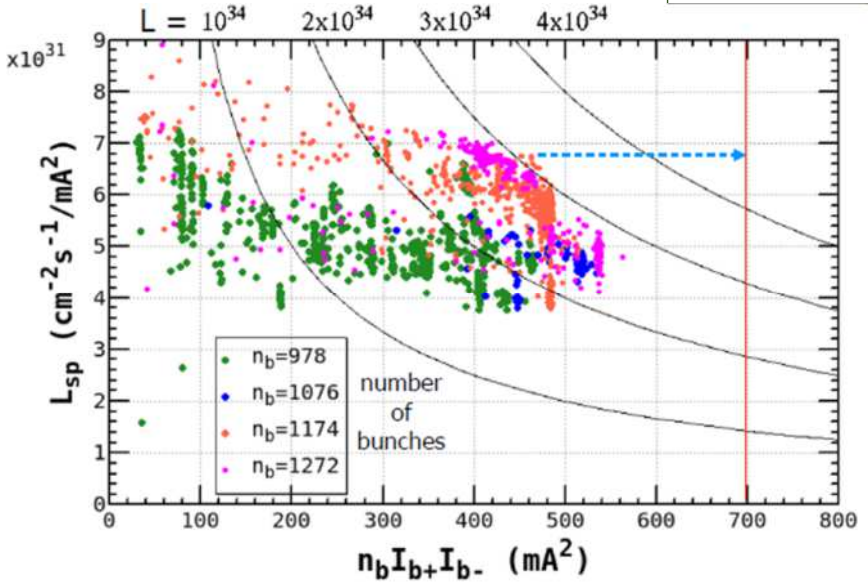
- Projection of specific luminosity in 2021ab
  - Definition of specific luminosity

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

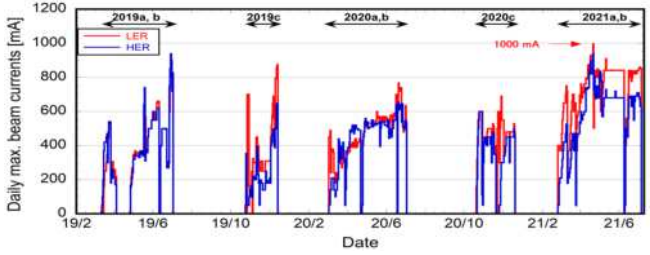
  - Max. of $n_b I_{b+} I_{b-}$ is 540 mA^2 (840 mA/818 mA, n_b = 1272)
  - Target of 2021b: 700 mA^2
  - LER / HER : 1.1 A / 1.0 A, n_b = 1565

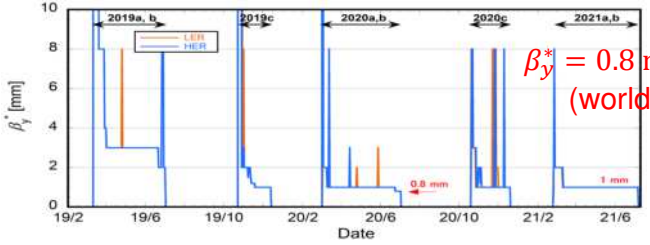
- L > 4x10^{34} cm^{-2}s^{-1}

Y. Ohnishi, ARC, 2021

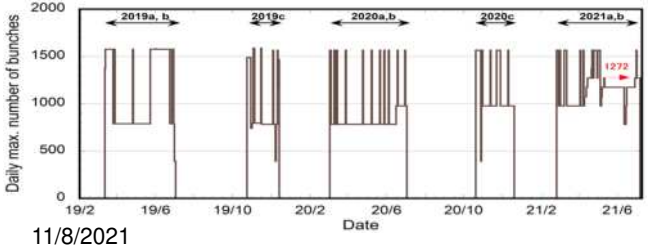


- The performance has been improved steadily.
- SuperKEKB is already exploring uncharted territory!

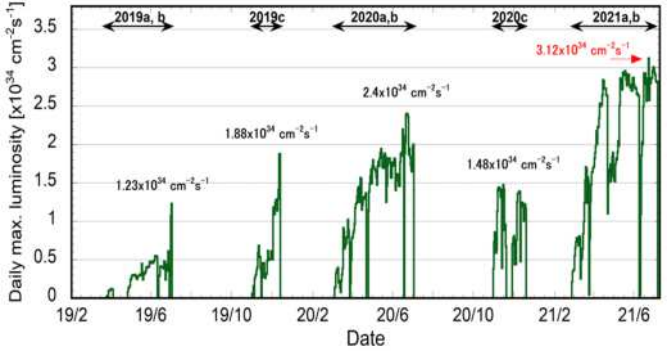




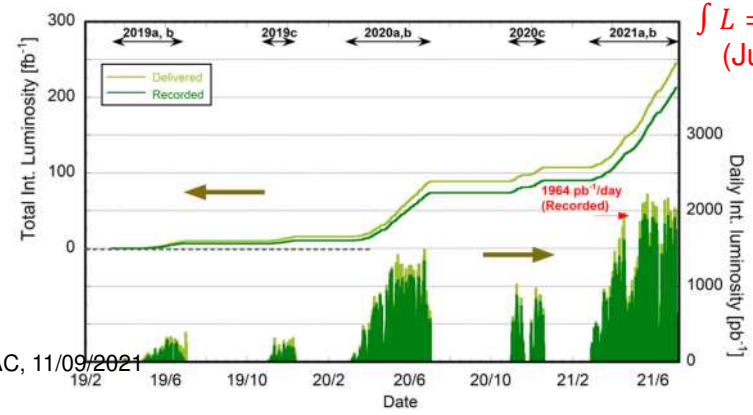
$\beta_y^* = 0.8$ mm
(world record)



$L_{peak} = 3.12 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
(world record)

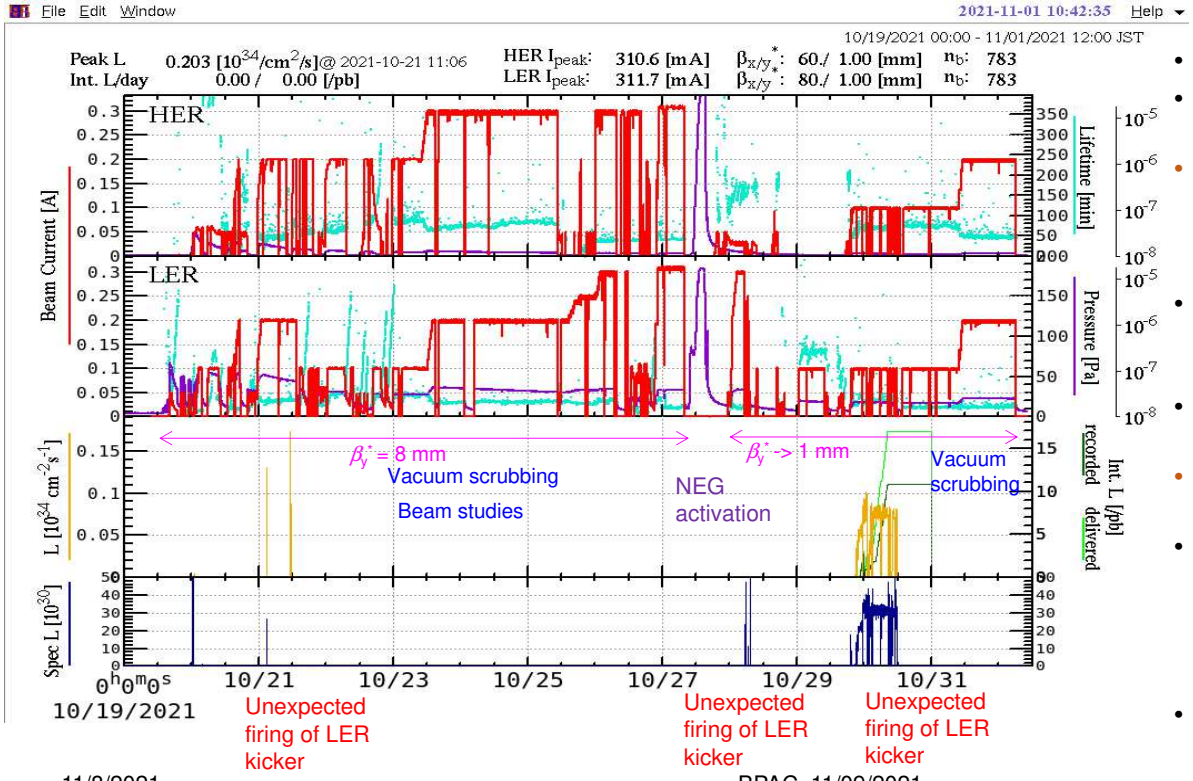


$\int L = 213.5\ \mathrm{fb}^{-1}$
(July, 2021)



Status of 2021c run

- 2021c run has started as scheduled from 19th October.

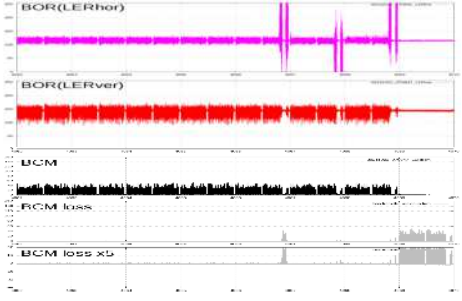


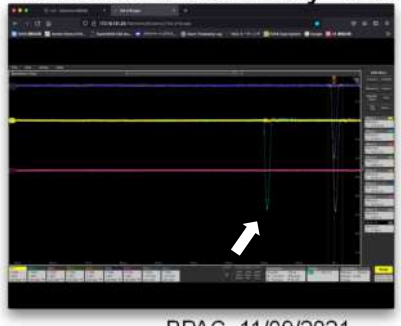
As of 1st November

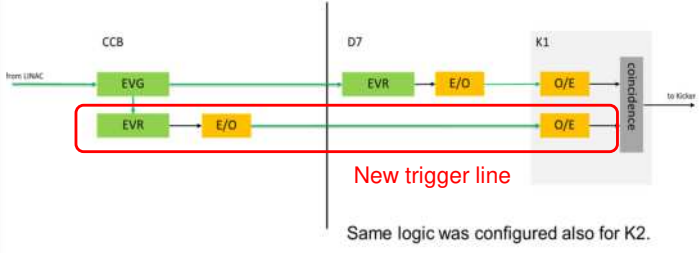
- 2021c run has started on 19th October.
- Vacuum scrubbing was performed until 27th at with β_y^* = 8 mm.
- Unexpected firing of LER injection kickers occurred on 21st, and the beam current was increased carefully after that, less than 300 mA
- Various beam studies, such as on TMCI, beam injection, were carried out during this period.
- β_y^* was squeezed to 1 mm after regular maintenance on 27th.
- Unexpected firing of the LER injection kickers recurred on 28th.
- Physics run started once from 29th, but stopped next day since unexpected firing of the LER injection kickers has occurred again and moved to vacuum scrubbing.
- QCS power supply turned off due to an earthquake on 1st November.

Status of 2021c run

- Troubles - unexpected-firing of LER injection kicker
  - On 21st October, unexpected-firing of LER injection kicker (#1) occurred.
    - Pressure burst at D06_H3 was observed at the same time. Damaged?
  - Since we have exchanged all of thyratrons of the kicker PSs to those with a higher withstand voltage during the last summer shutdown, noises to the trigger cables are suspected as a possible cause at first.
  - We have added a trigger line (optical fiber) connected directly to the event generator (EVR), and configured a "coincident circuit" before the kicker PSs to avoid fake trigger signal on 22nd.
  - However, the unexpected-firing again occurred at the kicker #1-1 and #1-2 on 28th.
  - The thyratron of kicker #1-1 was replaced with that had been used in #2-2. A thyratron stored at PF was used to #2-2 instead. Furthermore, the reservoir voltages were lowered by 0.1~0.2 V and the bias voltages of grid#2 were also increased by 20 V for all thyratrons of kickers #1.
  - The unexpected-firing occurred at the kicker #2-2 on 30th. The kicker #2-2 was turned off.
  - LER beam current will be increased carefully watching the situation.





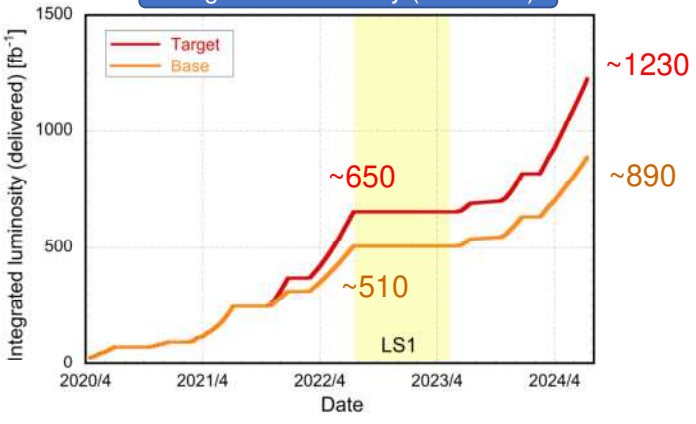


Luminosity profile for present plan

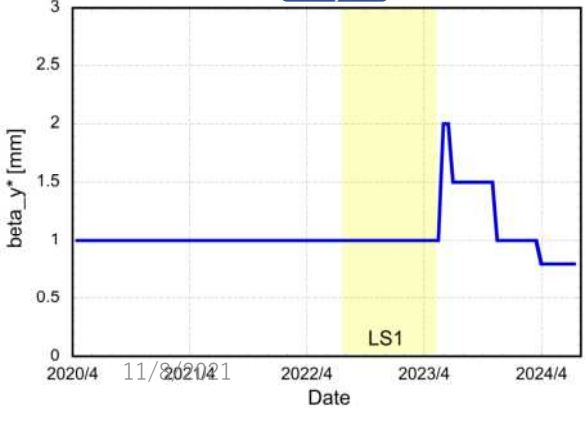
Present plan (Aug. 2021)

	2021									2022			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2021	4/1	2021b ~3.2M		7/5			10/19	2021c ~2.2M	12/23		2/9	2022a ~1.7M	Total ~7.0M/y
	2022									2023			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2022	4/1	2022b ~3.5M		7/15	LS1 (PXD, TOP exchange)								Total ~3.5M/y
	2023									2024			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2023	LS1	5/16	2023b ~2M	7/14			10/11	2023c ~2.5M	12/22		2/8	2024a ~1.7M	Total ~6.2M/y
	2024									2025			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2024	4/1	2024b ~3.4M		7/12			10/16	2024c ~2.3M	12/25		2/6	2025a ~1.8M	Total ~7.5M/y

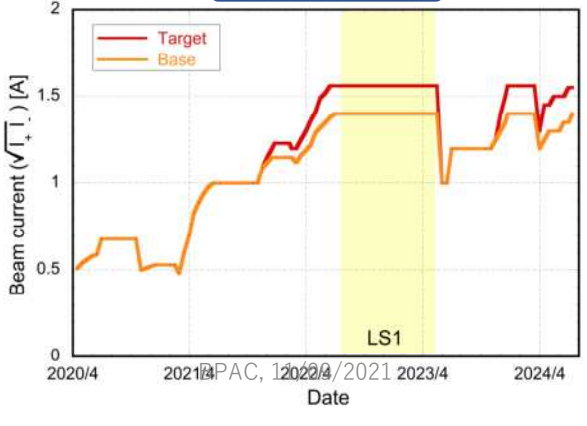
Integrated luminosity (delivered)



β_y^*



Beam current



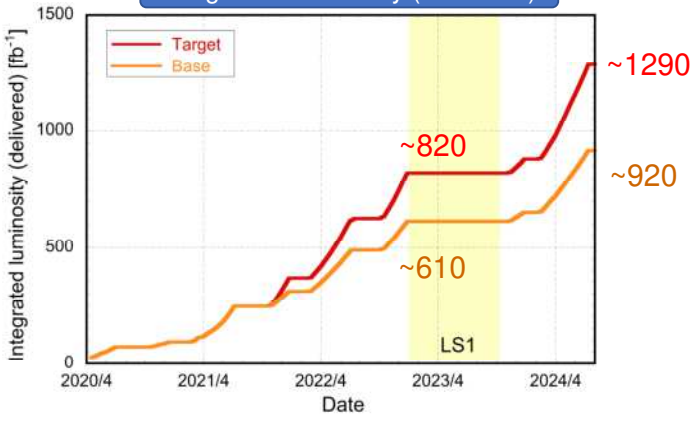
Luminosity

Luminosity profile for half a year delay plan

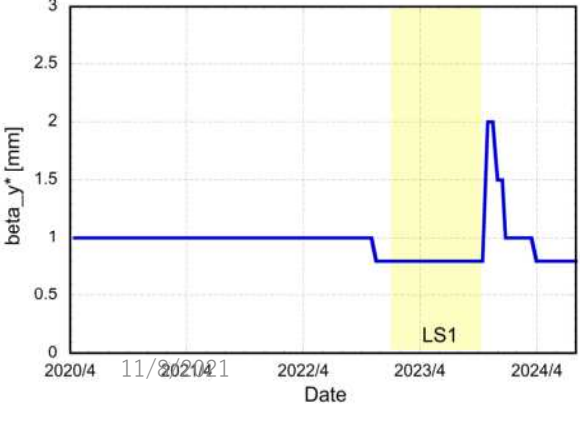
Half a year delay (2021/10/22)

	2021									2022			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2021		2021b ~3.2M						2021c ~2.2M				2022a ~1.2M	Total ~6.6M/y
	4/1			7/5			10/19		12/23		2/21		
	2022									2023			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2022		2022b ~3.2M			QCSR leak check			2022c ~2.8M		LS1			Total ~6.0M/y
	4/1			7/4			10/4		12/26				
	2023									2024			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2023	LS1 (PXD, TOP exchange)							2023c ~1.9M				2024a ~1.8M	Total ~3.7M/y
								10/31	12/25		2/6		
	2024									2025			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2024		2024b ~3.4M						2024c ~2.3M				2025a ~1.8M	Total ~7.5M/y
	4/1			7/12			10/16		12/25		2/6		

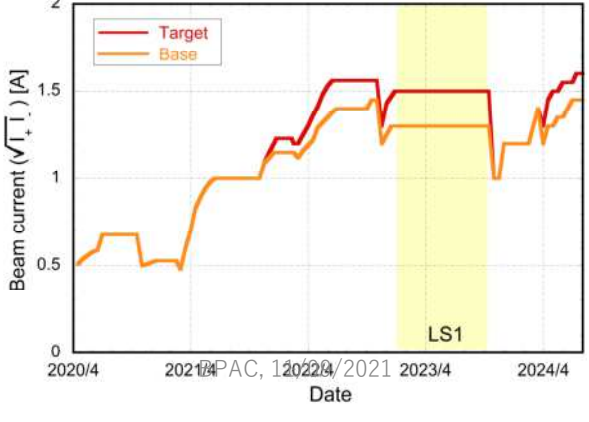
Integrated luminosity (delivered)



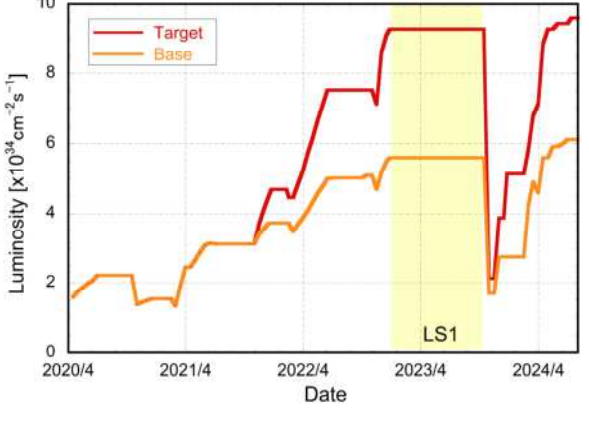
β_y^*



Beam current



Luminosity

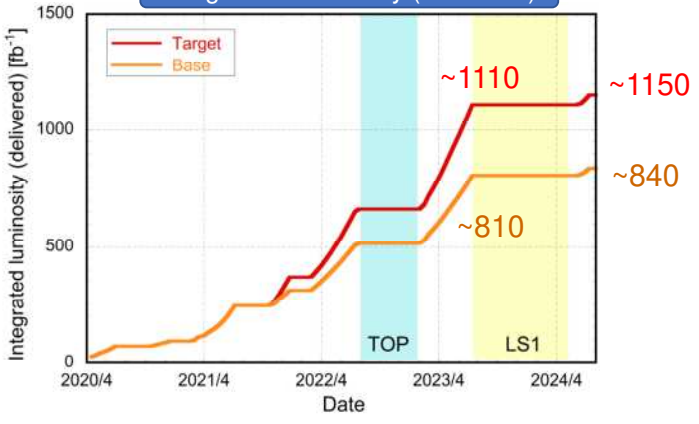


Luminosity profile for one year delay plan

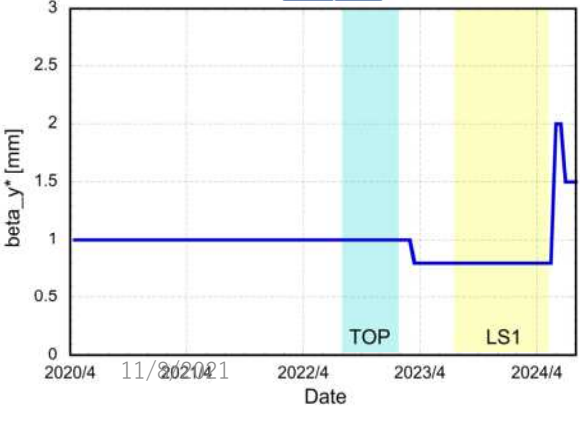
One year delay (2021/10/22)

	2021									2022			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2021		2021b						2021c				2022a	Total
	4/1	~3.2M		7/5			10/19	~2.2M	12/23		2/21	~1.2M	~6.6M/y
	2022									2023			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2022		2022b		QCSR leak check								2023a	Total
	4/1	~3.7M		7/19	TOP Exchange					1/23		~2.1 M	~5.8M/y
	2023									2024			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2023		2023b			LS1 (PXD exchange)								Total
	4/1	~3.5M		7/14									~3.5M/y
	2024									2025			
	4	5	6	7	8	9	10	11	12	1	2	3	
FY2024	LS1		2024b					2024c				2025a	Total
		5/14	~2M	7/12			10/10	~2.5M	12/25		2/6	~1.8M	~6.3M/y

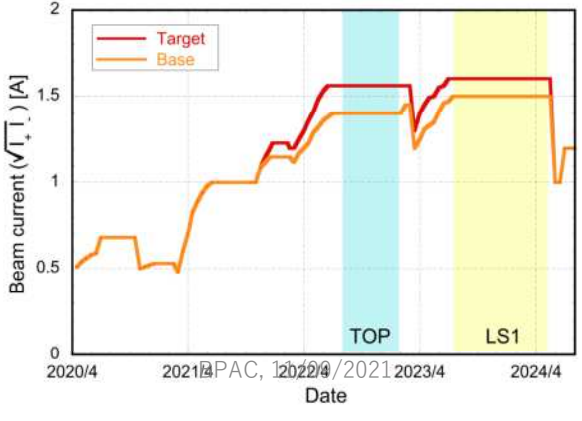
Integrated luminosity (delivered)



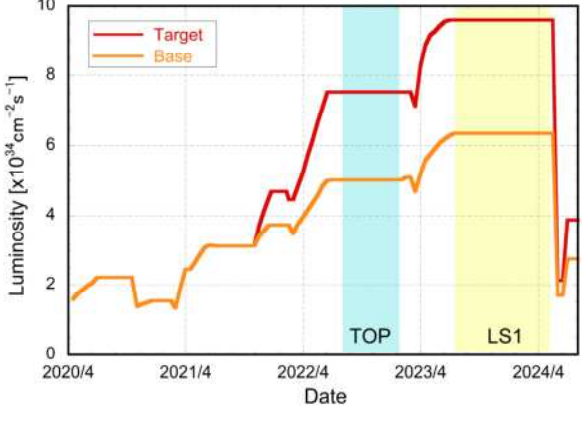
β_y^*



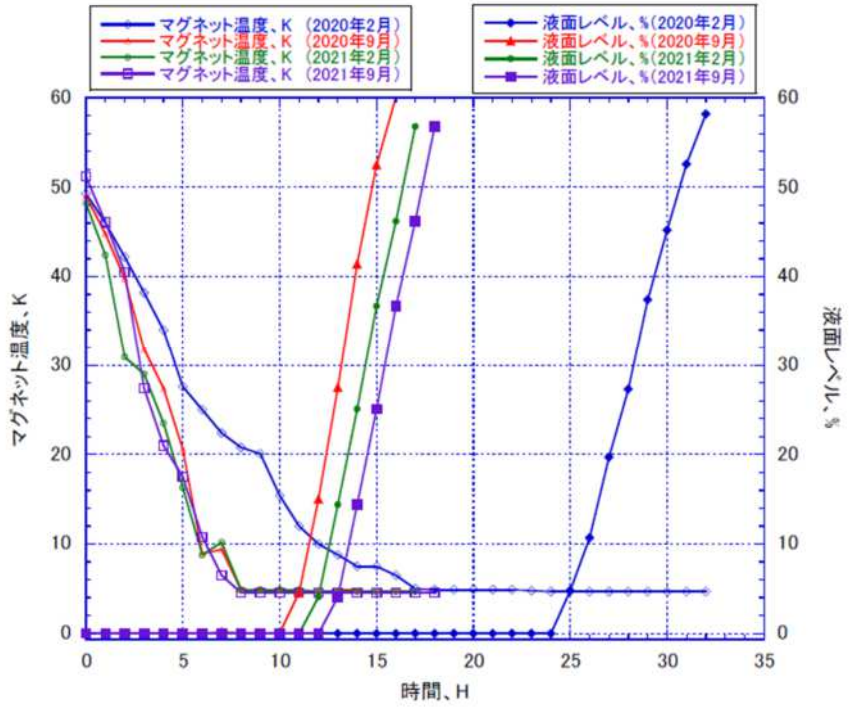
Beam current



Luminosity



Time until the liquid He starts to accumulate



International task force for SuperKEKB upgrade

- Charges
  - Consider effective ideas to realize luminosity of ~6x10^{35} cm^{-2} s^{-1} as a result of an intermediate upgrade around 2026, which could include modifications of IR, final focus systems, injectors, but without changing the boundary to the Belle II detectors.
  - Find a realistic way before long shutdown 1 (LS1) scheduled to start Jul/2022 in order to achieve luminosity of the order of 10^{35} cm^{-2} s^{-1} without large modification of accelerator components.
  - Consider longer-term alternative idea to achieve ~6x10^{35} cm^{-2} s^{-1} or more, even by largely modifying the IR and the Belle II detector.
- Activity period
  - Coming one year, before the LS1.
- Rough schedule
  - (Online) meeting per month basically.
  - Meetings are basically open, but may occasionally have closed sessions.
  - Special review by ARC per ~6 months.
  - Final report is to be submitted by the end of July, 2022.

Long-term operation plan

- To improve the machine further to achieve the goal, however, various challenges as follows should be solved:

1) Severe beam-beam effect (vertical beam size blow-up)
   - Vertical beam size (vertical emittance) blow-up has been observed at high bunch currents.
   - Relaxed by the crab-waist collision scheme, but it still remains.

2) Shorter beam lifetime than expected in the design phase.
   - The maximum bunch currents are limited by the balance between the lifetime and the injection power.
   - The dynamic aperture is very small due to the beam-beam effect and crab-waist sextupoles, while the physical aperture is limited by the beam collimators.

3) Lower bunch-current limit due to TMCI than expected.
   - The cause is higher impedance of beam collimators, where the apertures are smaller than the design values to suppress high background to Belle II.

4) Low machine stability
   - Abnormal beam aborts, sometimes leading to the damage of collimators.
   - Operation efficiency during 2021ab, for example, was almost 0.5, lower than expected one, 0.65. (Main causes: machine tunings, machine troubles, maintenance, etc.).

5) Low injection efficiency especially in HER
   - High residual radiation at injection point and beam collimators.
   - Large emittance of injected beam

6) Aging of hardware and facilities, and so on.

End