Near- and Long-term operation plans

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Contents

1) Near-term plan (until March, 2021)
   - Progress after the last Review (July 8, 2019)
   - Brief summary of results until 2020b run
   - Near-term plan and luminosity projection

2) Long-term plan (coming next 10 years)
   - Proposal to MEXT Roadmap2020
   - Update of operation plan
     - Reasons
     - Key points
   - Long-term plan and luminosity projection

Progress after the last review

- Recommendations in the last KEKB Review in relation to operation plan
  - The ARC endorses the proposed operational goals for Phase 3.1, toward β_y^* of 0.64 mm, 2 kAh, 200/fb, $3\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ by summer 2020. (R2.1)
  - 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.
- After the review, we discussed the commissioning scenario to realize the above goals.
  - It was finally decided that 2019 Autumn run (2019c) was mainly focused on the machine studies, especially to squeeze β_y^* to 1 mm (or less) in order to improve luminosity, to investigate the sources of beam background, and to further study the causes of beam-beam effects.
- Major works during 2019 summer shutdown
  - Replacement of IR bellows and BPMs.
  - Improvement in the beam-abort system to abort beams as fast as possible for safe operation at high-beam currents.

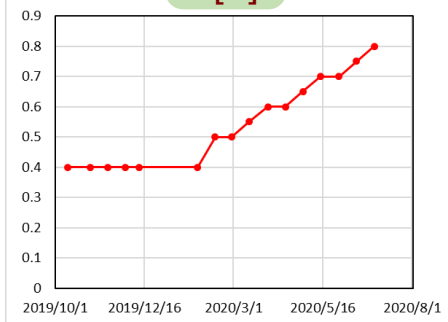
Progress after the last review

Operation plan: near term

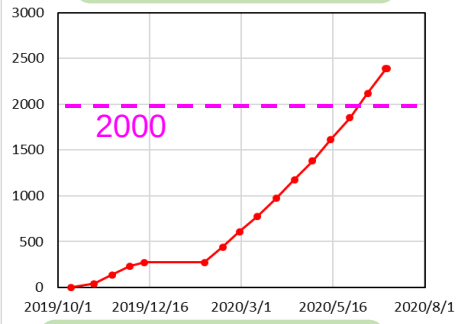
Presented at BPAC (2019/10/2)

- Expected luminosities in Base plan

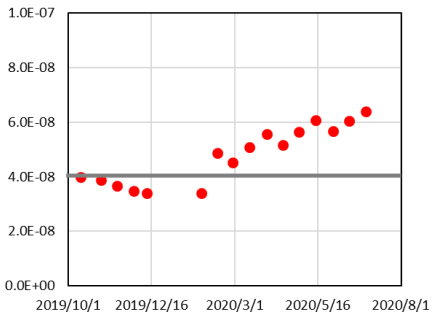
I [A]



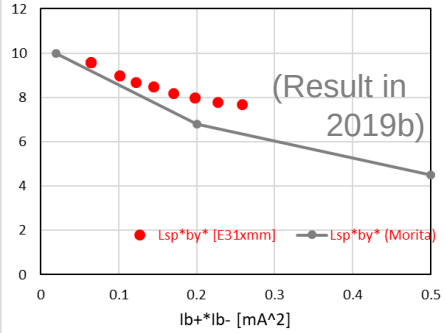
Beam dose [Ah]



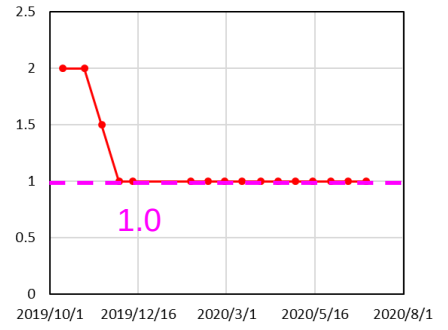
P x I [Pa A]



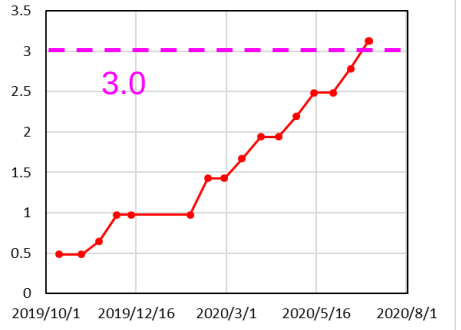
L_{sp} x β_y^* [x10^{31} cm^{-1}s^{-1}] vs I_{b+}xI_{b-}[mA^2]



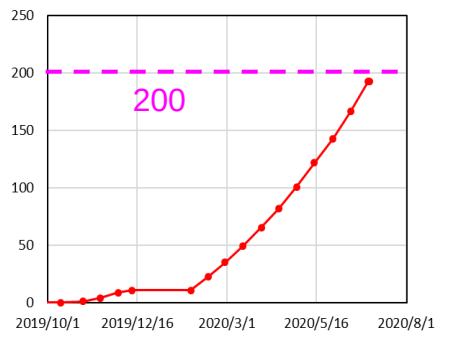
β_y^* [mm]



L_p [x10^{34} cm^{-2}s^{-1}]



Int. L [fb^{-1}]



Assumptions:

Similar background level as 2019b, with slightly improvement by 50%.

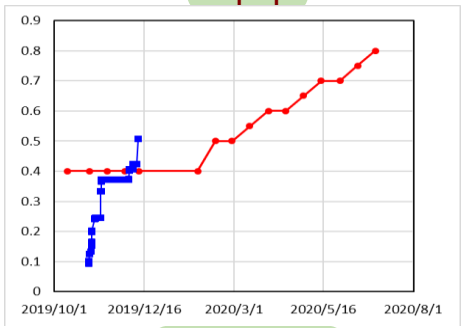
Similar beam-beam effects as 2019b, with slightly improvement by 20%.

Beam background is independent of β_y^*.

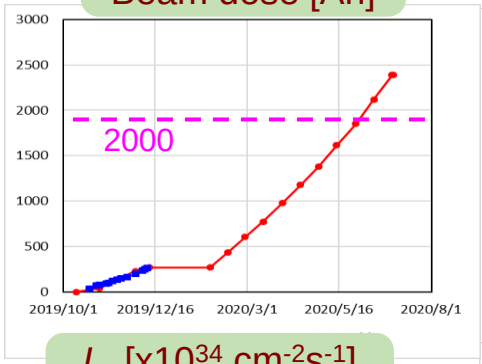
Progress after the last review

- Main results in 2019c

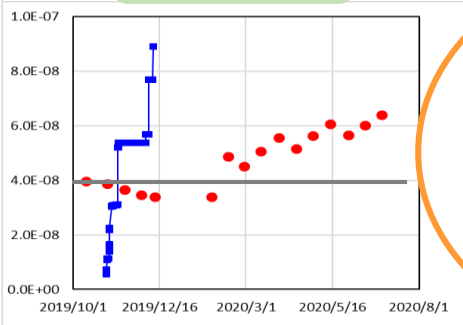
I [A]



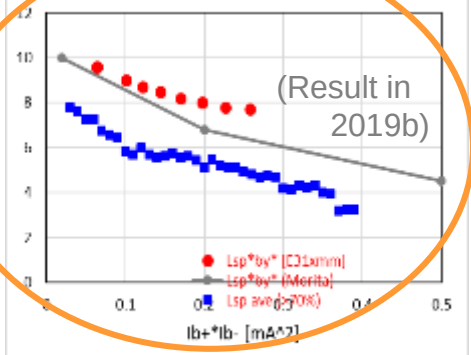
Beam dose [Ah]



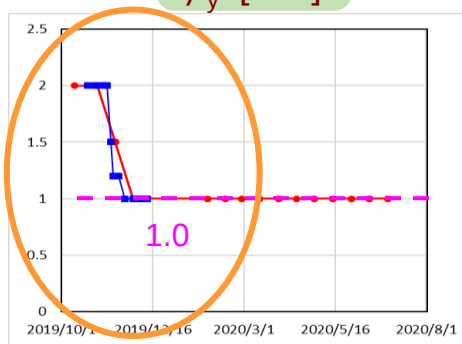
P x I [Pa A]



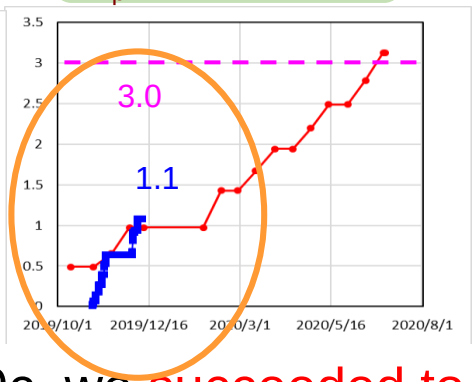
L_{sp} x β_y^* [x10^{31} cm^{-1}s^{-1}] vs I_{b+}xI_{b-}[mA^2]



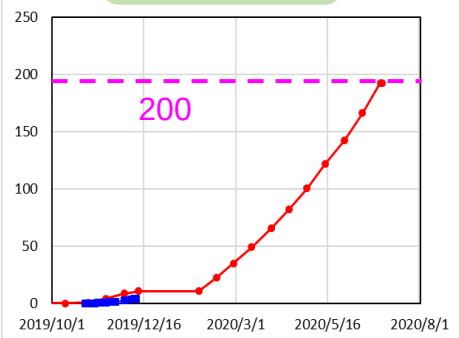
β_y^* [mm]



L_p [x10^{34} cm^{-2}s^{-1}]



Int. L [fb^{-1}]



- During 2019c, we succeeded to squeeze β_y^* to 1 mm as planned, and a peak luminosity of 1.14x10^{34}cm^{-2}s^{-1} (w/ Belle II) was achieved (1.88x10^{34}cm^{-2}s^{-1} w/o Belle II).
  - Background was well controlled thanks to collimator tunings.
  - On the other hand, the beam-size blow up due to beam-beam effects was still remained, and the specific luminosity was less than expected.

Progress after the last review

- After 2019c, we revised the operation plan until July 2020 (2020a and b) based on the results of 2019c.
  - The 2020a and b were decided to be basically dedicated to physics run, in parallel with various studies to improve the performance.
    - Crab-waist scheme for LER was prepared.
  - The luminosity projection was also re-evaluated based on the proven beam-beam effect as a base plan, and explained in SuperKEKB workshop, January, and proposed in BPAC, February.
    - Unfortunately, the operation period was limited to ~5.4 months due to lack of budget.
  - The goal values were, as a result, somewhat smaller than those recommended by ARC (July 2019), but they were more realistic.
- In January, we held the SuperKEKB workshop at KEK, and discussed the results of 2019c and the plan.
- Major works during 2019 winter shutdown
  - Installation of a vertical-type collimator into LER to further reduce beam background.
  - Preparation of the crab-waist scheme for LER

Progress after the last review

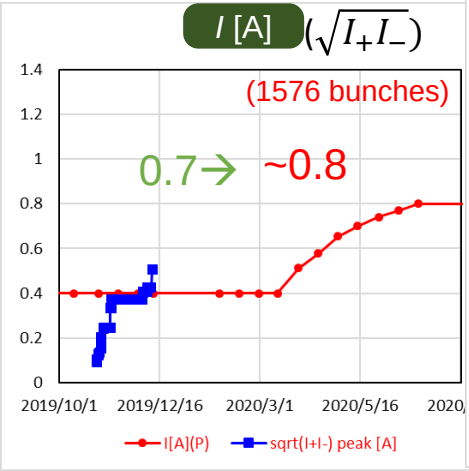
- Near term luminosity projection (~2020 June)

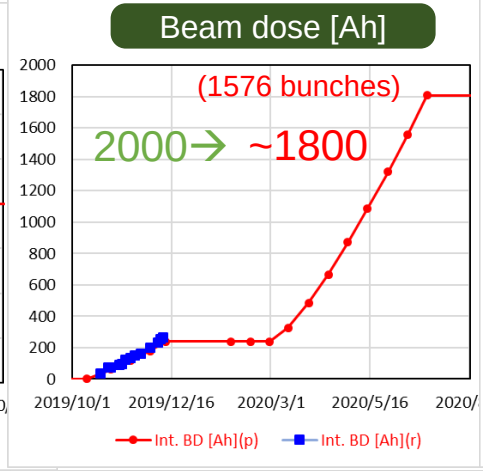
(1) Base (conservativ

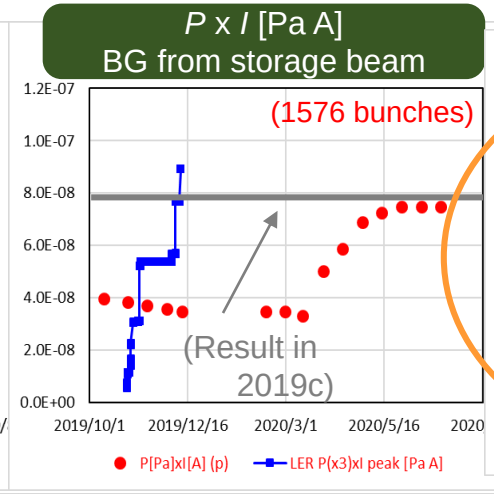
Presented at BPAC (2020/2/10)
And explained at SuperKEKB workshop (2020/1/31)

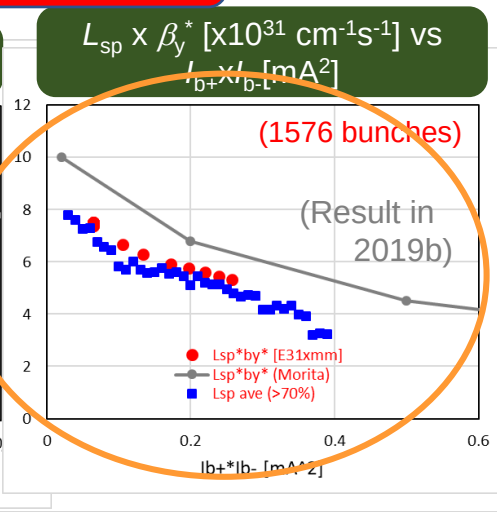
Cal., Assumption
Result in 2019c

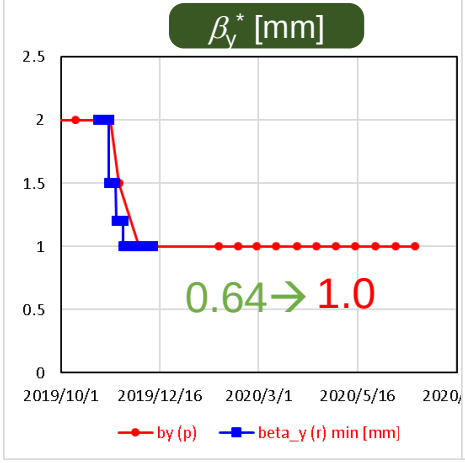
Goals at the last review (2019 July)

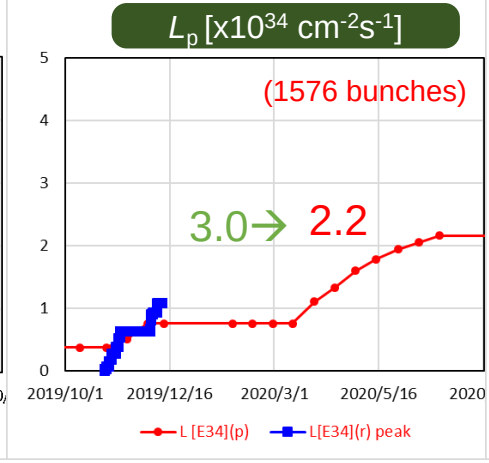


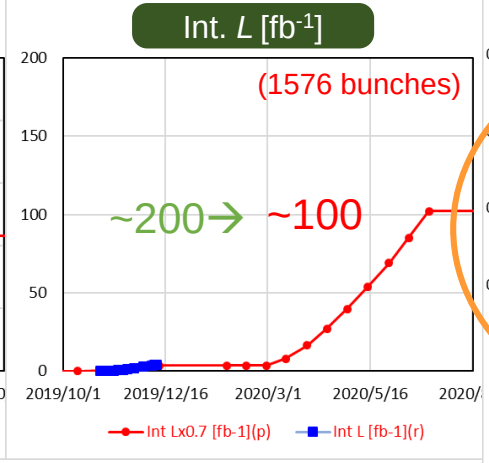


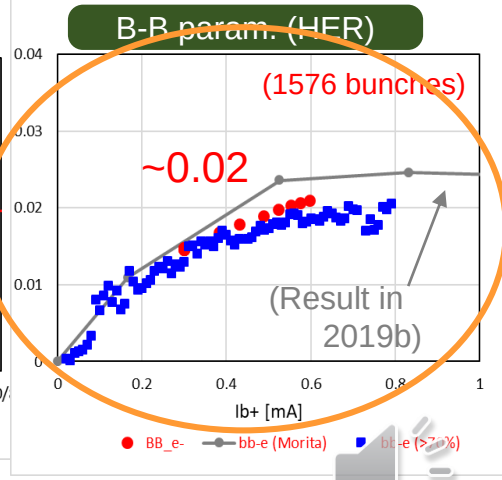












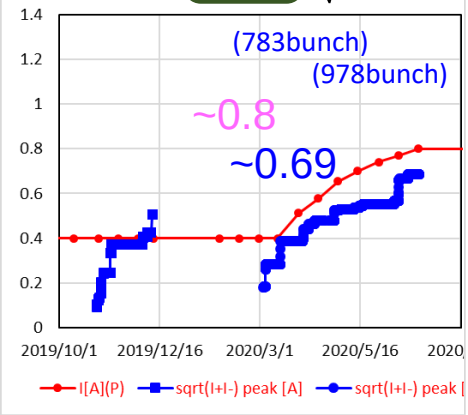
Brief summary of results until 2020b

- Main results in 2020a, b
  - Details are presented by Ohnishi-san.

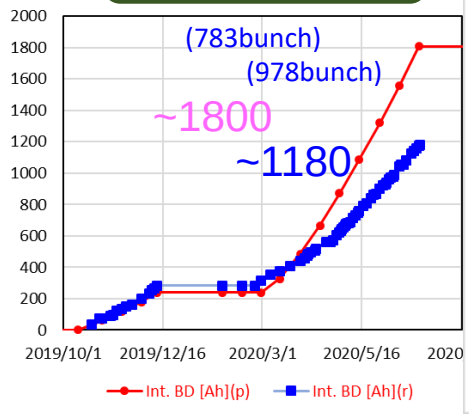
● Cal., Assumption
■ Result in 2019c, 2020a, b

Goals at BPAC (2020 Feb.)

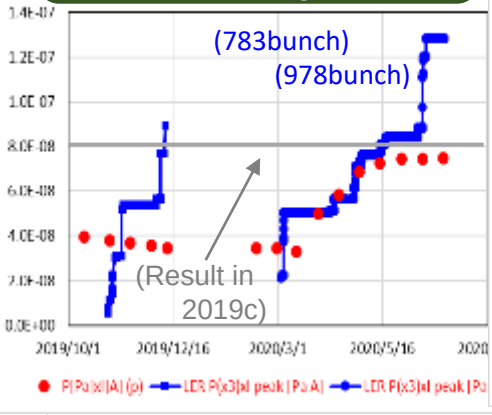
I [A] $(\sqrt{I_+ I_-})$



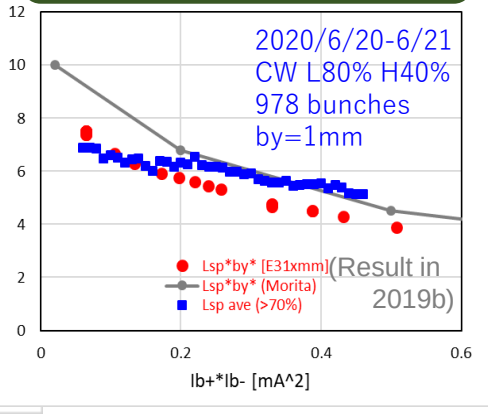
Beam dose [Ah]



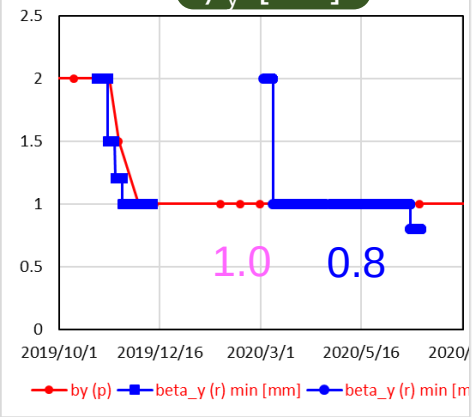
P x I [Pa A]
BG from storage beam



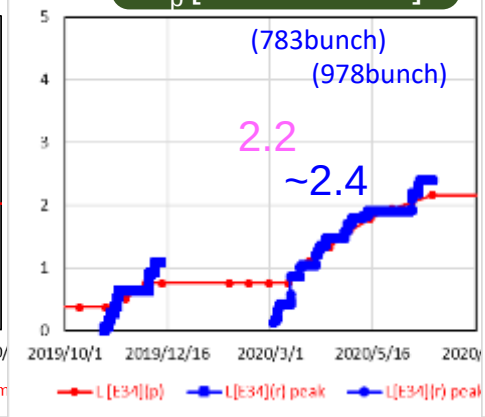
L_{sp} x β_y^* [x10^{31} cm^{-1}s^{-1}] vs I_{b+}xI_{b-}[mA^2]



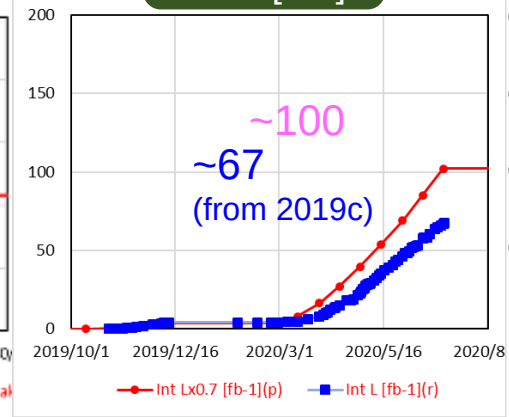
β_y^* [mm]



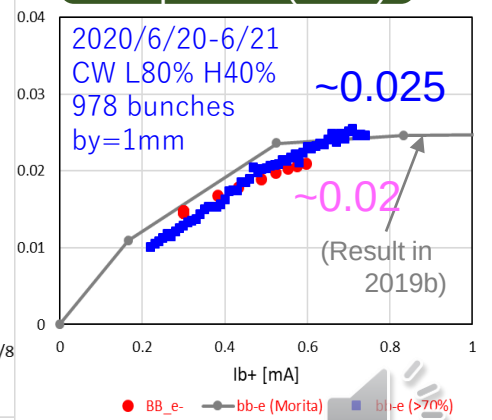
L_p [x10^{34} cm^{-2}s^{-1}]



Int. L [fb^{-1}]



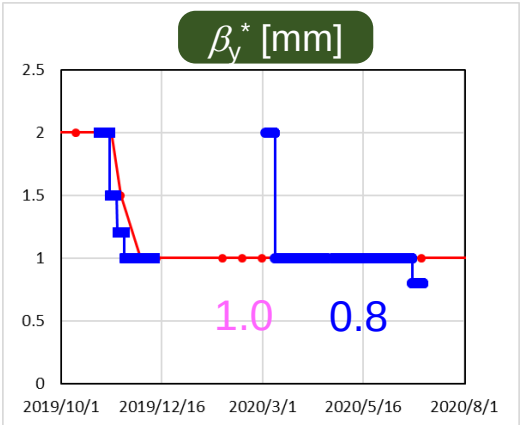
B-B param. (HER)

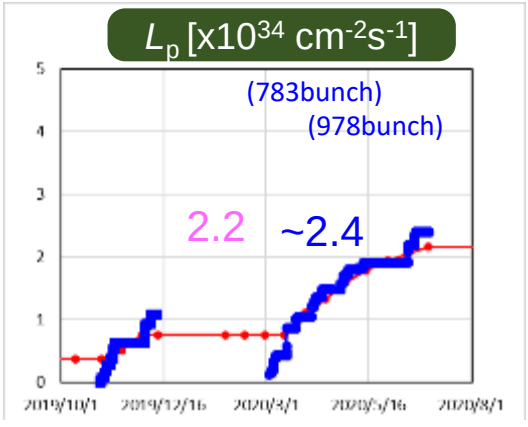


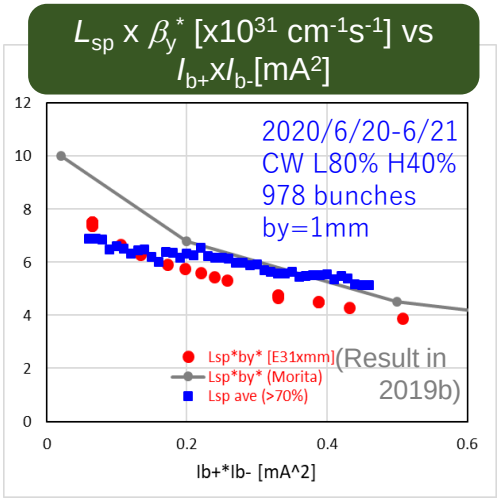
Brief summary of results until 2020b

- Results until 2020b

Goals at BPAC (2020 Feb.)





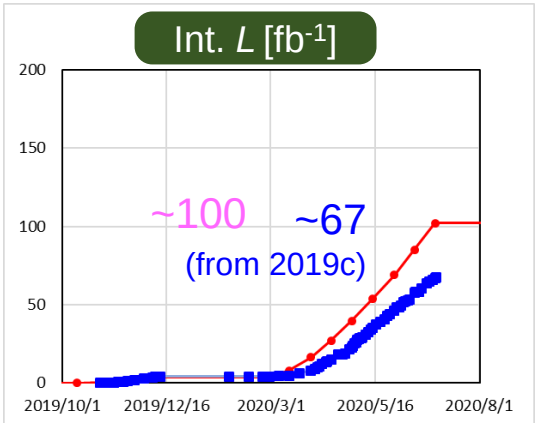


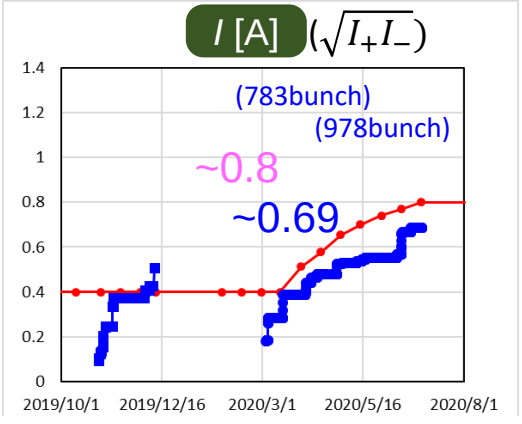
- β_y^* was kept at 1 mm
  - Stable physics run with β_y^* = 1 mm was achieved.
  - β_y^* = 0.8 mm was tried finally.
- Peak luminosity increased almost as expected.
  - Mainly thanks to the crab waist collision scheme in both LER and HER.
- Specific luminosity vs bunch-current products was almost as expected.
  - Specific luminosity was kept at high value at high bunch-currents thanks to the crab waist collision scheme.
  - But still affected from beam-beam effect.

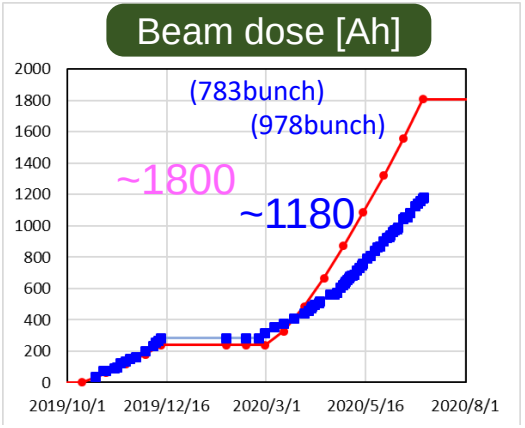
Brief summary of results until 2020b

- Results until 2020b

Goals at the last BPAC (2020 Feb.)



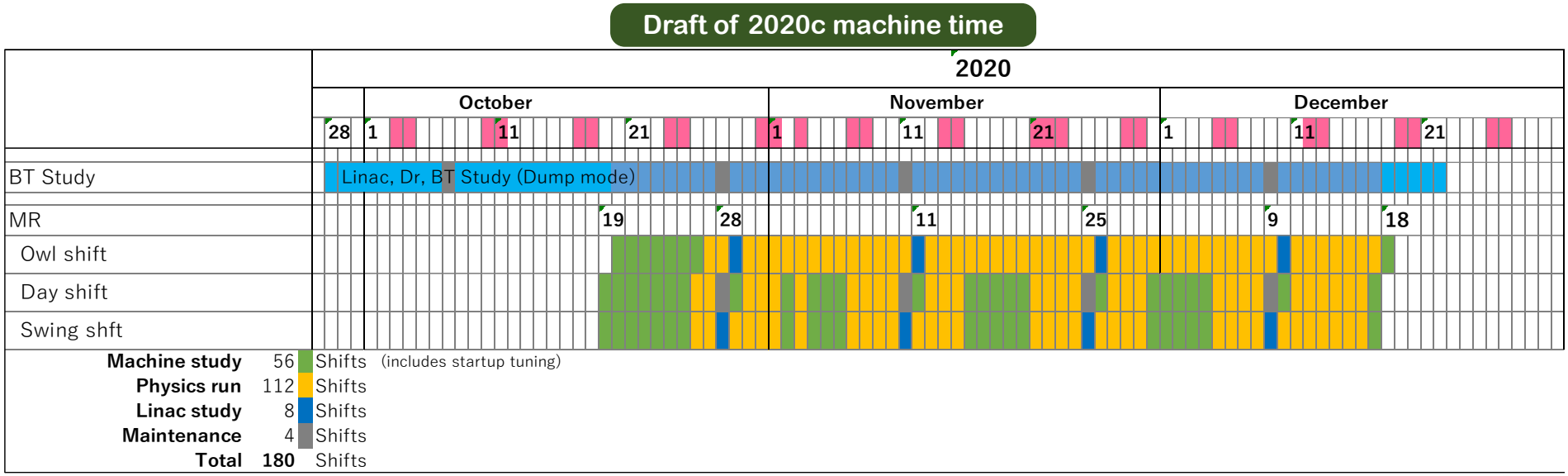




- Int. luminosity was less than expected.
  - More machine-study time than planned, such as HER crab waist scheme. But it contributed to increase peak luminosity.
  - More down time than expected due to machine troubles, Belle II detector troubles, lots of beam aborts, and so on.
  - As a result, the efficiency was less than 70% (50~60%).
- Beam currents were less than expected.
  - Operation with smaller number of bunches, and then difficulty in beam injection at high bunch currents due to beam-beam effect, short beam lifetime.
  - Hardware (vacuum) problem at high-bunch currents in HER.
- Due to low beam currents and shorter running time, the beam dose was also less than expected consequently.

Near-term plan and luminosity projection

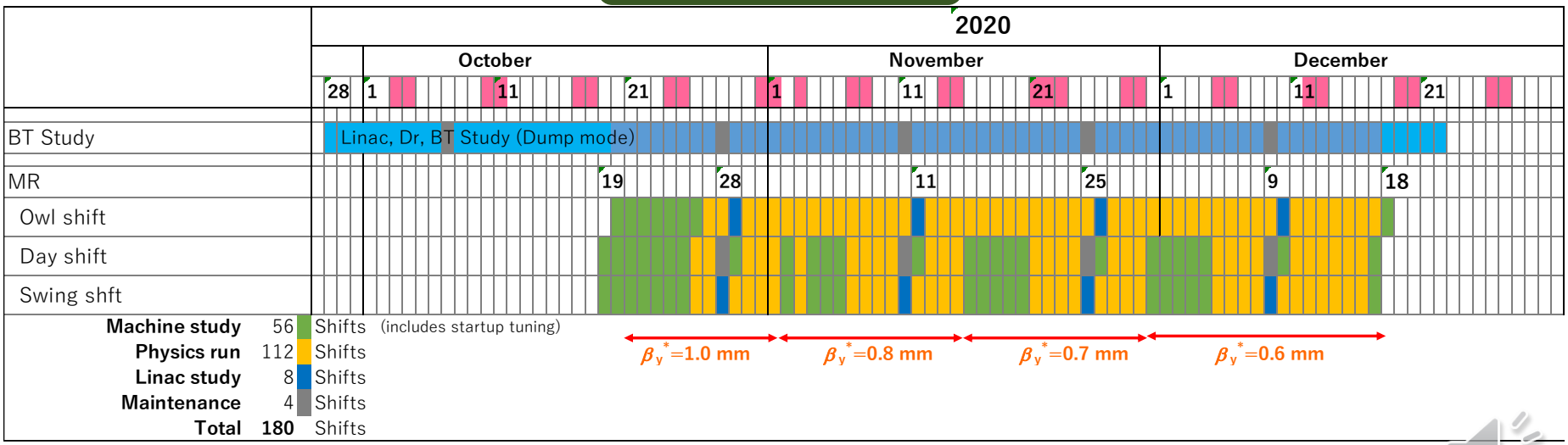
- 2020c will start from Oct. 19, after summer shutdown.
  - Linac will start from Sept. 28 prior to that for the tuning (BT, DR) and PF injection.
- 2020c will stop Dec.18.
- 180 shifts (60 days) in total
  - ~112 shifts for physics run
  - ~64 shifts for machine study and tuning
  - 4 shifts for regular maintenances, and 8 shifts for Linac studies



Near-term plan and luminosity projection

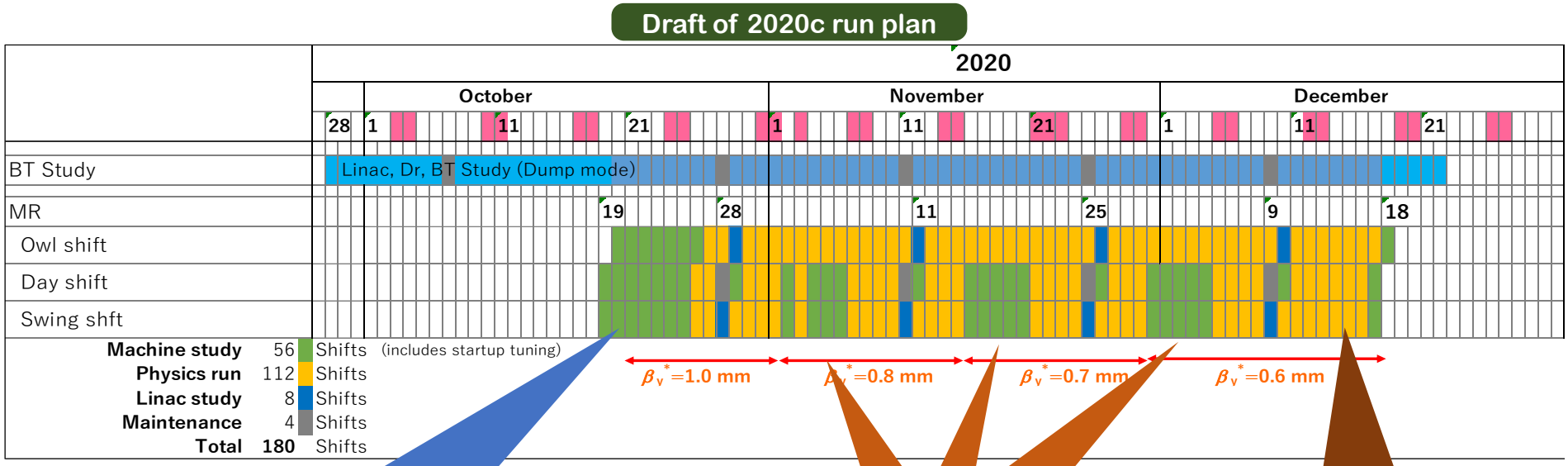
- 2020c commissioning plan was discussed based on the results until 2020b.
- Main theme of 2020c is to squeeze β_y^* as planned.
  - Operation with β_y^* = 1 mm was achieved in 2020b.
  - Goal is β_y^* ~ 0.6 mm.
- Machine studies will be scheduled appropriately in parallel with physics run, similarly to 2020b.
  - We need some time to calm down and think the results of studies.
  - Basically, owl shifts and weekends will be assigned to physics run.

Draft of 2020c run plan



Near-term plan and luminosity projection

- Study items
  - Main item is to squeeze β_y^*. (β_y^* = 0.8 mm was tried during 2020b).
  - Studies to realize stable operation with each β_y^*, accordingly.
    - Injection, background, etc.
  - Beam-beam and optics studies for future runs
    - The crab waist collision scheme will be kept in 2020c.



Start up
- Vacuum scrubbing (40 Ah)
- Recovery to 2020b condition
- Injection study

- Squeezing β_y^* to 0.8 mm, 0.7 mm, 0.6 mm
- Injection study/tuning
- Background study
- Beam-beam / optics study
- Other hardware/software studies

- Machin studies if necessary
- Optics study

Near-term plan and luminosity projection

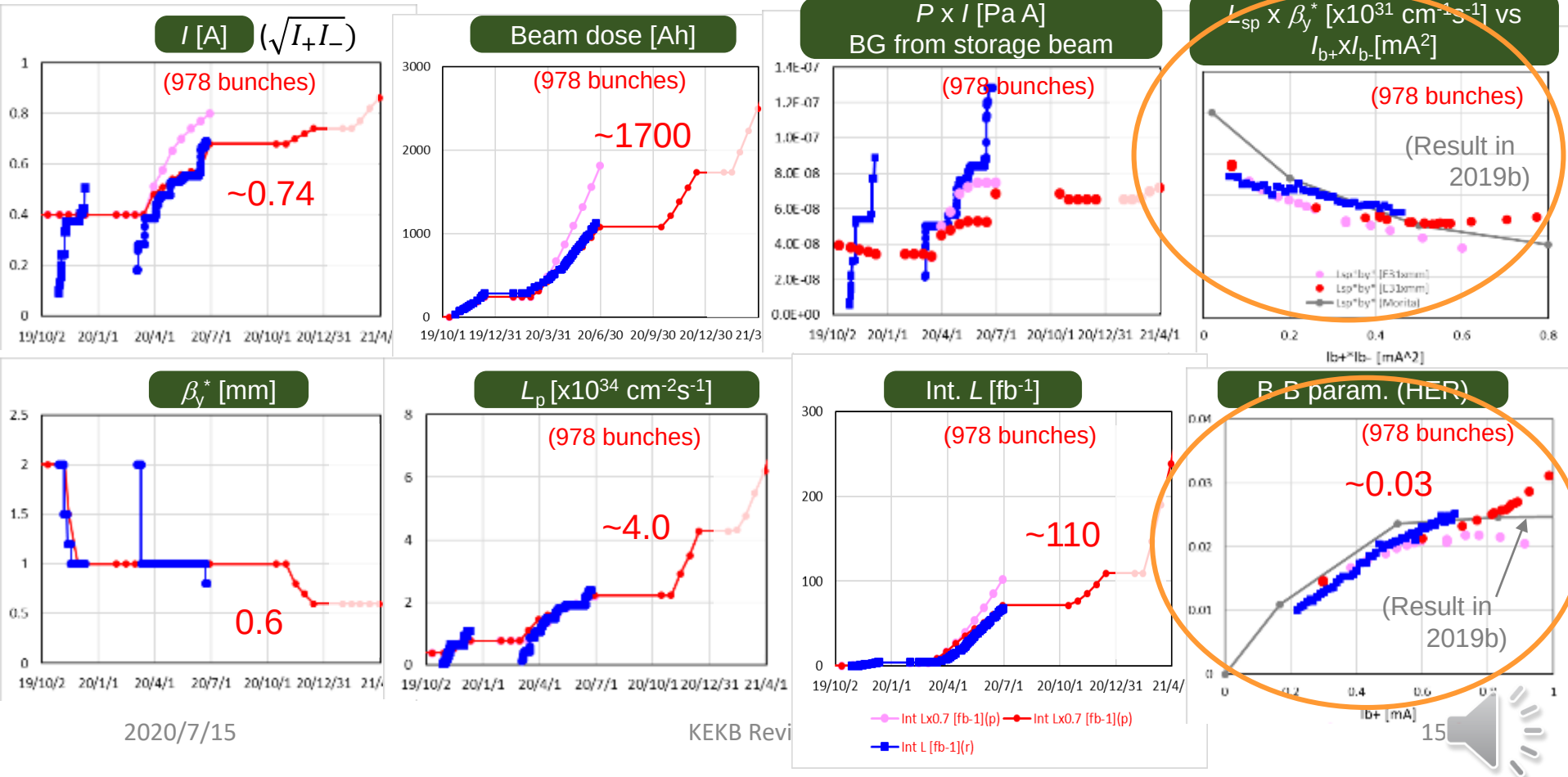
- Major works planned during this summer shutdown
- Hardware
  - Installation of one vertical-type beam collimator in LER
    - D03_V1
  - Replacement of D06_V1 collimator head
    - Change the material from Tantalum to Carbon
  - Replacement of flux concentrator (e^+) and pulsed bending magnets in Linac
- Software
  - Preparation of various tuning tools
    - For example, tools to control rotatable sextupole magnets in phase.
  - Preparation for synchrotron injection
  - Improvement in collision feed-back system
- Others
  - Regular maintenances, only possible in long shutdown.

→Improvement in background, injection efficiency and machine tunability are expected to some extent.

Near-term plan and luminosity projection

- Luminosity projection was re-evaluated.
  - Int. Luminosity etc. were adjusted to the results of 2020b.
  - Similar specific luminosities and beam-beam parameters were assumed as a base plan (with crab-waist).
- Until 2020c

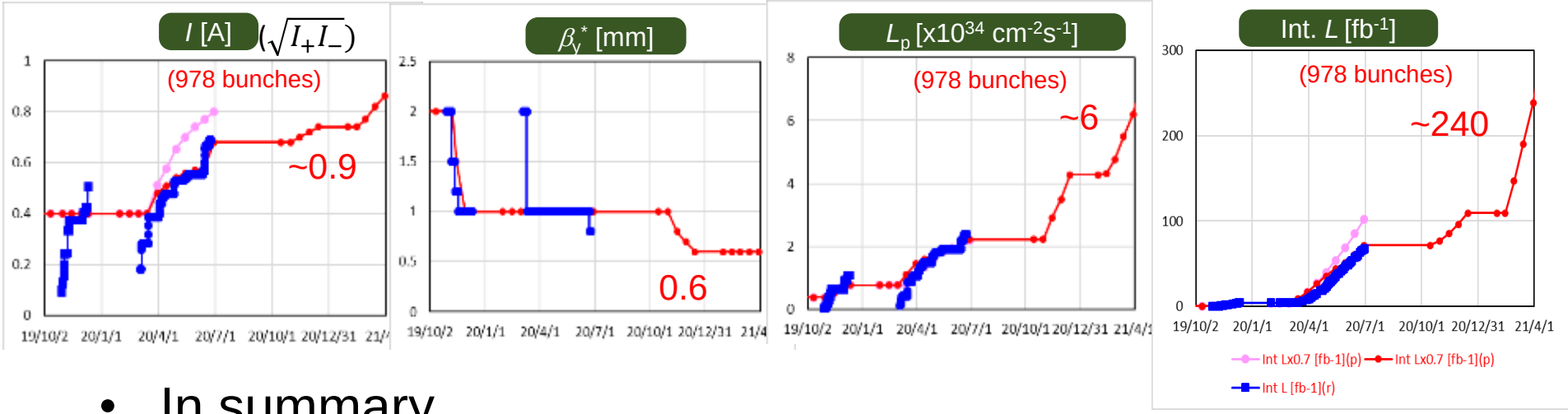
● Cal., Assumption ■ Result in 2019c, 2020a, b ● Original plan in 2019a,b



Near-term plan and luminosity projection

- Until 2021a
  - We assumed that it is dedicated to physics run, and that 6.5 ~ 5.5 months operation this year (depends on the budget, as you know.).

● Cal., Assumption ■ Result in 2019c, 2020a, b ● Original plan in 2019a,b



- In summary,

	Parameters			
	Int. L [fb^{-1}]	L_p [E34]	I_{max} [A] (ave.)	β_y^* [mm]
Base plan until 2020c	~110	~4	0.74	0.6
Base plan until 2021a (Depend on operation time)	240~140	6.5~4.5	0.9~0.75	0.6

Summary-1 (Near-term)

- 2020b has been operated successfully with β_y^* = 1 mm and adopting crab-waist collision scheme in both LER and HER.
- 2020c will start from Oct. 19, and will stop on Dec. 18.
  - 180 shifts (60 days) in total
- Machine study time will be scheduled appropriately in parallel with physics run.
- Main study item is to squeeze β_y^*, down to ~ 0.6 mm (goal).
  - Studies to realize stable operation with these β_y^*, accordingly.
    - Injection, background, etc.
  - Studies important to predict the future operation.
- Luminosity projection of 2020c (and 2021a) is re-evaluated based on the results until 2020a and b.

	Parameters			
	Int. L [fb^{-1}]	L_p [E34]	I_{max} [A] (ave.)	β_y^* [mm]
Base plan until 2020c	~110	~4	0.74	0.6
Base plan until 2021a* (Depend on operation time)	240~140	6.5~4.5	0.9~0.75	0.6

*Here we assumed 6.5 ~ 5.5 months' operation this year.

Contents

1) Near-term plan (until March, 2021)
   - Progress after the last Review (July 8, 2019)
   - Brief summary of results until 2020b run
   - Near-term plan and luminosity projection

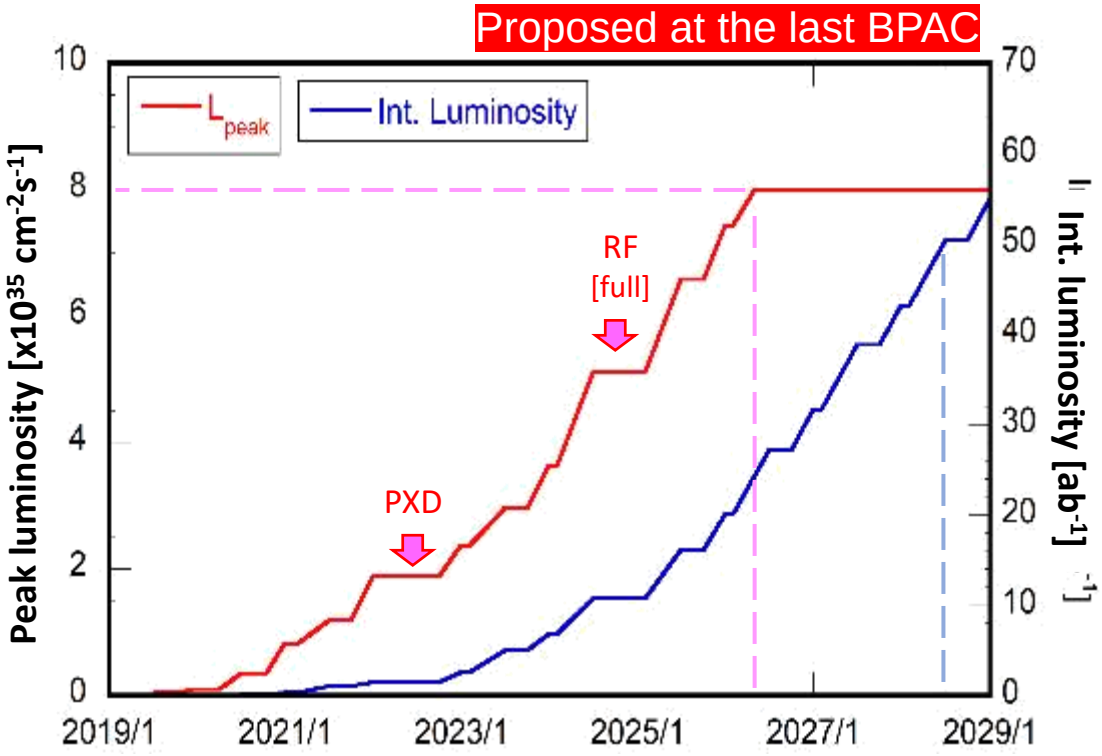
2) Long-term plan (coming next 10 years)
   - Proposal to MEXT Roadmap2020
   - Update of operation plan
     - Reasons
     - Key points
   - Long-term luminosity projection

Proposal to MEXT Roadmap2020

- KEK submitted 10 year SuperKEKB project to the SCJ Master plan 2020. The project was ranked as one of the 31 most important projects.
- The next step is the MEXT Roadmap2020 selection. The Roadmap2020 is a fundamental plan of the MEXT for the promotion of large-scale projects in academic research.
  - Revised every three years.
- Now we are making the SuperKEKB Roadmap2020, i.e., the budget and operation plan for the coming 10 years.
  - The proposal was already submitted to the MEXT in February. The hearing is planned in August.
- In this roadmap, we proposed to update the present operation plan (2019) considering the actual situation and the results obtained so far.
  - This is not such a large change as a successive project, but rather changes towards a more realistic plan.
- Here the reasons and key points in the update are explained.

Update of operation plan and its reasons

- Present plan
  - Proposed at the BPAC, Feb., 2020
  - Updated based on the results after Phase-2



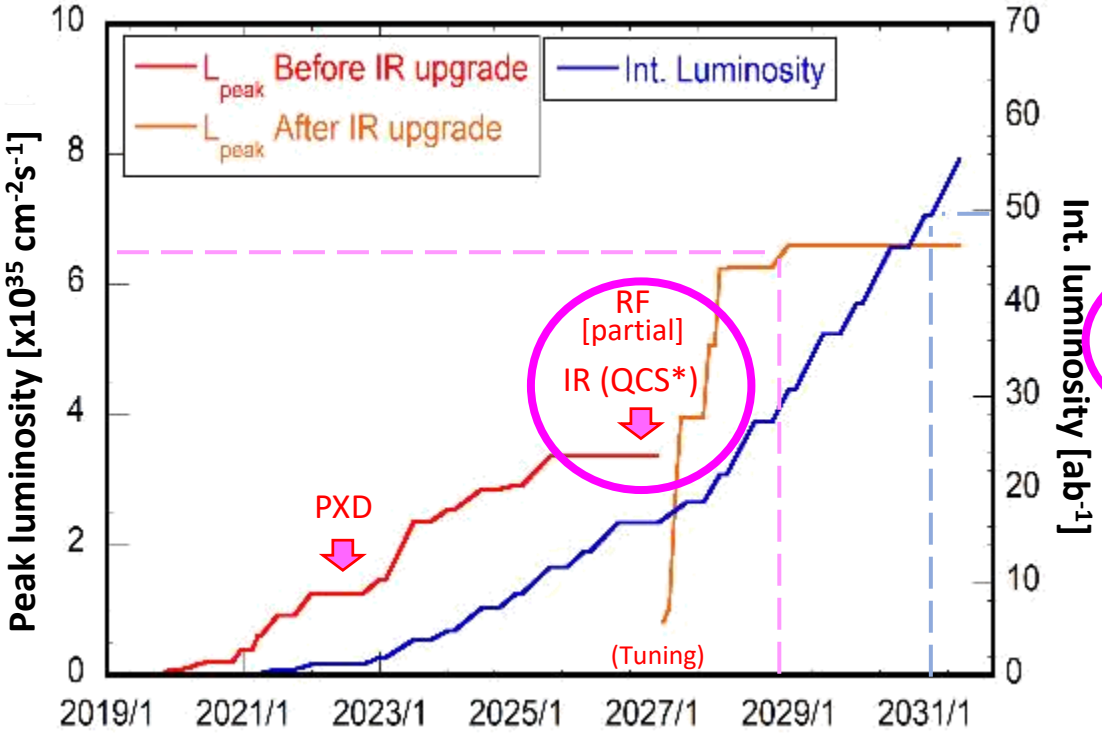
- Peak luminosity 8E35 $cm^{-2}s^{-1}$ in ~2026
- Integrated luminosity 50 ab^{-1} in ~2028
- β_y^*=0.3 mm in 2021
- PXD exchange in 2021~2022
- RF full upgrade (4 stations) in 2024
- Max. beam currents: LER 3.6 A, HER 2.6 A (2500 bunches) in 2026
- Basically, 8 months operation per year.

[Investment in equipment]

- Full-scale RF-power upgrade (add 4 stations)
- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade

Update of operation plan and its reasons

- Updated plan
  - Proposed in Roadmap 2020



*QCS:
Superconducting final focusing quadrupole magnet

- Peak luminosity ~6E35 $cm^{-2}s^{-1}$ in ~2028
- Integrated luminosity 50 ab^{-1} in ~2030 (40 ab^{-1} in ~2029)
- PXD exchange in 2021~2022
- Partial RF-power upgrade (2 stations) in 2026
- IR (QCS and its beam pipes etc.) upgrade in 2026
- β_y^*=0.3 mm in 2026 after IR upgrade, and ~0.5 mm before that
- Max. beam currents: LER 2.8 A, HER 2.0 A (1761 bunches) in 2027
- Basically, 8 months operation per year.

[Investment in equipment]

- IR (QCS and its beam pipes etc.)
- Partial RF-power upgrade (2 stations)
- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade

- Main motivations are explained below.

Update of operation plan and its reasons

- Main reasons:

(1) Increase in the running cost (utility cost)

(2) Challenges found in the initial operations (～2020b) ：

(a) Strong beam-beam effects in high bunch-current region
(b) Narrow physical aperture in the QCS
(c) High background in Belle II

(3) Small dynamic aperture in the high bunch-current region with small β_y^* (~0.3 mm), which had been recognized already as an issue in the design phase.

Update of operation plan and its reasons

- Reason-1

(1) Increase in the running cost (utility cost)

- If we want to run with the max. beam currents in the original design (LER 3.6A, HER 2.6A), approximately 1.6 times the electric power (i.e., running cost) is required compared to that used at present (0.5 ~ 1 A) .
- If the operation budget does NOT drastically increase, and the electricity unit cost remains at a similar level, the operation period per year will be strictly limited.
- As a result, it takes a long time to achieve the integrated-luminosity goal, and the total running cost will further increase in proportion.

→ More effective (ecological), that is, better collision performance with lower beam currents is required to achieve the goal in a reasonable time period.

Update of operation plan and its reasons

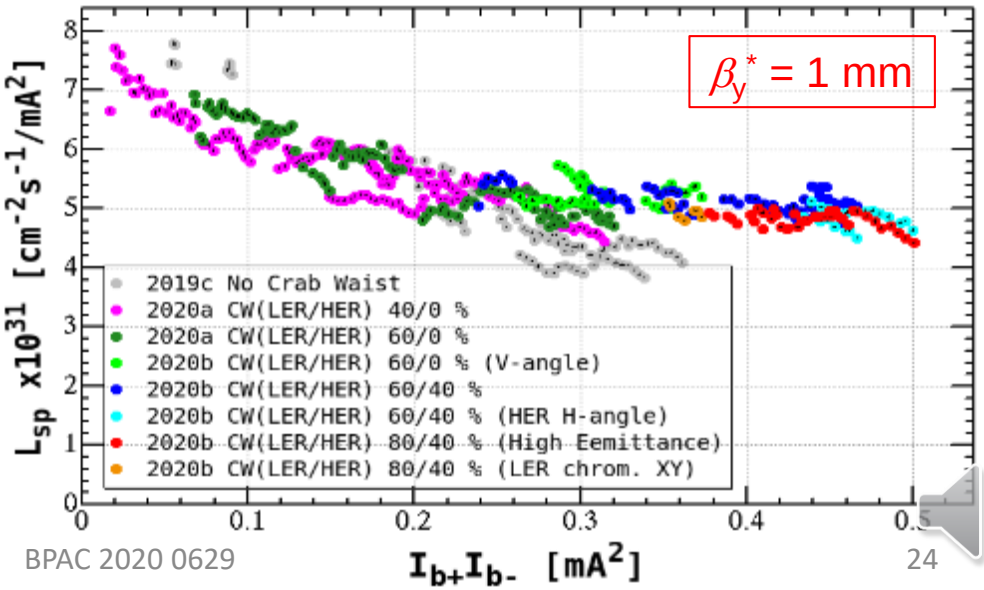
- Reason-2

(2) Challenges found in the initial operations (～2020b) ：

(a) Strong beam-beam effects in high bunch-current region

- In high bunch-current region (i_b^+ x i_b^->～0.2 mA^2), the specific luminosity is lower than expected owing to the vertical-beam size blowup due to the beam-beam effect, and the beam-beam parameter is also lower.
- Main reason is thought to be chromatic x-y coupling at the IP (Interaction Point), but this is not yet confirmed.
- Crab waist collision scheme and utilizing skew sextupole magnets are very promising solutions at present, but their effectiveness is not yet confirmed up to the final goal of β_y^*= 0.3 mm.

Specific luminosity vs. bunch-current products



Update of operation plan and its reasons

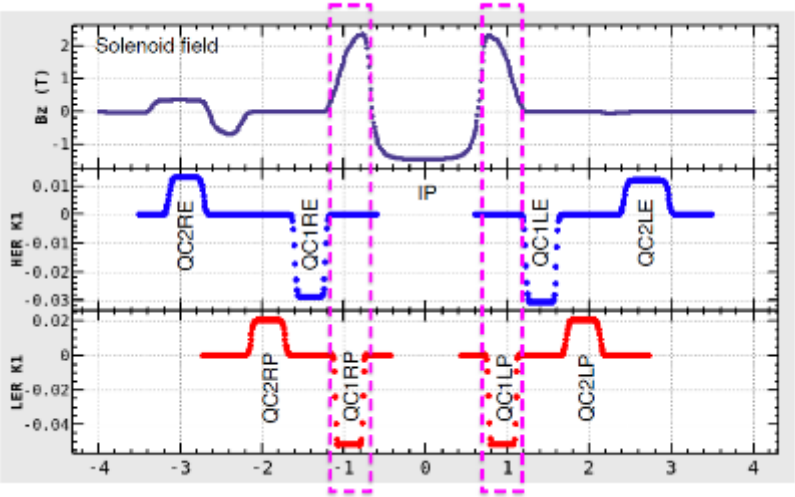
- Reason-2

(2) Challenges found in the initial operations (～2020b) ：

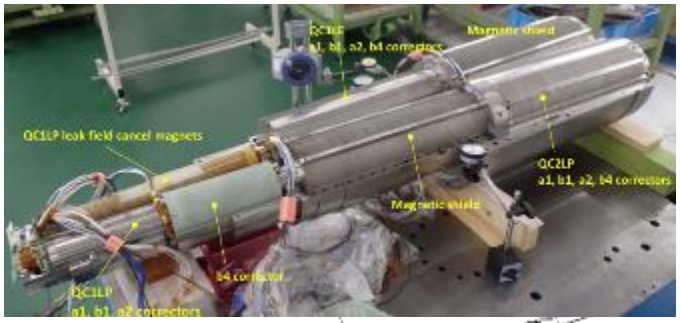
(a) Strong beam-beam effects in the high bunch-current region

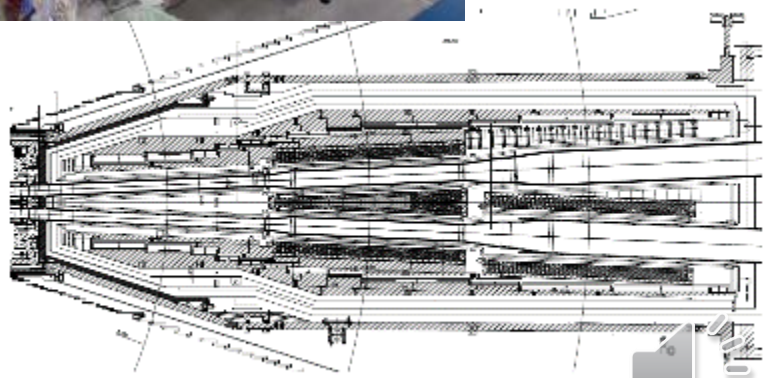
- A recent simulation indicated that one promising method to mitigate the effect will be the modification of QCS to avoid interference between the quadrupole magnetic field and the Belle II solenoid field for the LER.
- Further study is on-going.

Solenoid field (B_z) and integrated B_z in QCS



QCS magnets





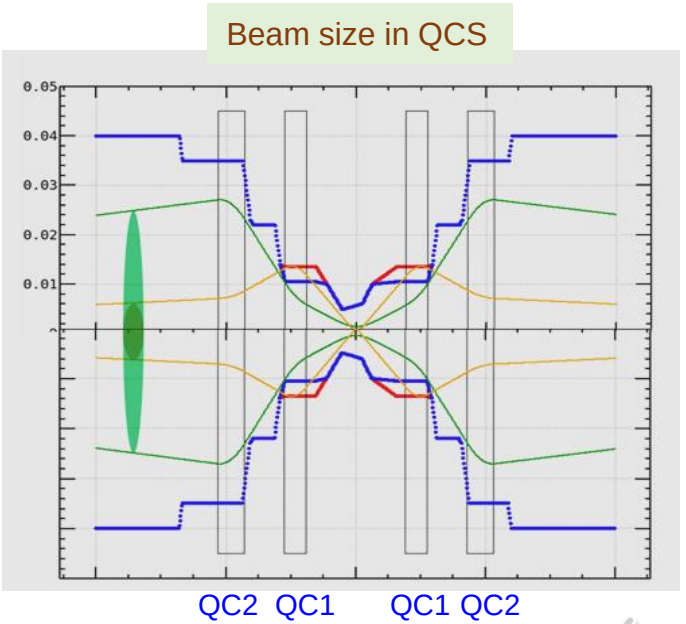
Update of operation plan and its reasons

- Reason-3

(2) Challenges found in the initial operations (～2020b) ：

(b) Narrow physical aperture in the QCS

- Quenches of QCS caused by hits from unstable beams have been observed.
  - In the worst case, this may result in damage of the QCS coils.
- At present, beam collimators are effectively preventing this by closing the collimators to narrower physical apertures than the beam pipe in the QCS.
- However, if we wish to squeeze β_y^* to less than 0.5 mm, β_y function at QCS will become even larger, and it will be difficult to protect the QCS by using collimators.
  - The narrower the beam collimators, the shorter the beam lifetime, and the higher the risk of damage of collimators due to beam loss.



Update of operation plan and its reasons

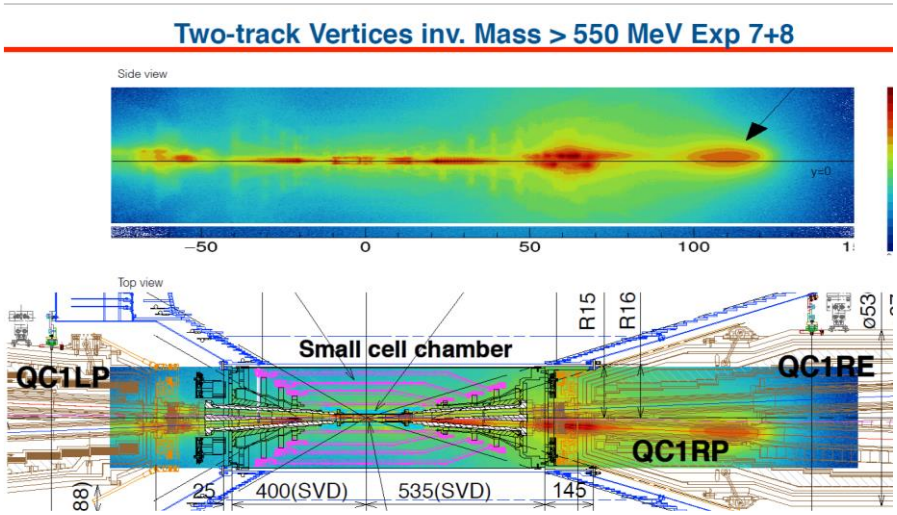
- Reason-4

(2) Challenges found in the initial operations (～2020b) ：

(c) High background in Belle II

- At present, the background in Belle II is larger than expected.
- One of main causes is hits from stored beams and/or injection beam halo on the beam pipe in the QCS.
  - The background also depends on the vacuum pressure in the ring and the quality of injection beams.
- The background will become more severe as β_y^* is squeezed further.
  - The β_y function at the QCS will become large. And hence it will be easier for the beam halo to hit the beam pipe.

Source points of background (reconstructed from CDC track data) [H. Nakayama, SuperKEKB WS.]



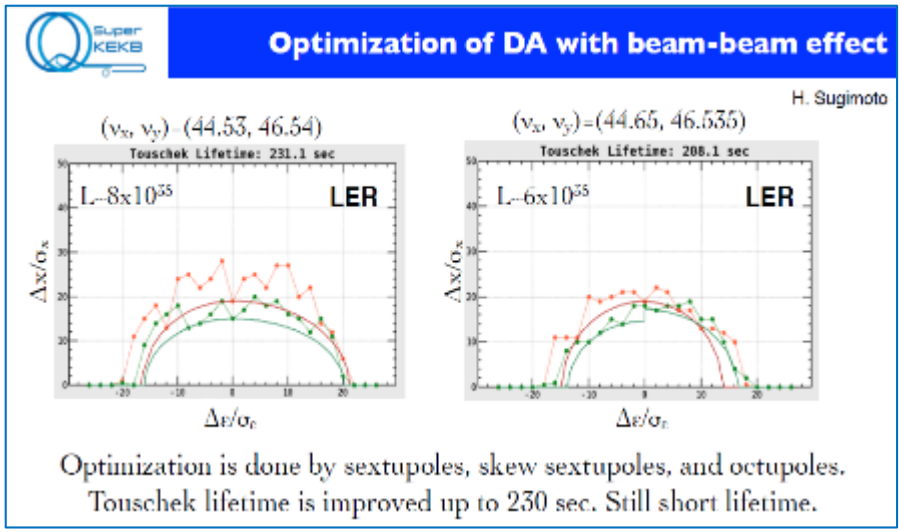
Update of operation plan and its reasons

- Reason-5

(3) Narrow dynamic aperture at high-bunch current at small β_y^*

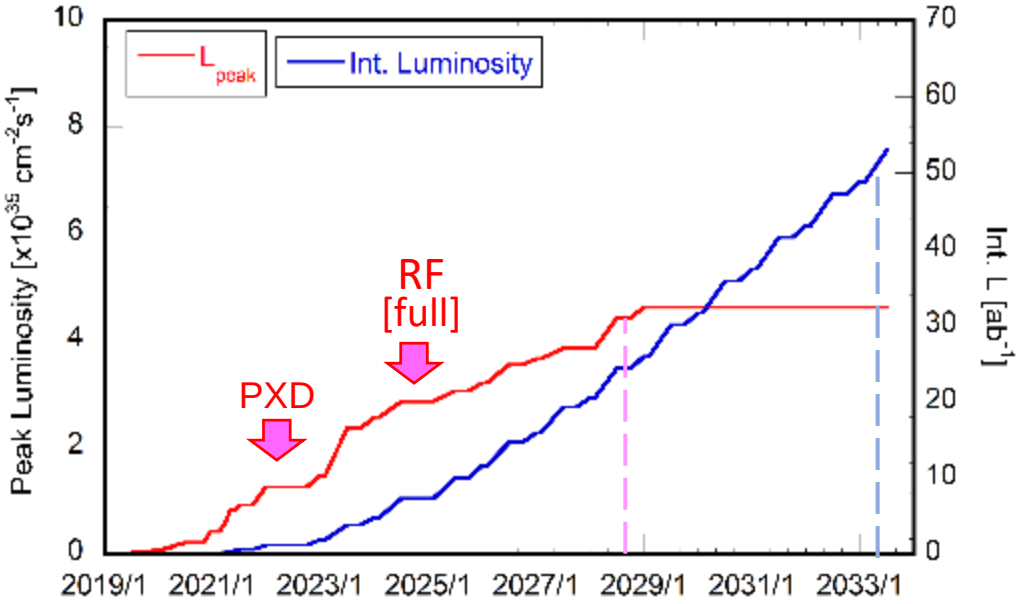
- It was reported that the LER Touschek lifetime will be approximately 200s due to the narrow dynamic aperture at β_y^* = 0.3 mm and the beam-beam parameters ~0.09. (Designed lifetime is approximately 600 s)
- This fact had been pointed out around 2014, and simulation studies have continued since then.
- The problem, however, has not been solved so far. Some measures should be considered to reduce β_y^* further.

[Y. Ohnishi, 18th KEKB Review, 2014]



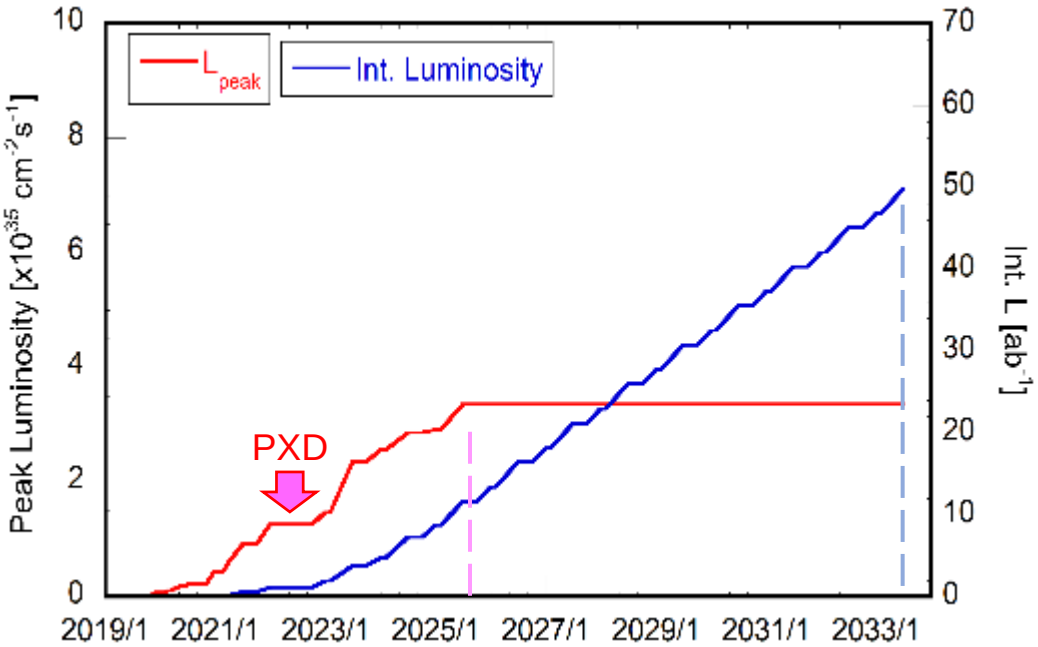
Update of operation plan and its reasons

- A possible scenario in the present situation -1
  - Even if the design beam currents of LER 3.6 A and HER 2.6 A are realized (2185 bunches) after the full-scale RF upgrade, but β_y^* is limited to 0.5 mm, the peak luminosity will be ~4E35 cm^{-2} s^{-1} at most.
  - As described before, we need more utility cost to operate with these beam currents. Even if we can operate for 7 months per year, after making various efforts, it will be 2032~2033 before achieving the integrated luminosity of 50 ab^{-1}.



Update of operation plan and its reasons

- A possible scenario in the present situation -2
  - If we have NO upgrade of RF system (i. e. Max. LER 2.5 A /HER 1.8 A), and β_y^* is limited to 0.5 mm, the peak luminosity will be ~3E35 cm^{-2} s^{-1} at most.
  - In this case, we have no long-shutdown.
  - Even if we assume 8 months operation per year, the integrated luminosity goal of 50 ab^{-1} will be achieved in 2032~2033.



Update of present operation plan

Key points in the update

(1) Aim at an ecological operation reducing running cost, i.e., beam currents, as much as possible.
- Put the priority on the integrated luminosity, rather than the peak luminosity.
- Realize an integrated luminosity of ~50 ab^{-1} within a reasonable time period not so different from the original plan.

(2) Modify the IR, especially upgrade QCS and its beam pipes
- Relocation of magnets: Make it possible to squeeze β_y^* to 0.3 mm, mitigate the beam-beam effect in the high bunch-current region
- Enlargement of QCS beam pipes: Protect QCS, and reduce the background.

(3) Retain the option to upgrade the RF power at the minimum level.
- Store beam currents of LER 2.8 A and HER 2.0 A stably.
  - Even without an upgrade, beam currents of LER 2.5 A and HER1.8A will be possible.

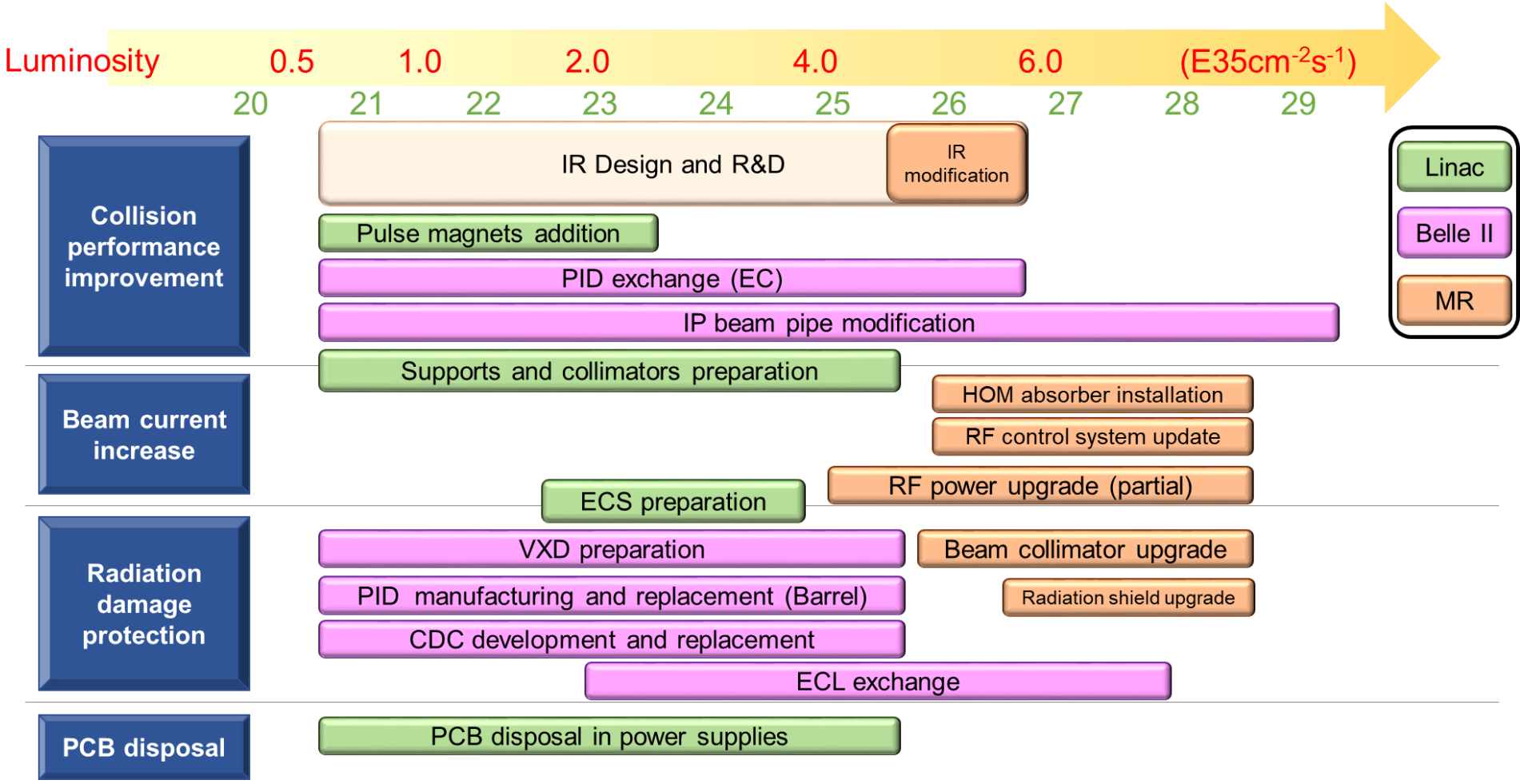
(4) Keep essential investment of equipment for the upgrade of Linac, Belle II and beam collimators of MR as before for stable and high-efficiency operation.

Key points in the update

- Major hardware upgrades (Investment of equipment)
- Belle II
  - Preparation of VXD spare.
  - Replacement of CDC FEE and readout circuits
  - Replacement of PID (MCP-PMT) in Barrel
  - Replacement of PID (HAPD) in ARICH
  - Replacement of a part of ECL
  - Modification of the IP beam pipe
- Linac
  - Development of collimators and high-precision supports
  - Installation of ECS (Energy Compression System) for e- line
  - Addition of pulsed magnets
  - Replacement of a thousand capacitors containing PCBs
- MR
  - Modification of the IR, including QCS, its cryostat, beam pipes inside, and RVC
  - Upgrade of RF power stations and the control system
  - Development of robust beam collimators
  - Reinforcement of a radiation shield around the IR and collimators

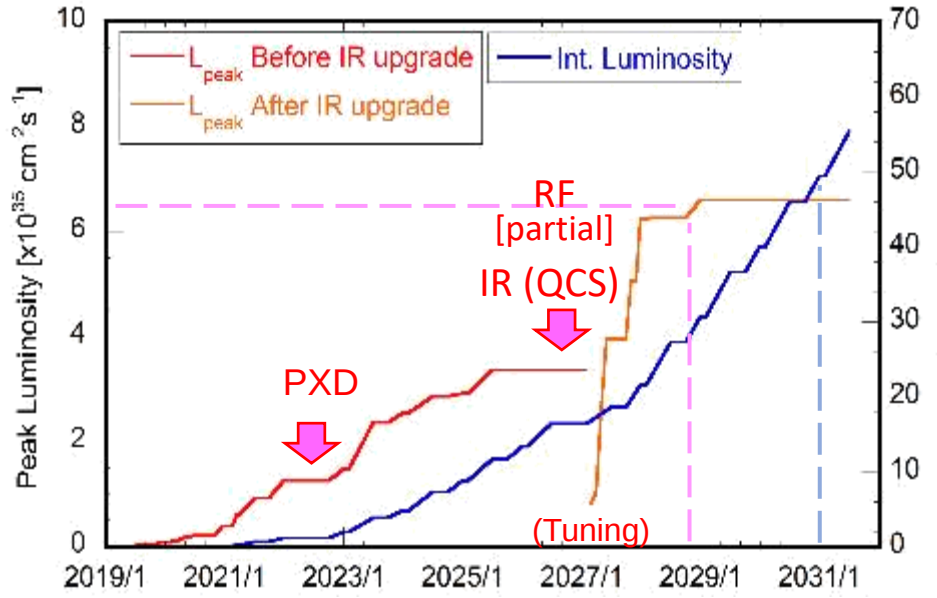
Key points in the update

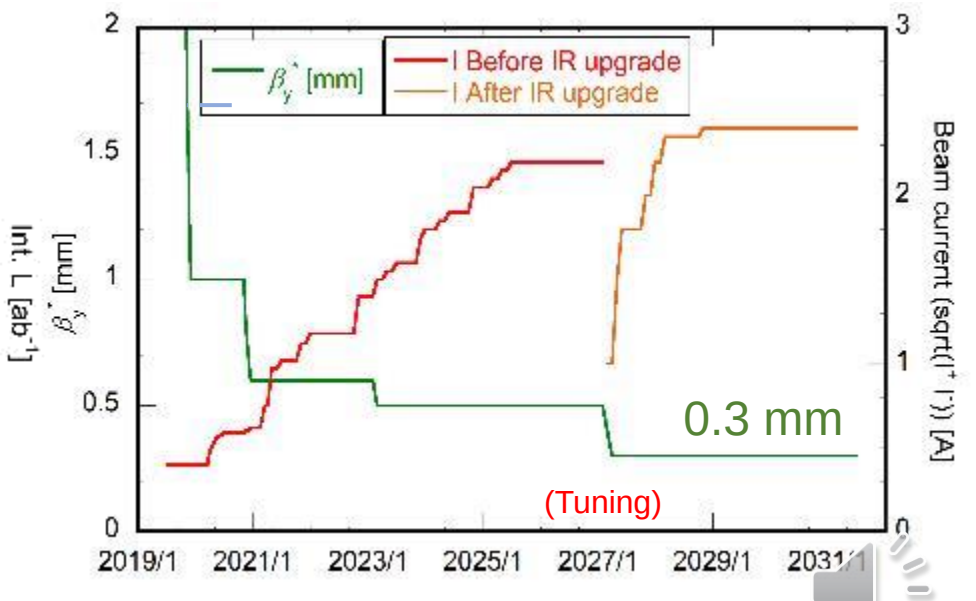
- A rough time chart



Long-term luminosity projection

- luminosity projection in the proposed update
  - After these upgrades, the stable operation at beam currents (LER 2.8A and HER 2.0A) with β_y^* of 0.3 mm will be possible after 2026. If the beam-beam parameters of 0.07~0.08 are achieved, the peak luminosity will be ~6E35 cm^{-2} s^{-1}.
  - If 8 months operation per year is realized, again after making various efforts, the integrated luminosity of 50 ab^{-1} will be achieved in ~2030.

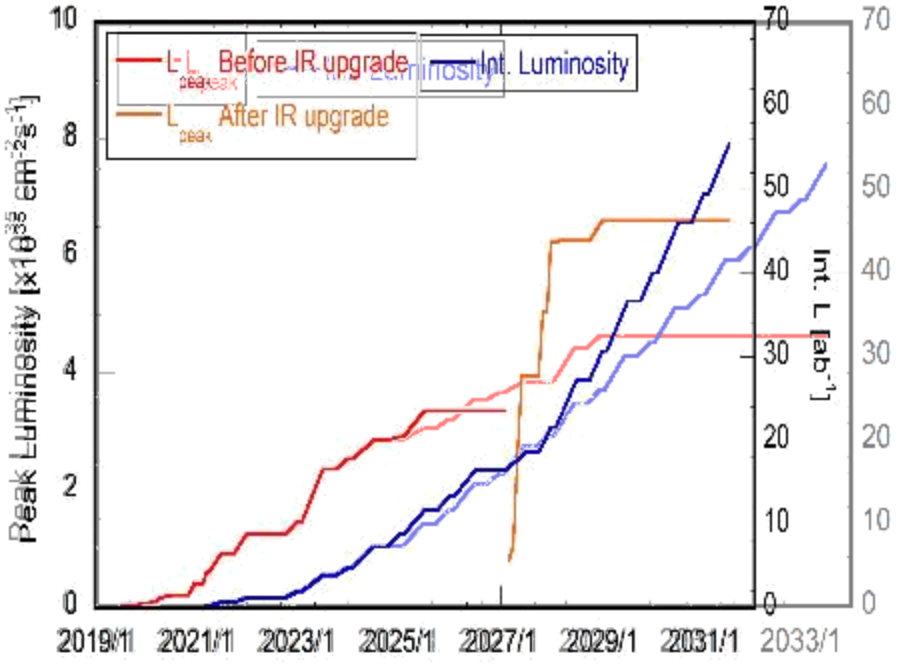




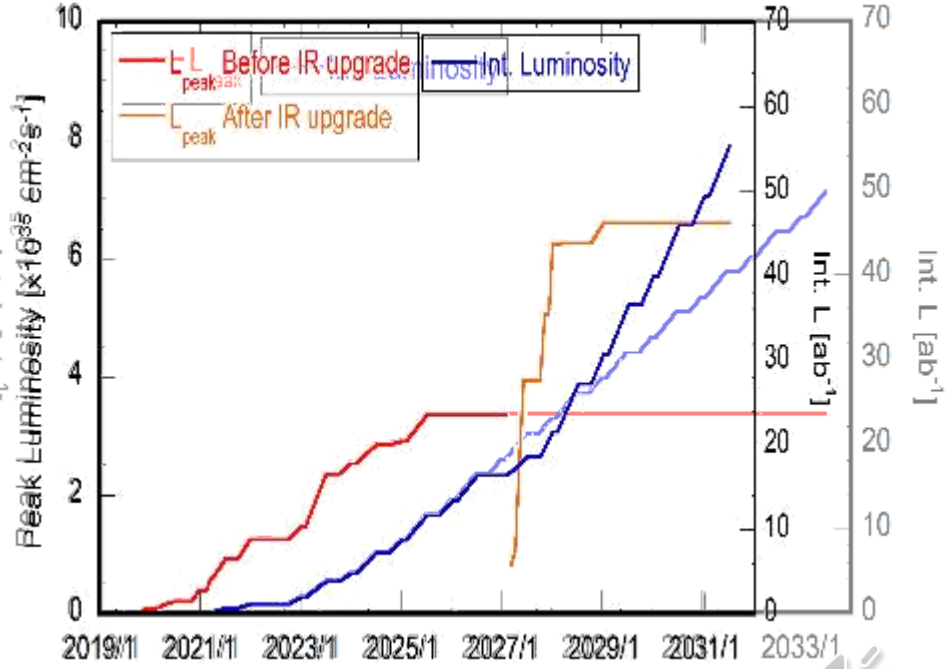
Long-term luminosity projection

- luminosity projection in the proposed update
  - These upgrades promote the achievement of the goal, 50 ab^{-1} in the coming 10 years.
  - They also expand the options or flexibility in the operation, and as a result, reduce the risk.

(RF full-upgrade in 2024, no IR upgrade)



(No RF full-upgrade, no IR upgrade)



Summary-2 (Long-term)

- MEXT SuperKEKB Roadmap 2020
  - Deliver colliding beams to the experiment with a several ten-times higher luminosity than in the preceding KEKB project by using the nano-beam collision scheme.
  - Aim at an integrated luminosity of 50 ab^{-1} in coming 10 years.
  - Proposed update of the operation plan:
    - Aim at ecological operation with high efficiency, and put priority on integrated luminosity, rather than the peak luminosity.
    - Modify the IR, especially upgrade the QCS and its beam pipes, to squeeze β_y^* to 0.3 mm as designed, and then improve the collision performance.
    - Investment of equipment, such as Linac upgrade, Belle II upgrade, beam collimator upgrade, are planned as before, which are essential for stable and efficient operation at high beam currents.
- The plan is within the framework of MEXT Roadmap, but it is more realistic considering the present situation and recent experience.

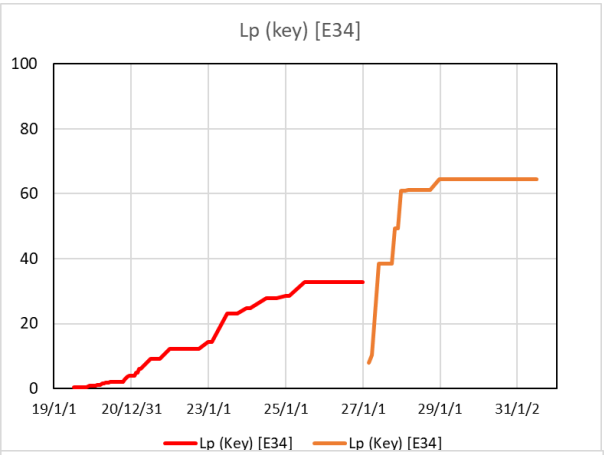
Thank you for your attention.

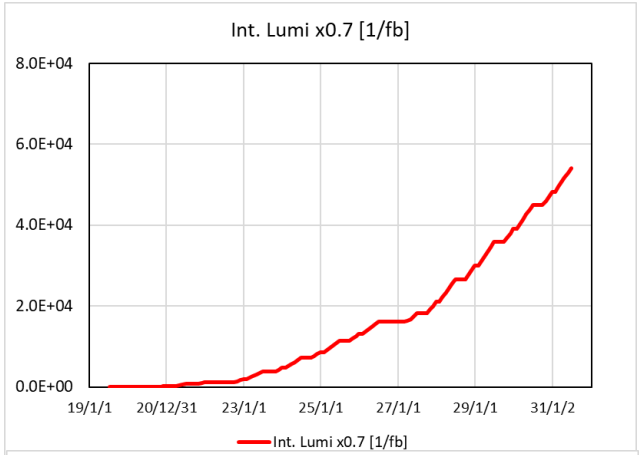
2020c run plan

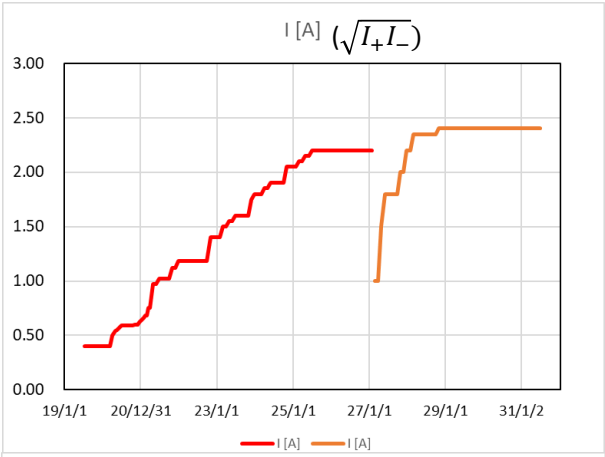
- Major study items
  - Optics
    - Squeezing β_y* down to 0.6 mm
    - Precise measurement and correction of optics parameters
  - Injections
    - Two bunch injection
    - Synchrotron injection
  - Beam background
    - Beam collimator tuning
  - Beam aborts
    - Investigation of the cause
  - Fill patterns
    - Bunch spacing and number of bunches
  - Beam-beam
    - Effect of IP chromatic coupling on beam-beam blowup
      - Measurement of optics parameters at IP
      - Utilization of rotatable sextupole magnets (LER) and skew sextupole magnets (HER)
    - High bunch-current operation to check beam-beam effect
    - Crab waist scheme

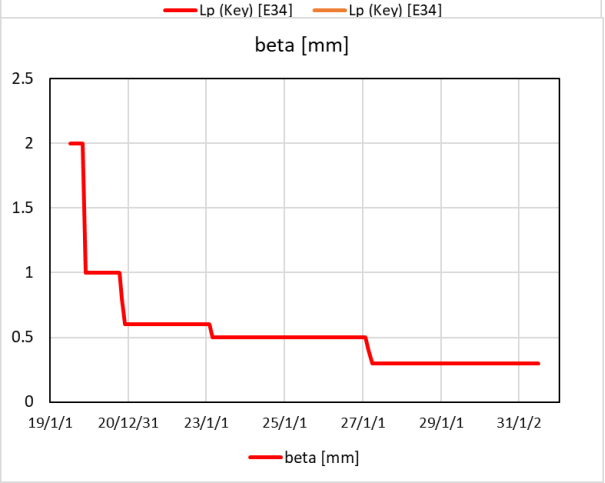
Updated luminosity projection (parameters)

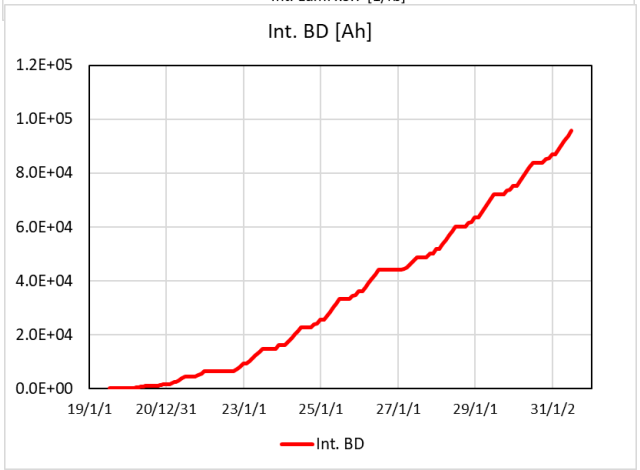
- Long term operation plan-1

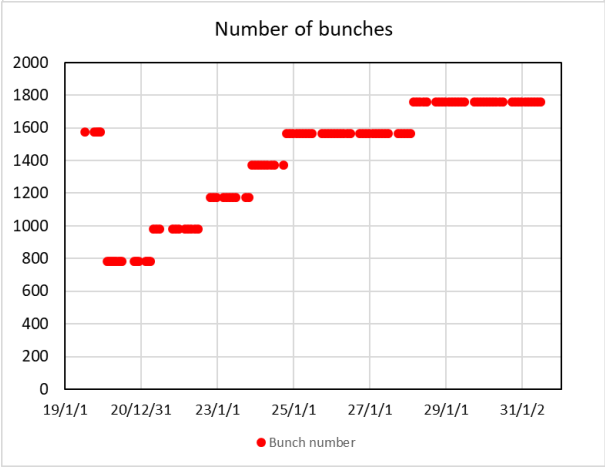






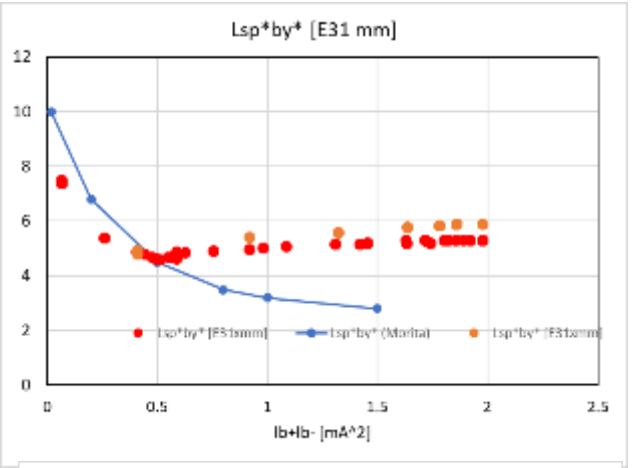


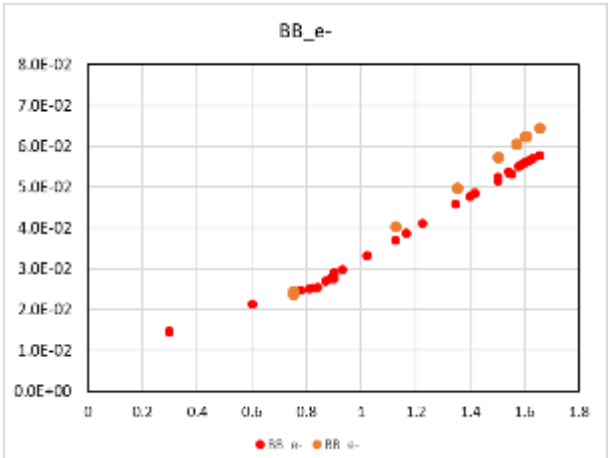


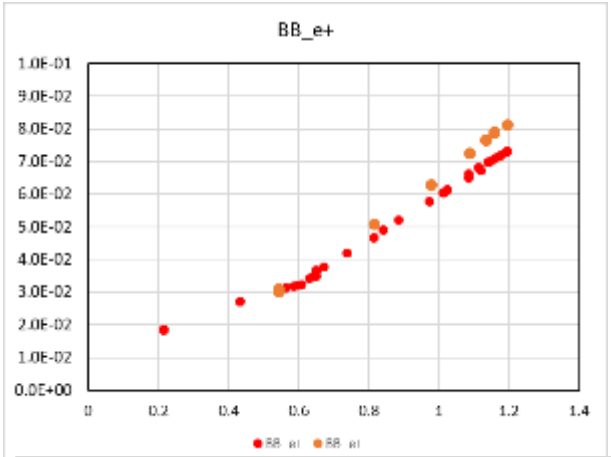


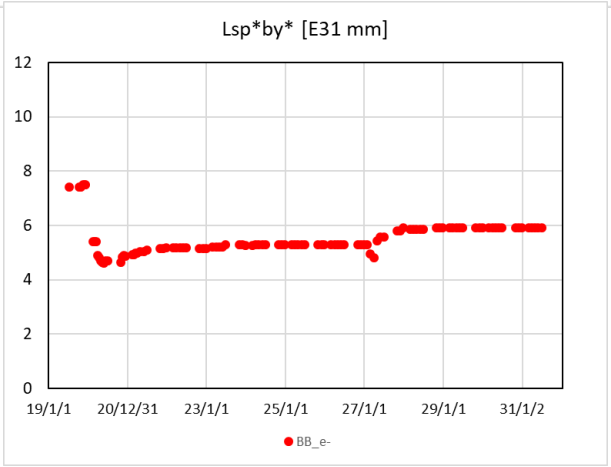
Updated luminosity projection (parameters)

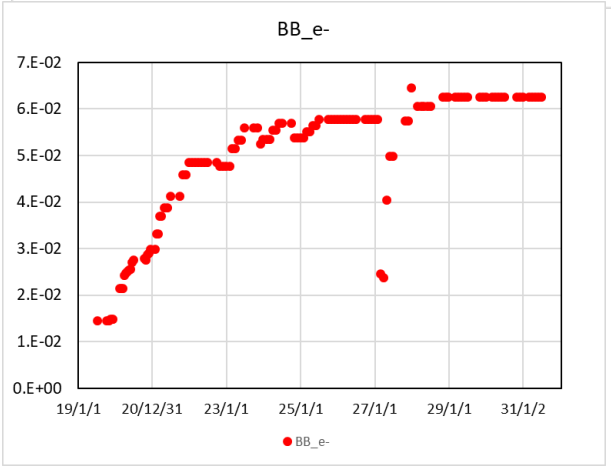
- Long term operation plan-2

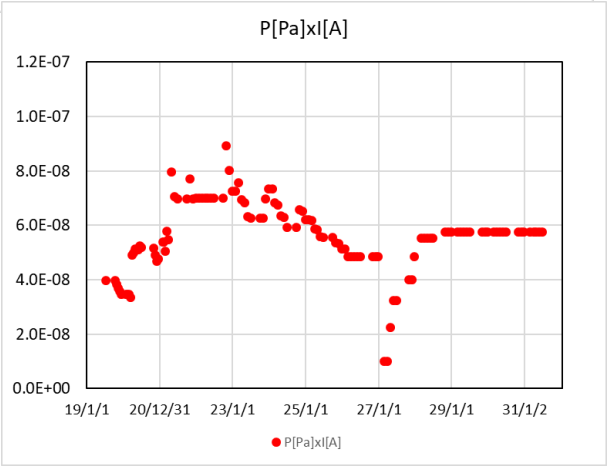






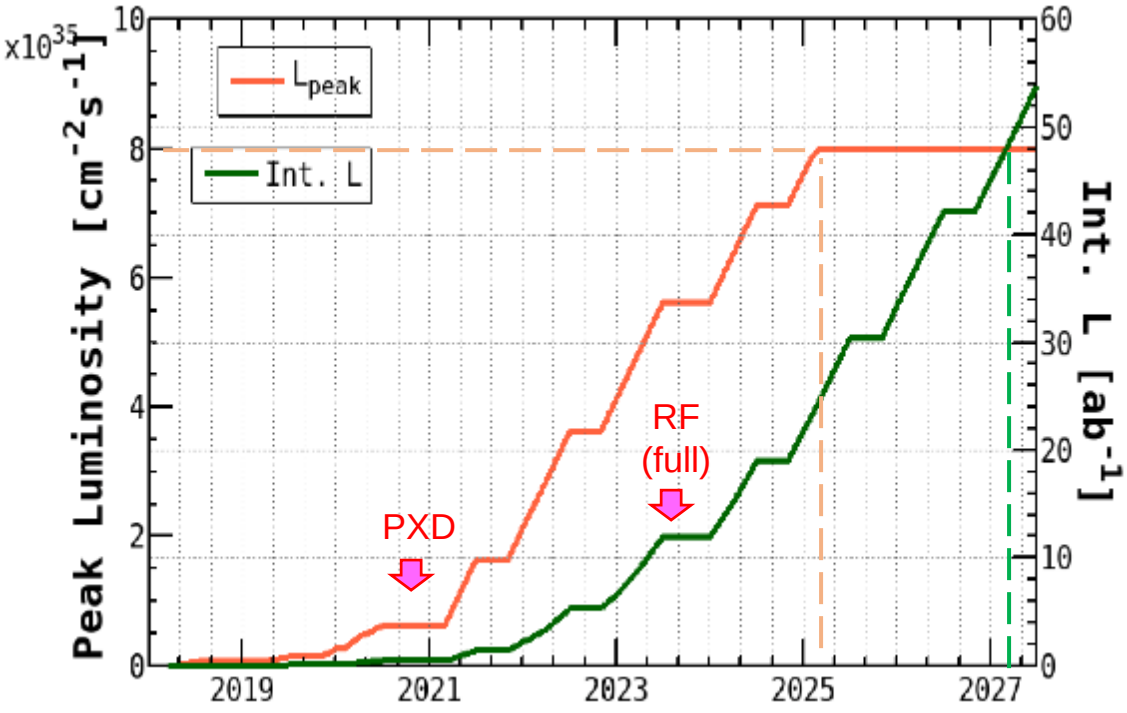






SuperKEKB Roadmap2020

- Original plan (until 2018)



http://www-superkekb.kek.jp/img/ProjectedLuminosity_v20190128.png

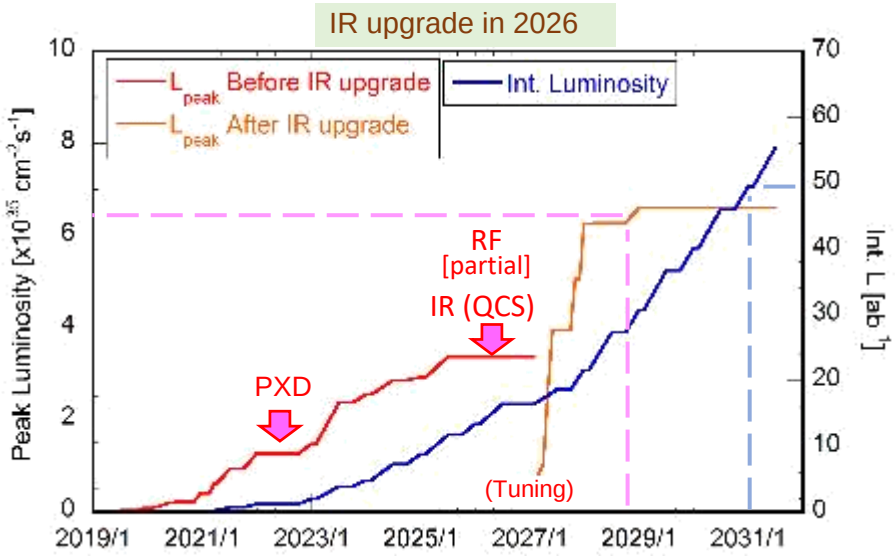
- Peak luminosity 8E35 $cm^{-2}s^{-1}$ in ~2025
- Integrated luminosity 50 ab^{-1} in ~2027
- PXD exchange in 2020~2021
- RF full upgrade (4 stations) in ~2023
- Max. beam currents: LER 3.6 A, HER 2.6 A (2500 bunches)
- Basically, 8 moths' MR operation per year.

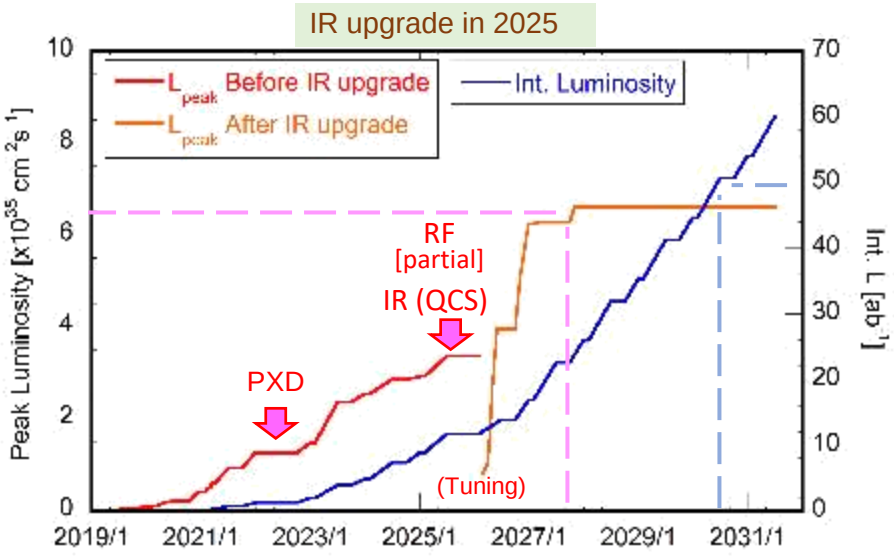
Investment in equipment

- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade
- Full-scale RF-power upgrade (4 stations)

Long-term luminosity projection

- Note-2
  - It is clear that ahead of upgrade schedule of QCS/RF greatly speed up the luminosity accumulation.





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