2020c run plan and MEXT SuperKEKB Roadmap2020

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KEK

1) 2020c run plan
    1) Brief summary of results in 2020a, b until June 20
    2) 2020c run plan and luminosity projection

2) MEXT SuperKEKB Roadmap2020
    1) Update of Roadmap2020
    2) Reasons of the update
    3) Long-term luminosity projection

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Brief summary of results in 2020a, b

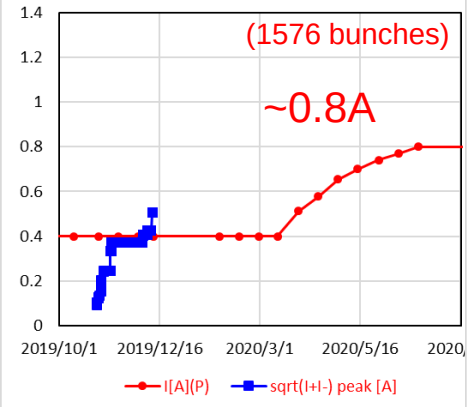
- Near term luminosity projection (~2020/June)

(1) Base (conservative) plan

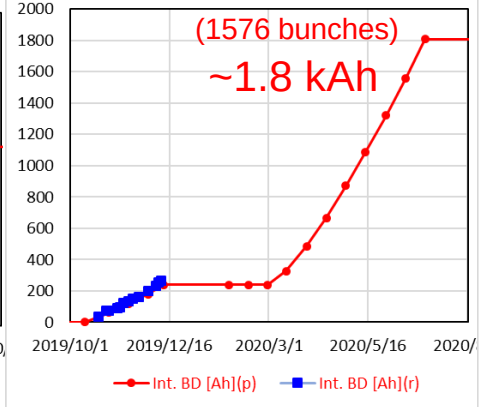
Presented in last BPAC

● Cal., Assumption
■ Result in 2019c

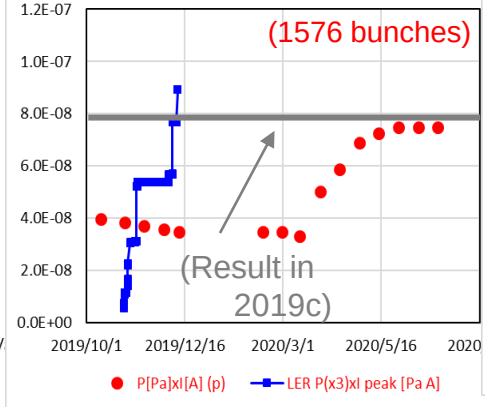
I [A] $(\sqrt{I_+ I_-})$



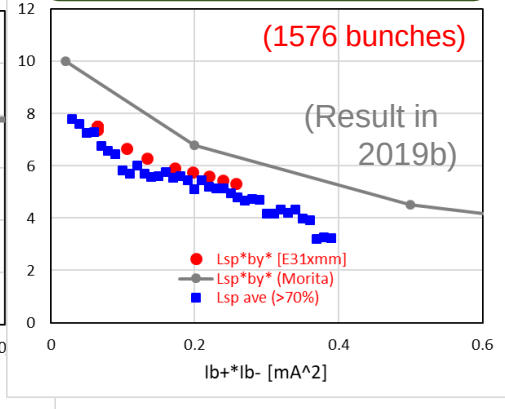
Beam dose [Ah]



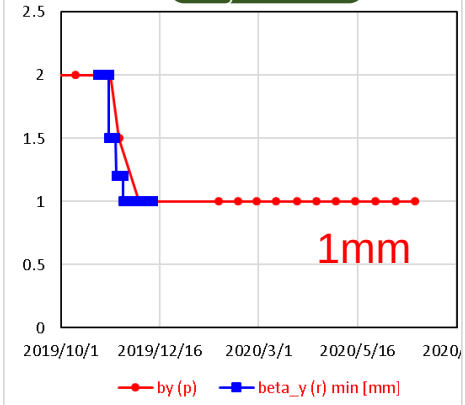
P x I [Pa A]
BG from storage beam



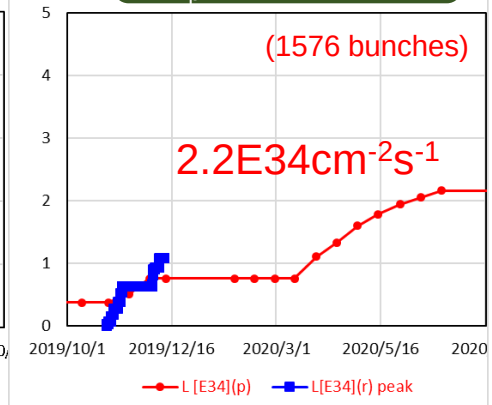
L_{sp} x β_y^* [x10^{31} cm^{-1}s^{-1}] vs I_{b+}xI_{b-}[mA^2]



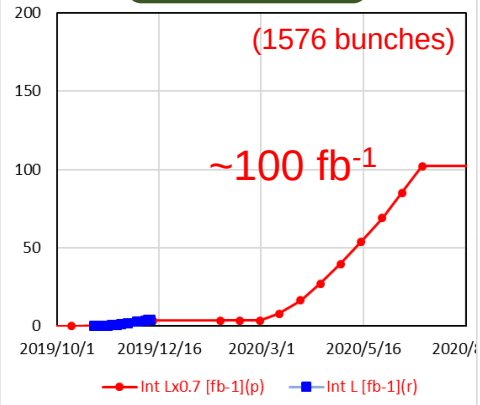
β_y^* [mm]



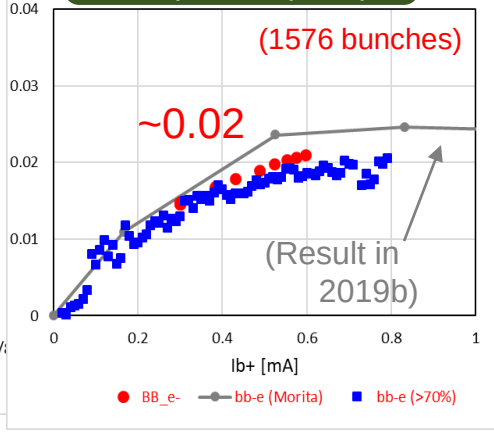
L_p [x10^{34} cm^{-2}s^{-1}]



Int. L [fb^{-1}]



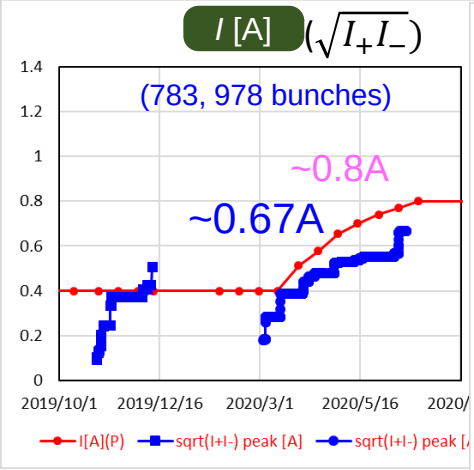
B-B param. (HER)

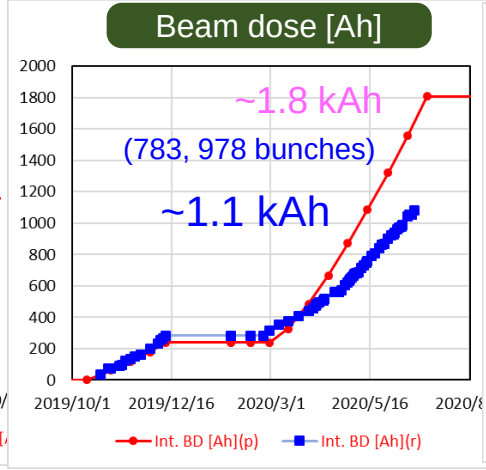


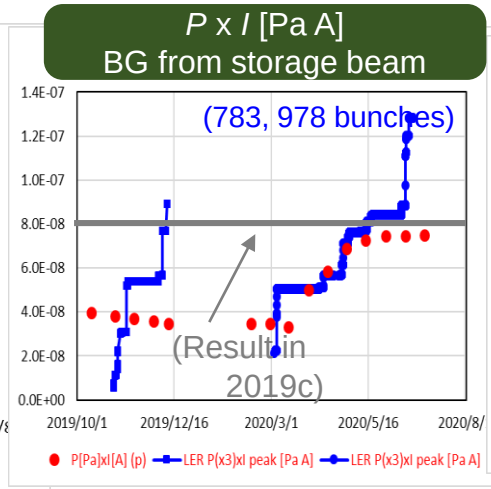
Brief summary of results in 2020a, b

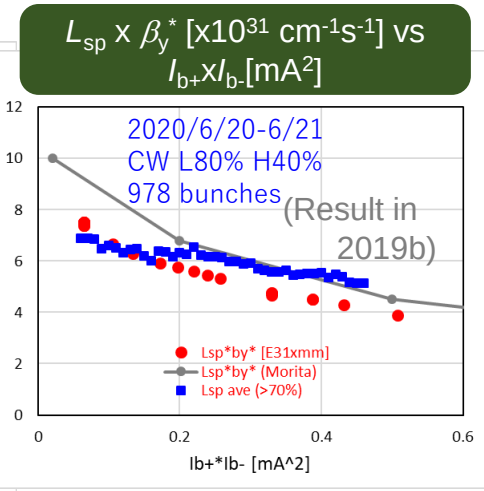
- Results until June 20

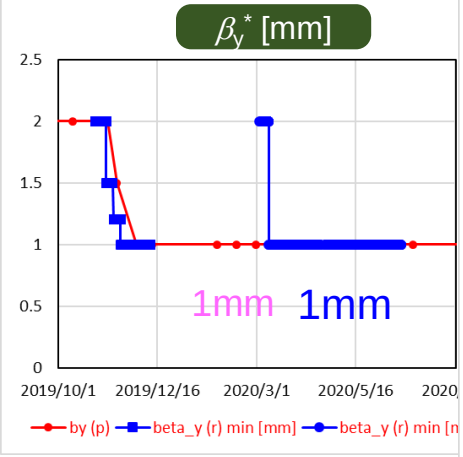
● Cal., Assumption
■ Result in 2019c, 2020a, b

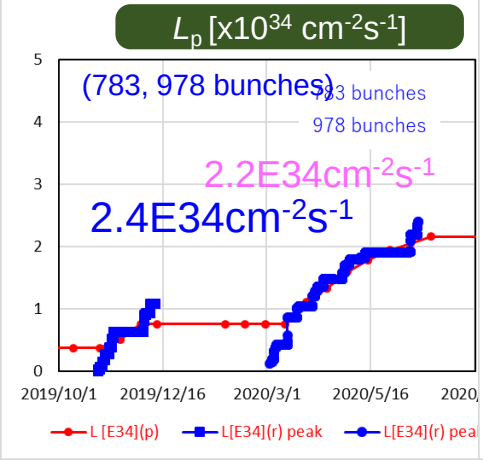


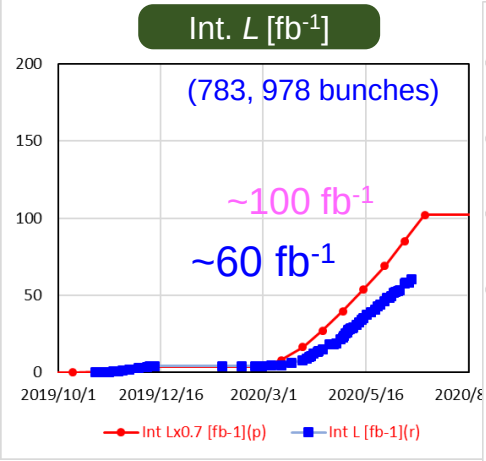


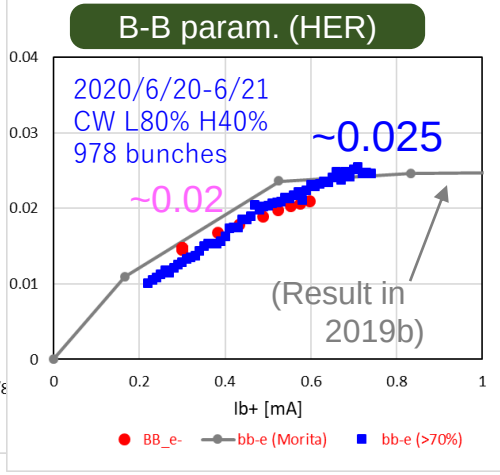






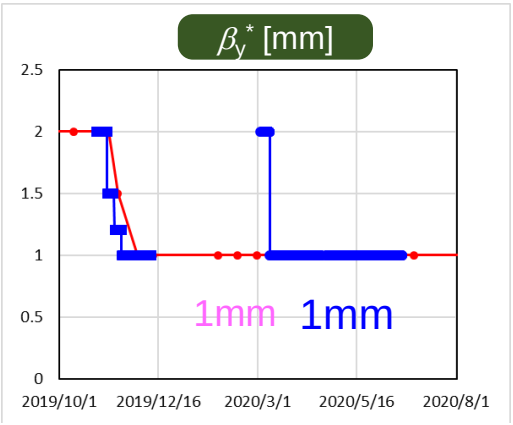


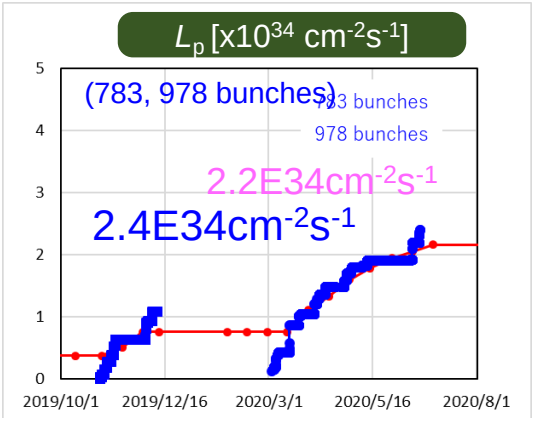


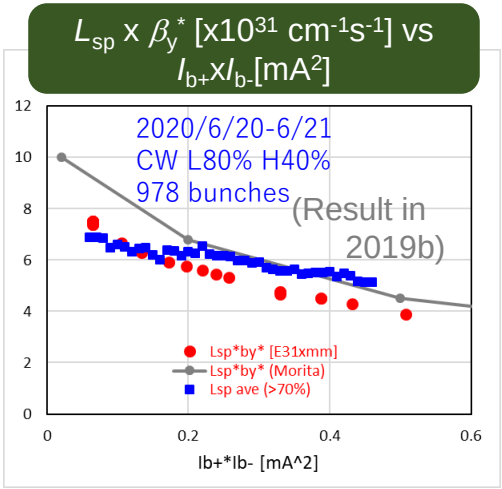


Brief summary of results in 2020a, b

- Results until June 20



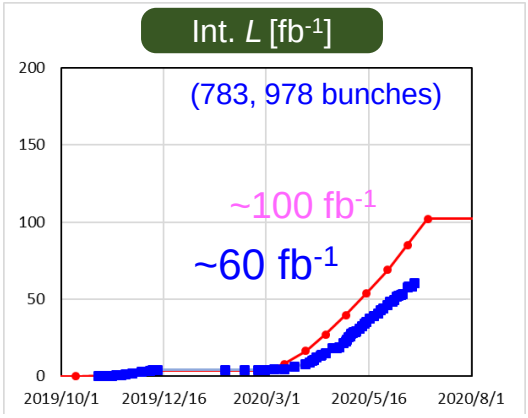


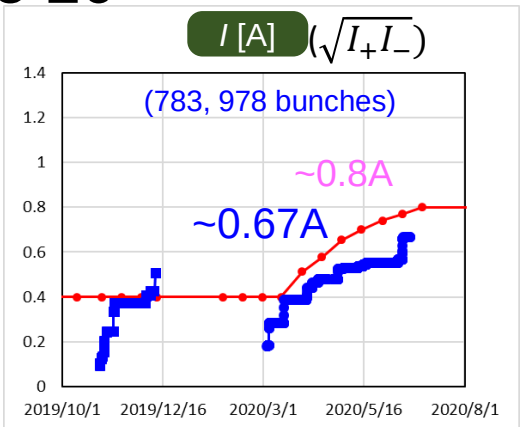


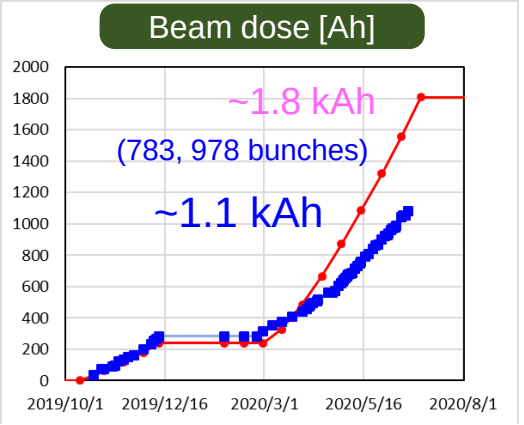
- β_y^* was kept at 1 mm
  - Physics run with β_y^* = 1 mm was achieved.
- Peak luminosity increased almost as expected.
  - Mainly thanks to the crab waist collision scheme in both LER and HER.
- Specific luminosity vs bunch-current products was almost as expected, and higher at high bunch-currents.
  - 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 in 2020a, b

- Results until June 20







  - 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 current was less than expected.
    - Operation with smaller number of bunches, and then difficulty in beam injection at high bunch currents due to beam-beam effect.
    - Some hardware (vacuum) problem at high-bunch currents.
    - Limit of TOP background level was lowered to 1 MHz.
  - Due to low beam currents and shorter running time, the beam dose was also less than expected consequently.

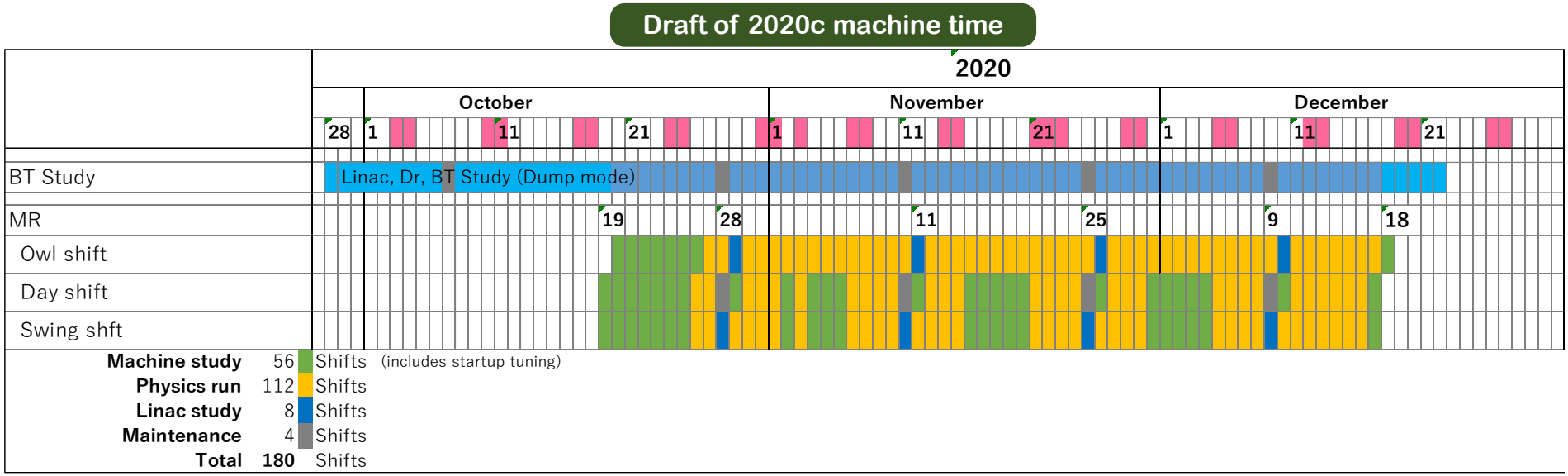
Major works during summer shutdown

- 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
  - 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.

2020c machine time

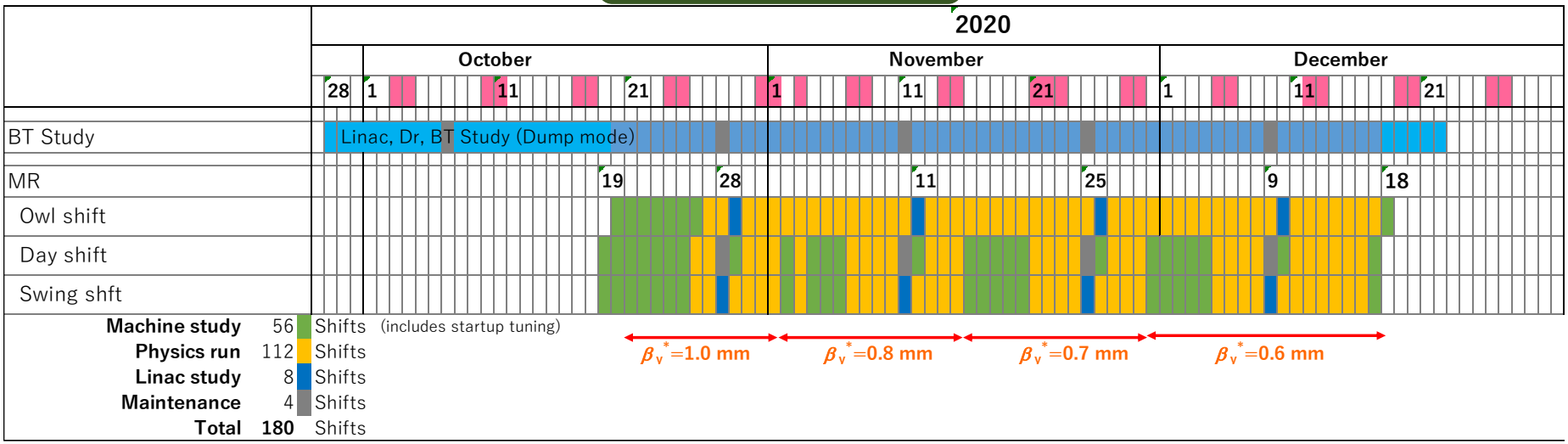
- 2020c will start from Oct. 19, after summer shutdown.
  - Linac will start from Sept. 28 prior to that for the tuning (BT, DR) and PF injection.
- 2020c will stop Dec.18.
- 180 shifts (60 days) in total
  - ~112 shifts for physics run
  - ~64 shifts for machine study and tuning
  - 4 shifts for regular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



2020c run plan

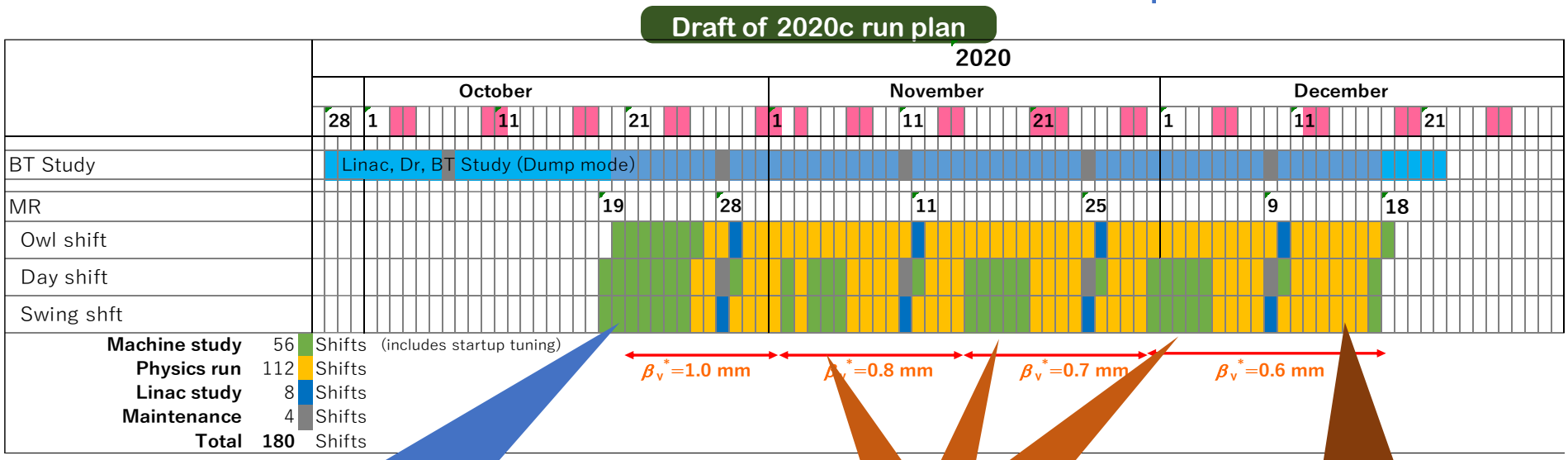
- Main theme of 2020c is to squeeze β_y^* as planned.
  - Operation with β_y^* = 1 mm was achieved in 2020b.
  - Goal is β_y^* ~ 0.6 mm.
- Machine time will not be dedicated to machine studies, but the studies will be scheduled appropriately in parallel with physics run.
  - Similar to 2020b.
  - We need some time to calm down and think the results of studies.
  - Basically, owl shifts and weekends are assigned to physics run.

Draft of 2020c run plan



2020c run plan

- Major study items
  - Main item is to squeeze β_y^*. We will try β_y^* of 0.8 mm in this run.
  - Studies to realize stable operation with these 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

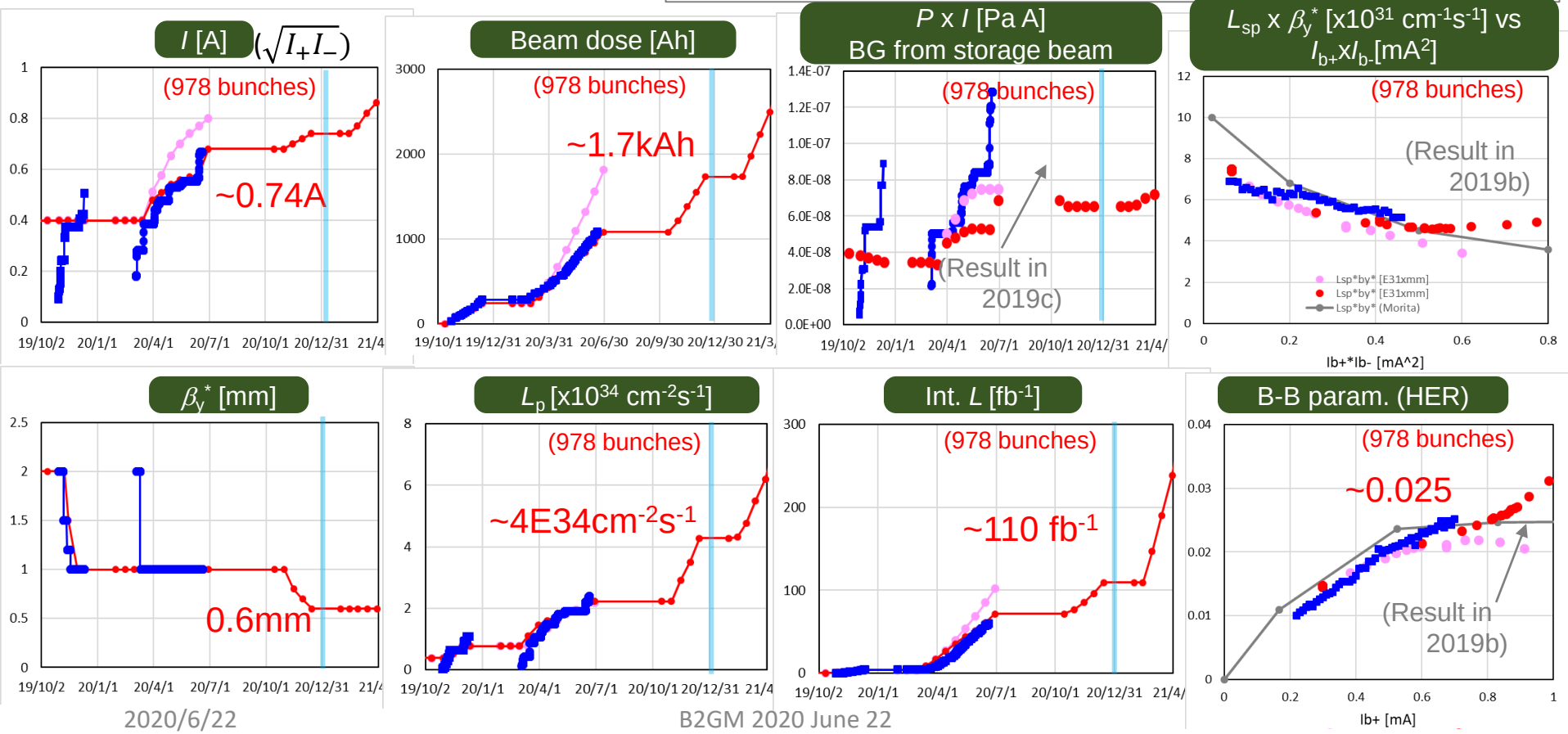
- Squeezing β_y^* to 0.8 mm, 0.7 mm, 0.6 mm
- Injection study/tuning
- Background study
- Beam-beam / optics study
- Other hardware/software studies

- Machin studies if necessary
- Optics study

Luminosity projection of 2020c (and 2021a)

- On the basis of the results in 2020a and b, luminosity projection was re-evaluated. [Base plan]
  - Int. Luminosity etc. were adjusted to the present values.
  - Similar specific luminosities and beam-beam parameters.
    - Crab-waist collision scheme

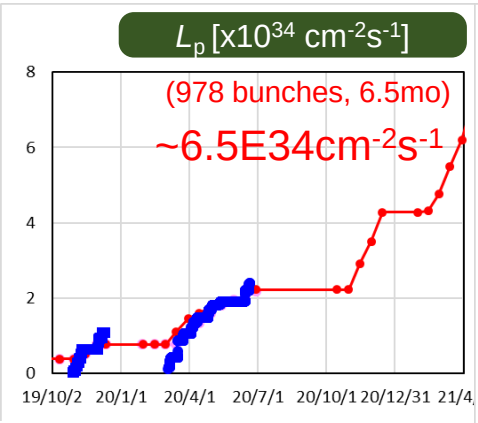
● Cal., Assumption ■ Result in 2019c, 2020a, b ● Original plan in 2019a,b

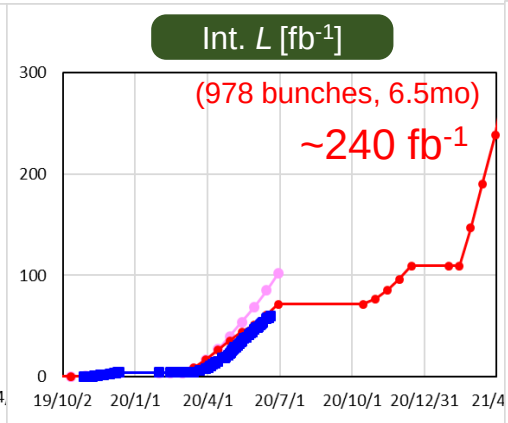


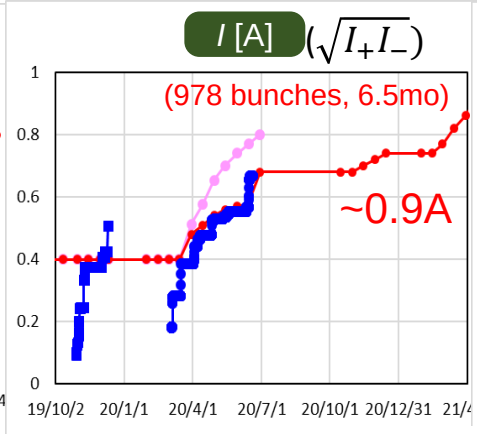
Luminosity projection of 2020c (and 2021a)

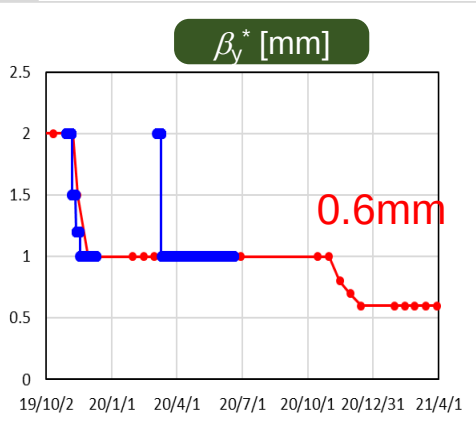
- For 2021a, we assumed that it is dedicated to physics run, and that 6.5 ~ 5.5 months' operation this year (depends on the budget, as you know.).

● 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

- 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 time will not be dedicated to machine studies, but 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.
  - 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.

1) 2020c run plan
   1) Brief summary of results in 2020a, b until June 20
   2) 2020c run plan and luminosity projection

2) MEXT SuperKEKB Roadmap2020
   1) Update of Roadmap2020
   2) Reasons of the update
   3) Long-term luminosity projection

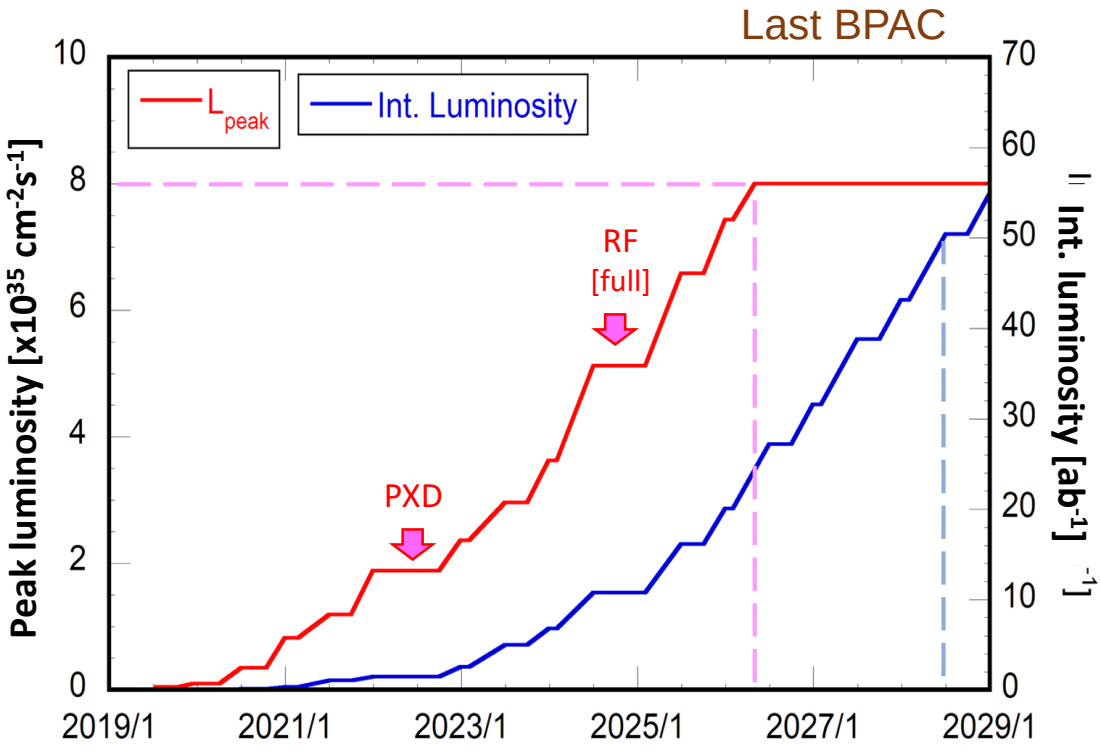
SuperKEKB Roadmap2020

- Roadmap2020 is a fundamental plan of MEXT on the promotion of large-scale projects in academic research.
  - Revised every three years.
- Now we are making the SuperKEKB Roadmap2020, i.e., the coming ten years' operation plan.
  - The proposal was already submitted to MEXT in February. The examination will start from June, and the hearing is planned in August (if selected).
- In this roadmap, we updated the present operation plan (2019) considering the actual situation and the results obtained so far.
  - It is not so big change as a successive project, but changes towards more realistic one.

- Here we report key points in the update.

SuperKEKB Roadmap2020

- Present plan
  - Proposed in last BPAC, 2019
  - Updated based on the results until Phase-2



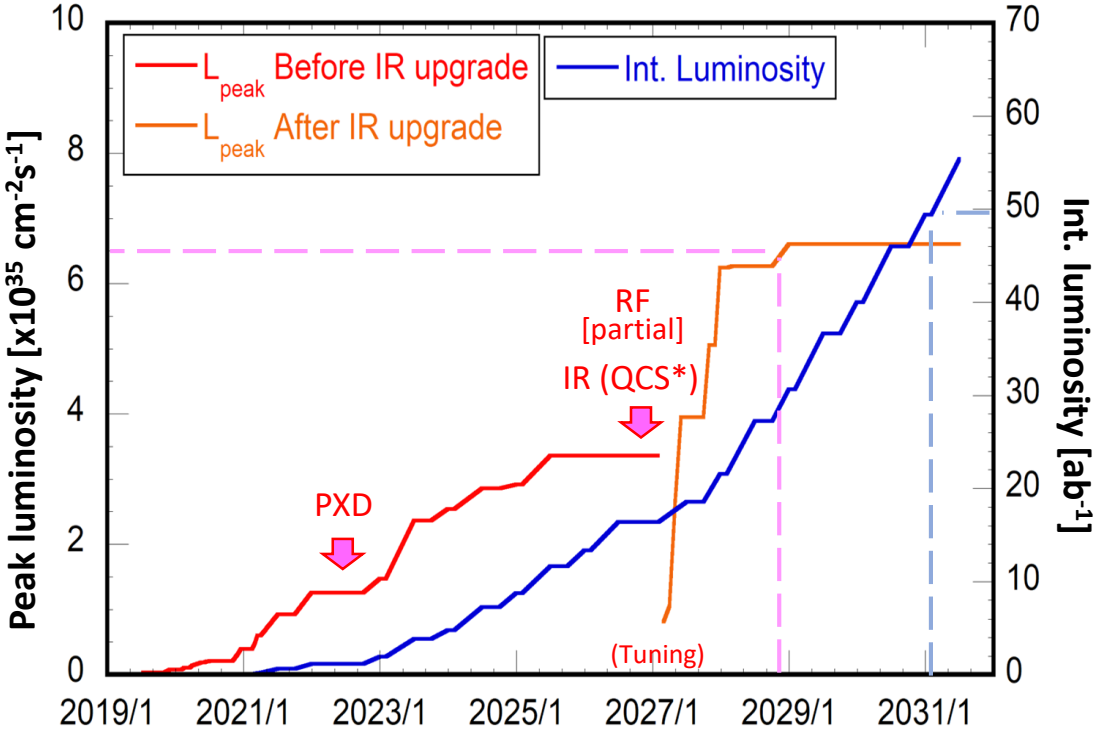
- Peak luminosity 8E35 cm^{-2}s^{-1} in ~2026
- Integrated luminosity 50 ab^{-1} in ~2028
- β_y^*=0.3 mm in 2021
- PXD exchange in 2021~2022
- RF full upgrade (4 stations) in 2024
- Max. beam currents: LER 3.6 A, HER 2.6 A (2500 bunches) in 2026
- Basically, 8 moths' operation per year.

[Investment in equipment]

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

SuperKEKB Roadmap2020

- Update plan (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
- IR (QCS and its beam pipes etc.) upgrade in 2026
- Partial RF-power upgrade (2 stations) 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 moths' operation per year.

[Investment in equipment]

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

Main reasons to update the operation plan

- Main reasons:

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

(2) Challenges found in the initial operations (～2019c) ：
  (a) Strong beam-beam effects at high bunch-current region
  (b) Narrow physical aperture in QCS
  (c) High background in Belle II

(3) Small dynamic aperture at high bunch-current region at small β_y^* (~0.3 mm), which has been recognized from the design phase.

Main reasons to update the operation plan

- 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 of the electric power (i.e., running cost) is required compared to that at present (1～0.5 A) .
- If the operation budget does NOT drastically increase, and the electricity unit cost remains at similar level, the operation period per year will be strictly limited.
- As a result, it takes long time to achieve the goal integrated-luminosity, and the total running cost will further increase consequently.

→ More effective (ecological), that is, more higher collision performance with smaller beam currents is required to achieve the goal in a reasonable period

Main reasons to update the operation plan

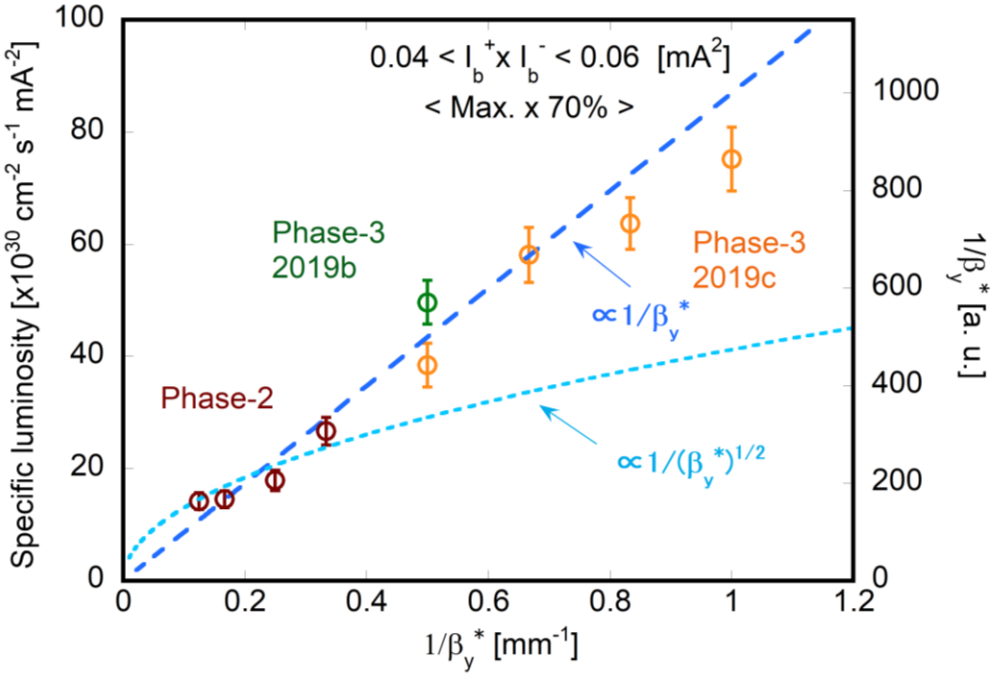
- Reason-2

(2) Challenges found in the initial operations (～2019c) ：

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

- In the low bunch-current region($i_b^+ \times i_b^- < 0.1$ mA^2), the specific luminosity increased in proportion to $1/\beta_y^*$ until β_y^*=1 mm.
- This clearly indicates that the nano-beam scheme works well as expected in SuperKEKB.
- A great achievement in SuperKEKB

Dependence of specific luminosity on $1/\beta_y^*$ at low-bunch current region



Main reasons to update the operation plan

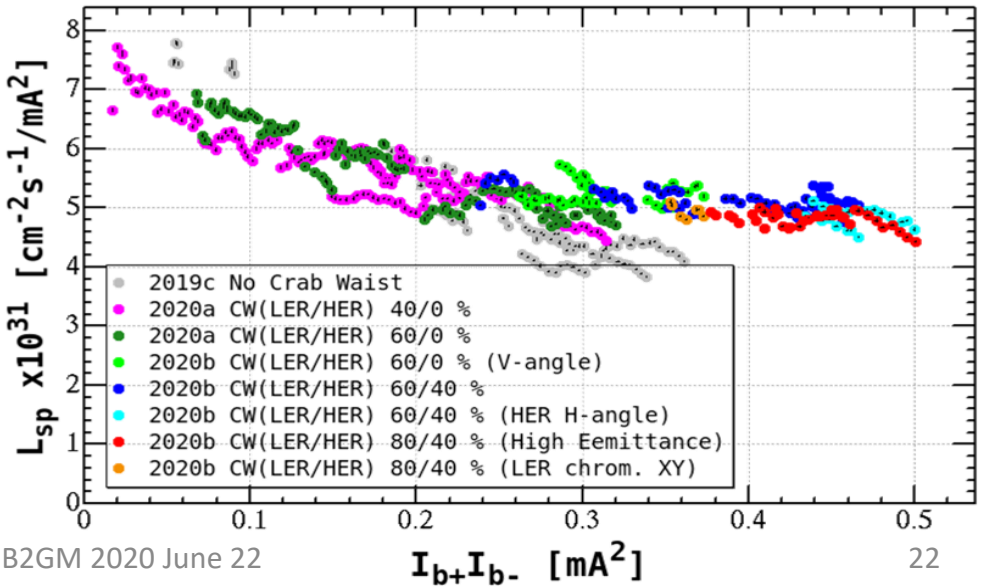
- Reason-2

(2) Challenges found in the initial operations (～2019c) ：

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

- On the other hand, in high bunch-current region ($i_b^+ \times i_b^- > 0.2 \sim 0.3$ mA^2), owing to the vertical-beam size blowup due to the beam-beam effect, the specific luminosity is lower than expected, and the beam-beam parameter is also lower.
- Main reason is said to be the chromatic x-y coupling at IP (Interaction Point), but not yet confirmed.
- Crab waist collision scheme and utilizing skew sextupole magnets are promising solutions at present, but the effectiveness is not confirmed yet until the final goal of $\beta_y^* = 0.3$ mm.

Specific luminosity vs. bunch-current products



Main reasons to update the operation plan

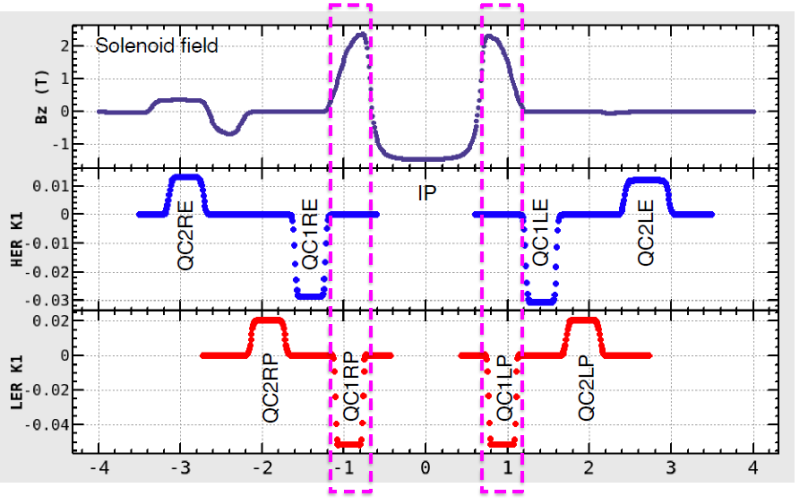
- Reason-2

(2) Challenges found in the initial operations (～2019c) ：

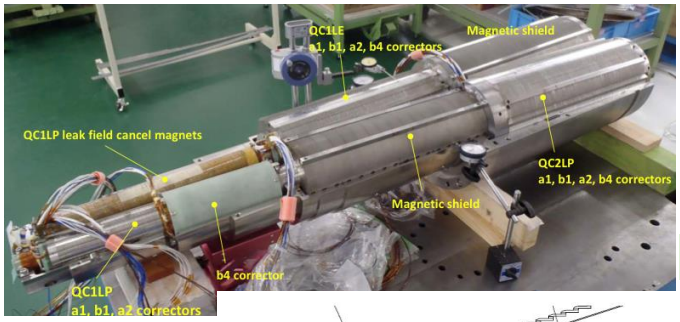
(a) Strong beam-beam effects at high bunch-current region

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

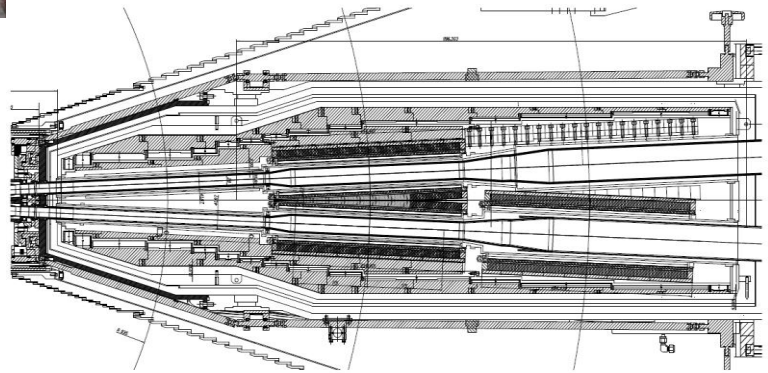
Solenoid field (B_z) and integrated B_z in QCS



QCS magnets



Cross section of QCS



Main reasons to update the operation plan

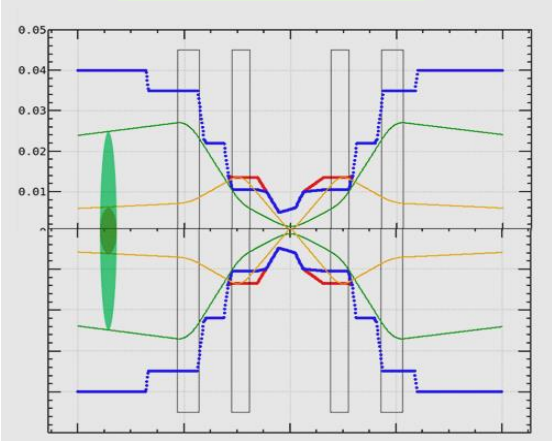
- Reason-3

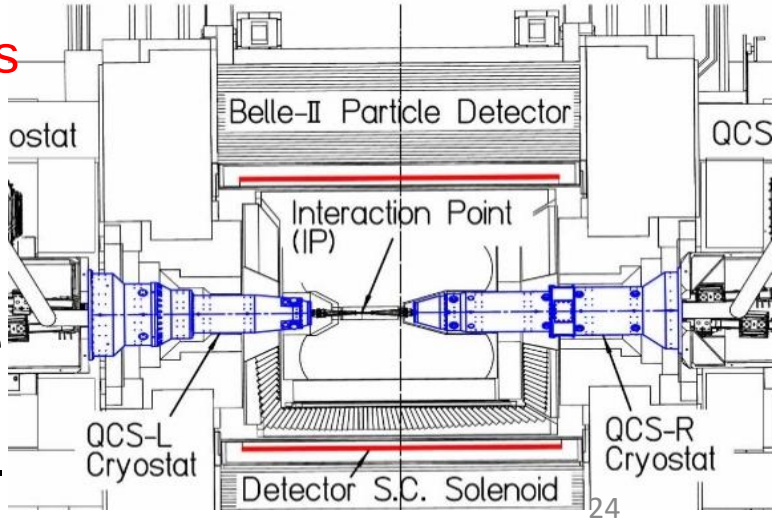
(2) Challenges found in the initial operations (～2019c) ：

(b) Narrow physical aperture in the QCS

- Quenches of QCS caused by the hitting of unstable beams have been observed.
  - In the worst case, it may result in the damage of coils.
- At present, beam collimators is effectively preventing them by closing the collimators to the narrower physical apertures than the beam pipe in QCS.
- However, if we want to squeeze β_y^* to less than 0.5 mm, the β_y at QCS become further 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 the hitting of beam.

Beam size in QCS





Main reasons to update the operation plan

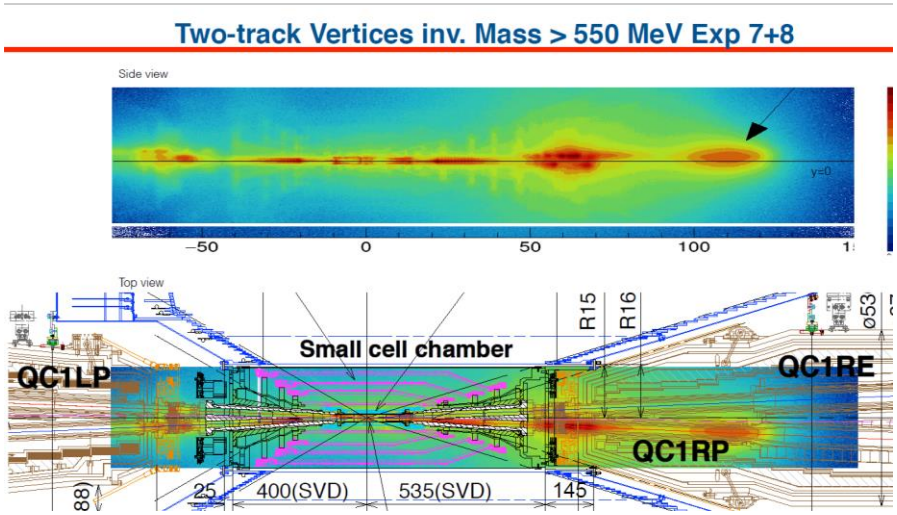
- Reason-4

(2) Challenges found in the initial operations (～2019c) ：

(c) High background in Belle II

- At present, the background of Belle II is larger than expected.
- Main cause is the hitting of storage and/or injection beam halo to the beam pipe in QCS.
  - The background also depends on the vacuum pressure in the ring and the quality of injection beams.
- The background will become severer as squeezing β_y^* further.
  - The β_y at QCS become large and the beam hallow will be easier to hit the beam pipe.

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



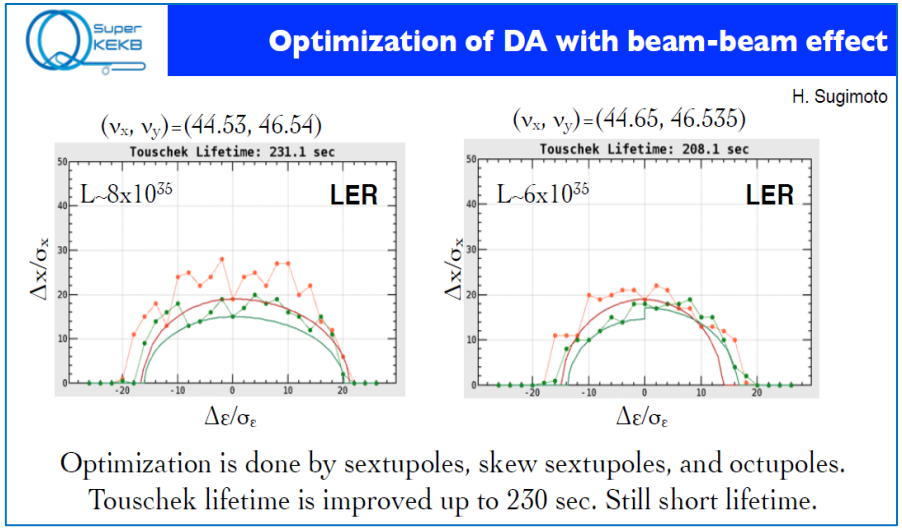
Main reasons to update the operation plan

- Reason-5

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

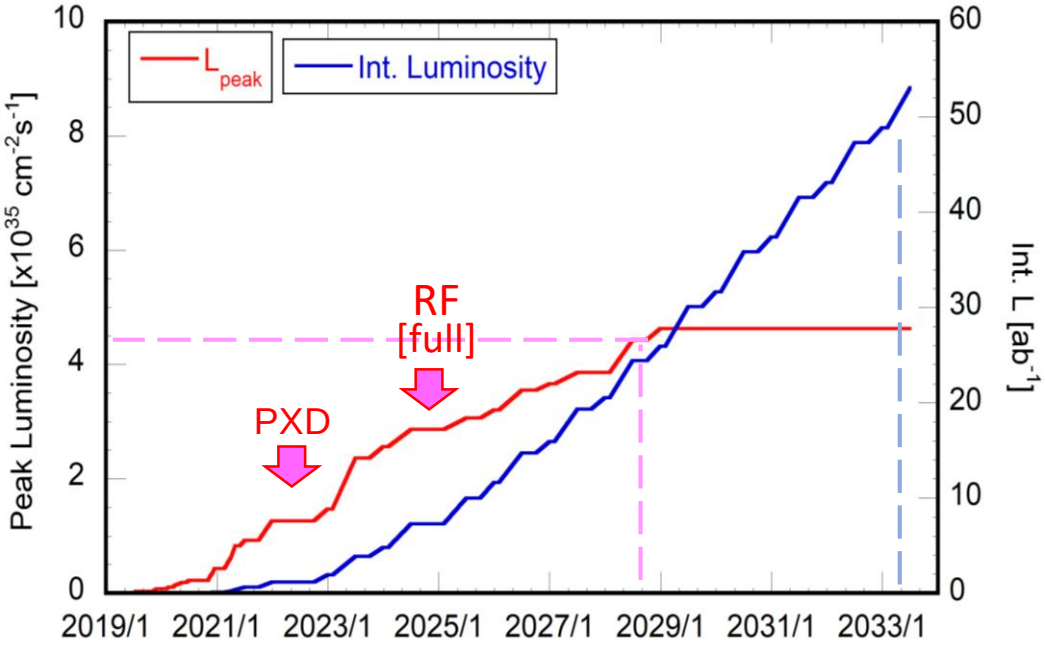
- It was reported that the LER Touschek life time will be approximately 200 s due to the narrow dynamic aperture at β_y^* = 0.3 mm and the beam-beam parameters ~0.09. (Designed lifetime is approximately 600 s)
- This fact has been pointed out around 2014, and the simulation studies has been continued 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]



Main reasons to update the operation plan

- Present situation
  - If the design beam currents of LER 3.6 A and HER 2.6 A are realized (2185 bunches) after full-scale RF upgrade, but the 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 to achieve the integrated luminosity of 50 ab^{-1} (~40 ab^{-1} at ~2031).



Update of present operation plan

Key points of update

(1) Aim an ecological operation suppressing 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} at the reasonable time not so different from the previous plan.

(2) Modify IR, especially upgrade QCS and it's beam pipes, in order to make it possible squeeze β_y^* to 0.3 mm, to mitigate the beam-beam effect at high bunch-current region, to protect QCS, and to reduce the background, then to increase the collision performance, the stability and the data-taking efficiency.

Key points of update

- Upgrade of QCS and its beam pipe

(1) Relocation of magnet positions

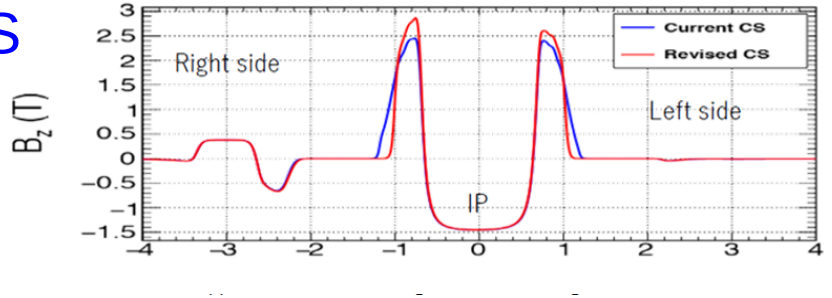
- Mitigate the beam-beam effect by avoiding the interference between quadrupole magnetic field and the Belle II solenoid.
  - Further study is on going.
- The narrow dynamic aperture issue at small β_y^* might be solved by modifying QCS.

(2) Enlargement of apertures of QCS beam pipes

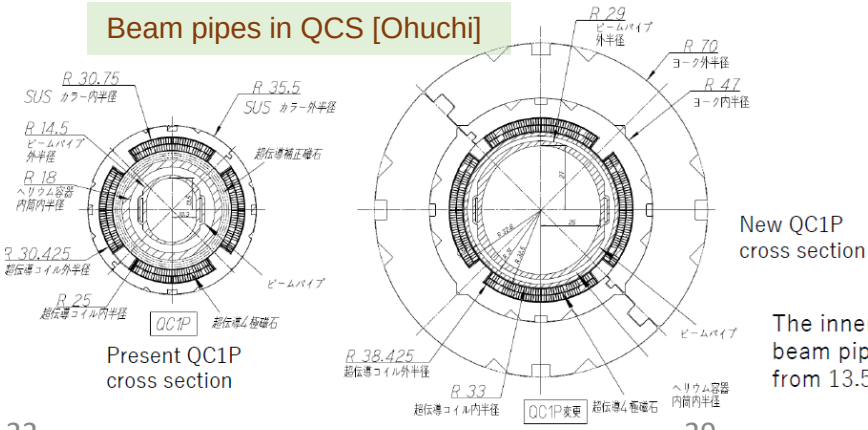
- Make it possible to squeeze β_y^* down to 0.3 mm and to operate safely at high beam currents.
- Effective to mitigate the background.

- Installation of radiating shield (heavy metals) inside the QCS cryostat will be possible at the same time.

Field profiles [Ohuchi]



Beam pipes in QCS [Ohuchi]



Key points of update

(1) Aim an ecological operation suppressing 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} at the reasonable time not so different from the previous plan.

(2) Modify IR, especially upgrade QCS and it's beam pipes, in order to make it possible squeeze β_y^* to 0.3 mm, to mitigate the beam-beam effect at high bunch-current region, to protect QCS, and to reduce the background, then to increase the collision performance, the stability and the data-taking efficiency.

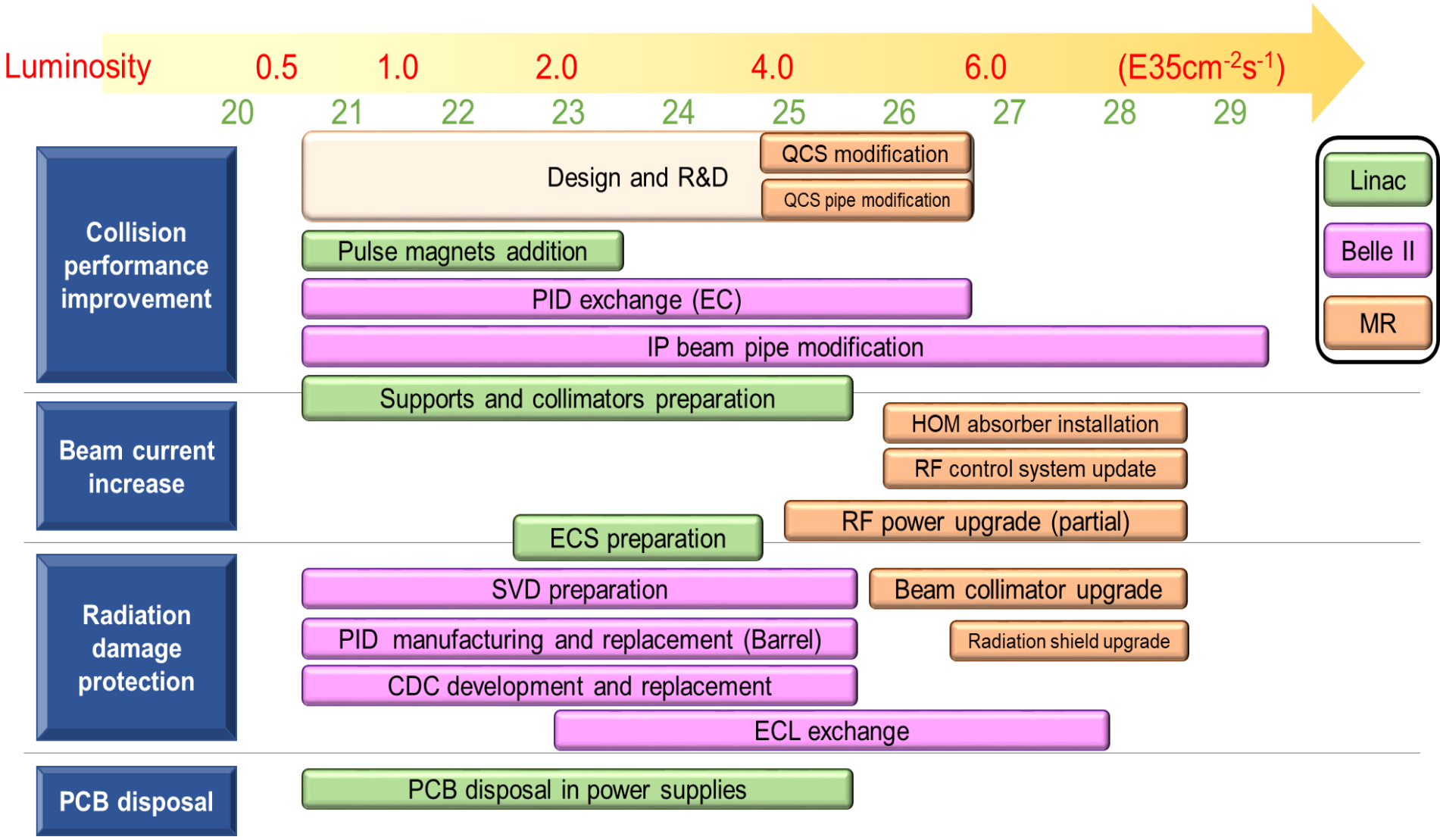
(3) Keep option to upgrade the RF power at the minimum level.
- Store the beam currents of LER 2.8 A and HER 2.0 A stably.
  - Even if not upgraded, the beam currents of LER 2.5 A and HER1.8A will be possible.

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

Key points of update

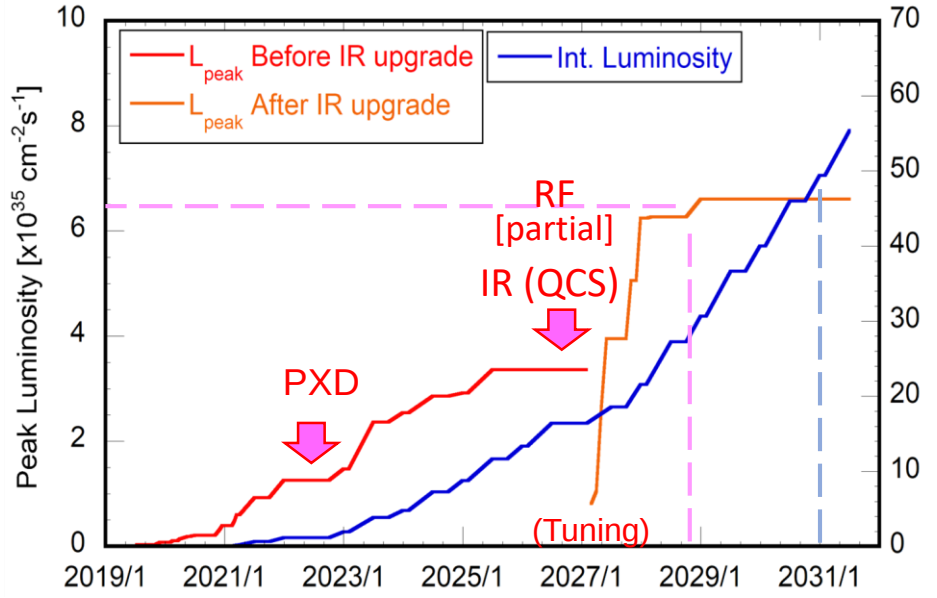
- Major upgrades (Investment of equipment)
- Belle II
  - Preparation of SVD spare.
  - Replacement of CDC FEE and readout circuits
  - Replacement of PID (MCP-PMT) in Barrel
  - Replacement of PID (HAPD) in ARICH
  - Replacement of a part of ECL
  - Modification of IP beam pipe
- Linac
  - Development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

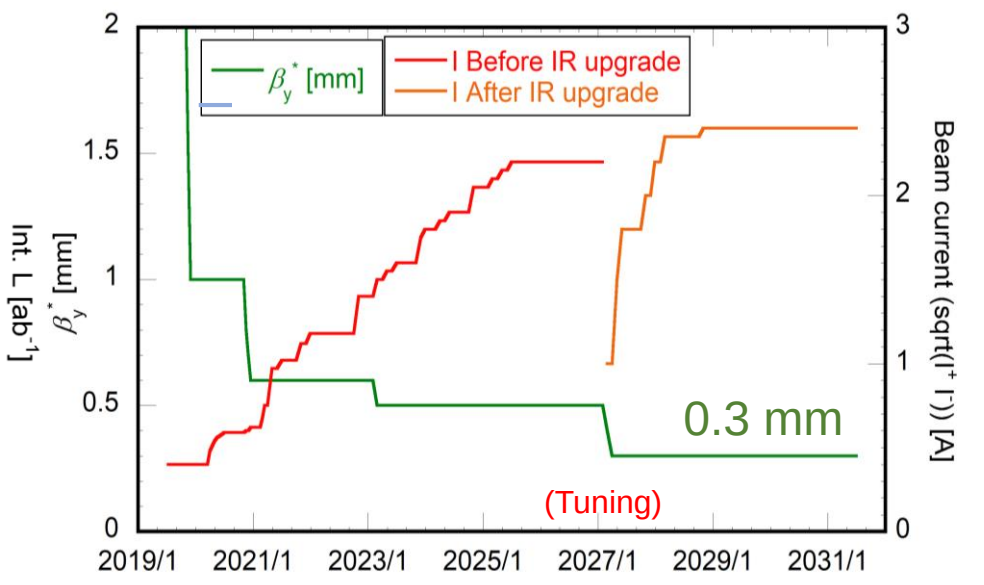
Rough schedule of upgrade



Long-term luminosity projection

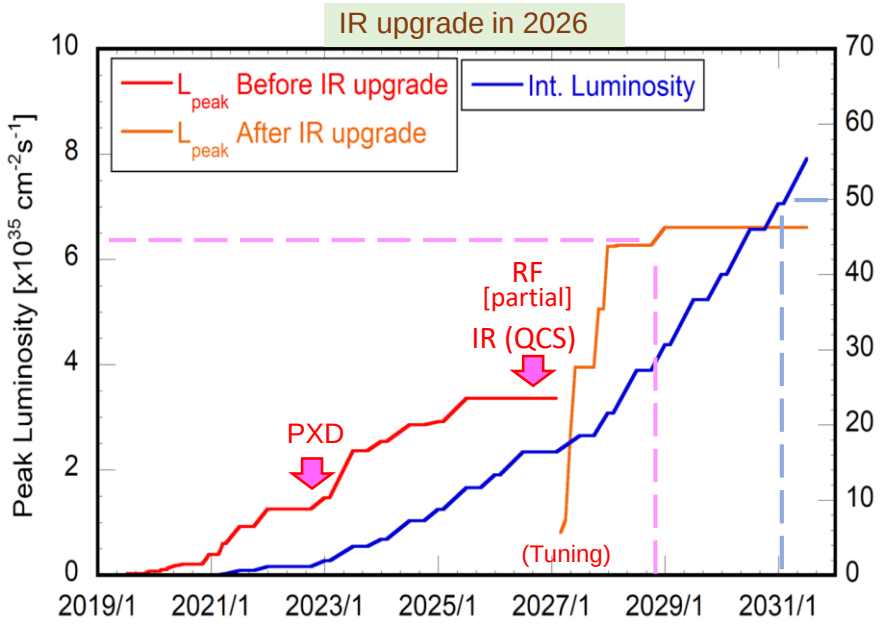
- Update of luminosity projection
  - After these upgrades in 2026, the stable operation at high beam currents (LER 2.8A and HER 2.0A) with β_y^* of 0.3 mm will be possible. If the beam-beam parameters of 0.07~0.08 are achieved, the peak luminosity will be ~6E35 cm^{-2} s^{-1}.
  - If 8 months' operation per year is realized, again after making various efforts, the integrated luminosity of 50 ab^{-1} will be achieved in ~2030 (40 ab^{-1} in ～2029).

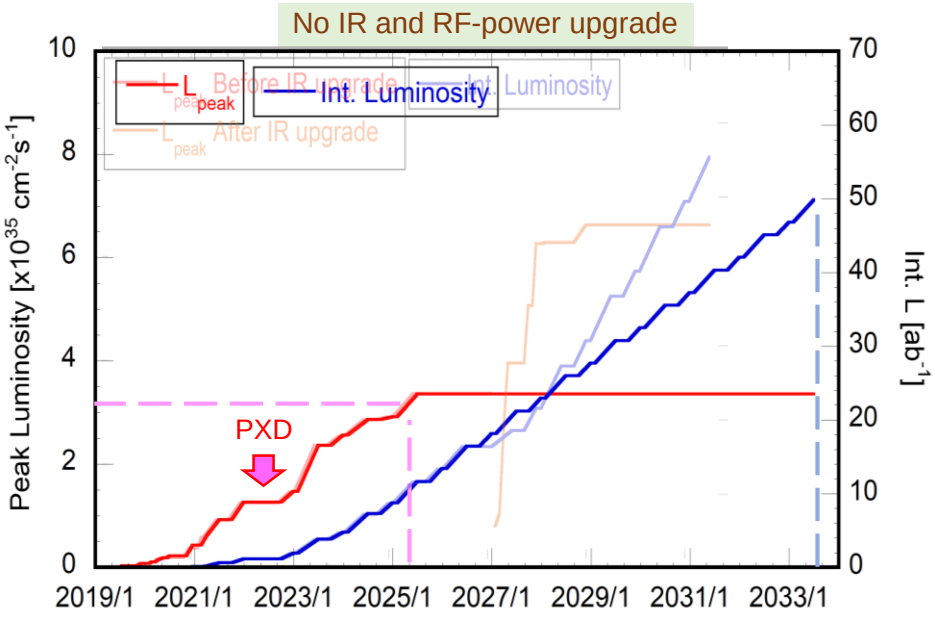




Long-term luminosity projection

- Note
  - If we have NO upgrade of IR (QCS and beam pipes) and RF power (Max. LER 2.5 A /HER 1.8 A, β_y^*= 0.5 mm), assuming 8 months' operation per year, the integrated luminosity of 50 ab^{-1} will be achieved in 2032~2033 (40 ab^{-1} in 2031).
  - These upgrades promote the achievement of the goal, and also expand option in the operation, and as a result, reduce the risk.





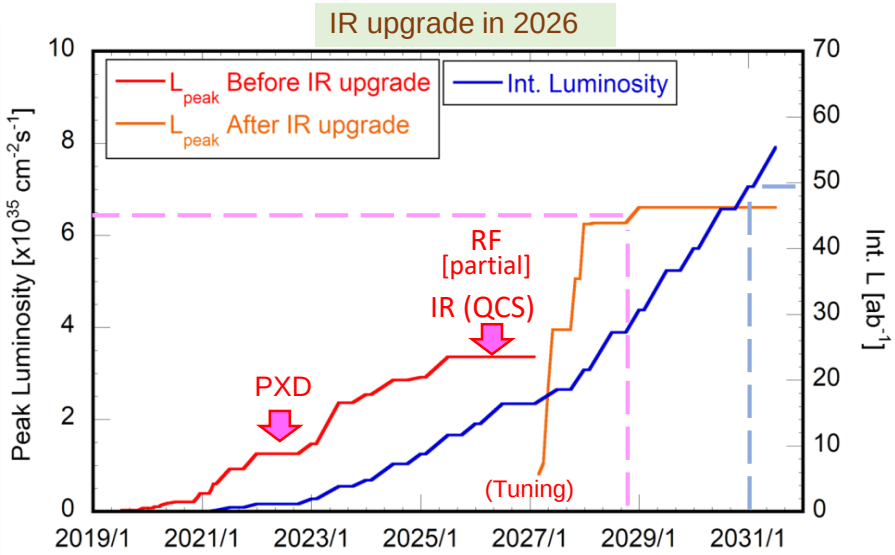
Summary

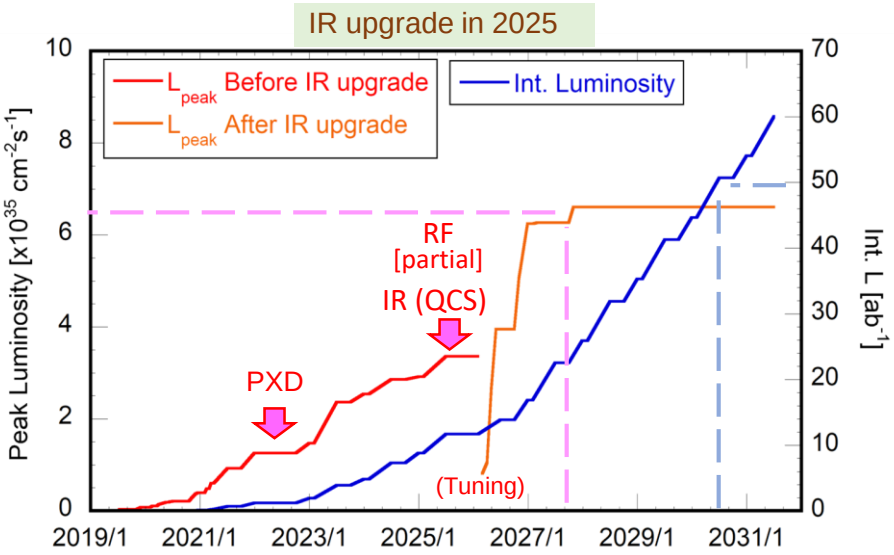
- MEXT SuperKEKB Roadmap 2020
  - Perform the collision experiments with a several ten-times higher luminosity than that in the preceding KEKB project by using the nano-beam collision scheme.
  - Aim an integrated luminosity of 50 ab^{-1} in coming 10 years.
  - Update the operation plan:
    - Aim ecological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

Thank you for your attention.

Long-term luminosity projection

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





2020/6/16

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

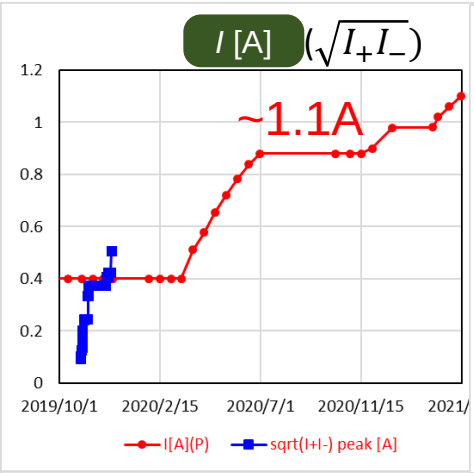
Operation plan and luminosity projection

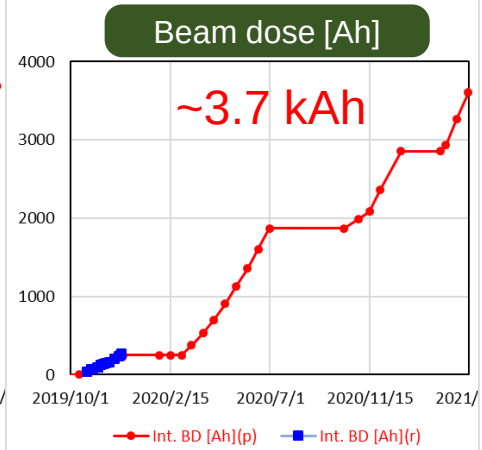
- Near term operation plan (~2021/March=FY2020)

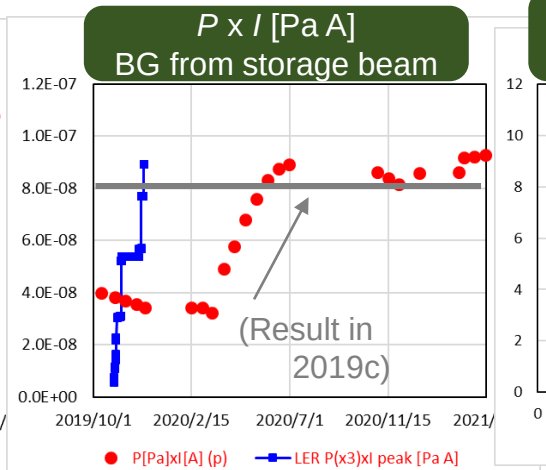
(1) Case N1: 6.5 months operati

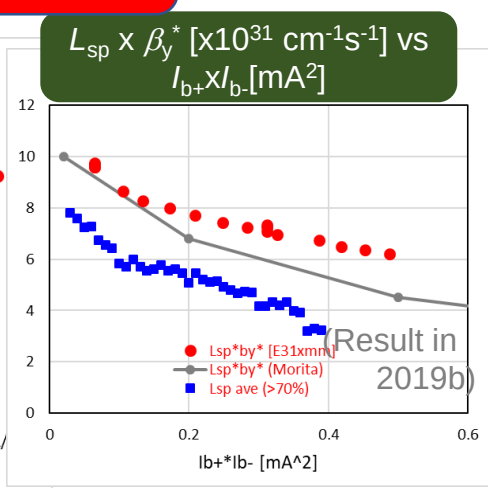
Presented in last BPAC

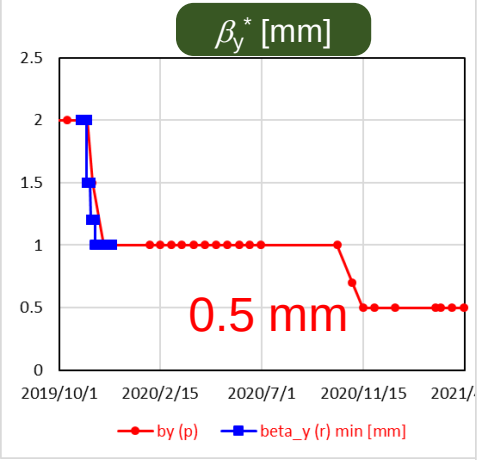
● Cal., Assumption
■ Result in 2019c

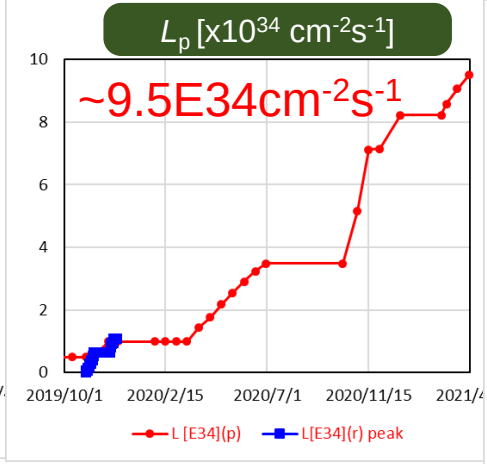


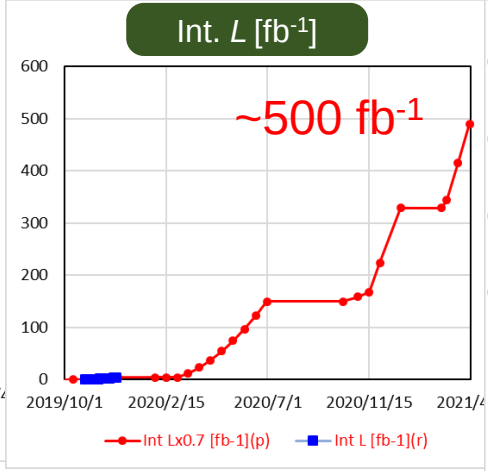


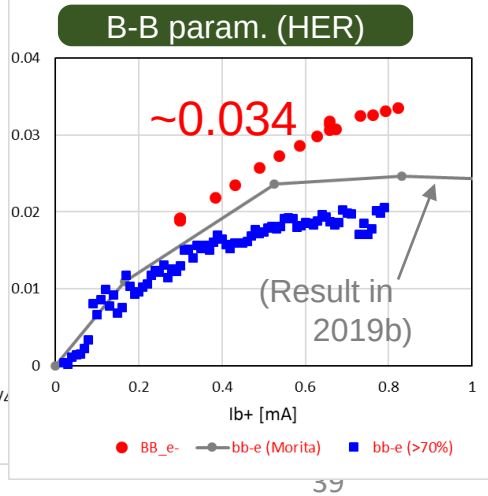






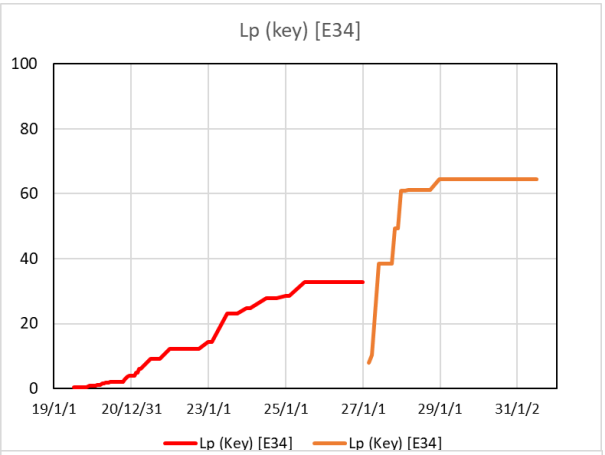


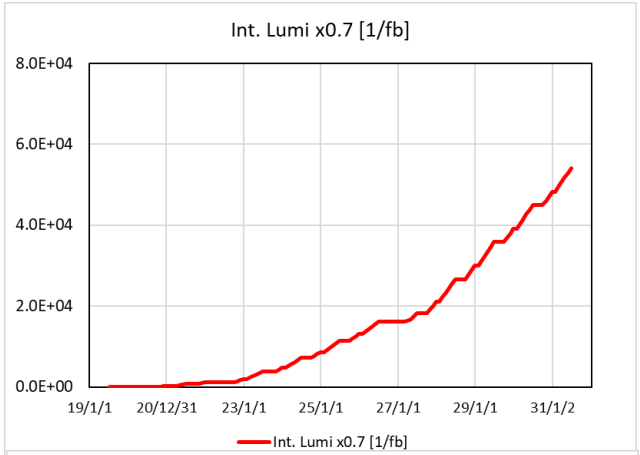


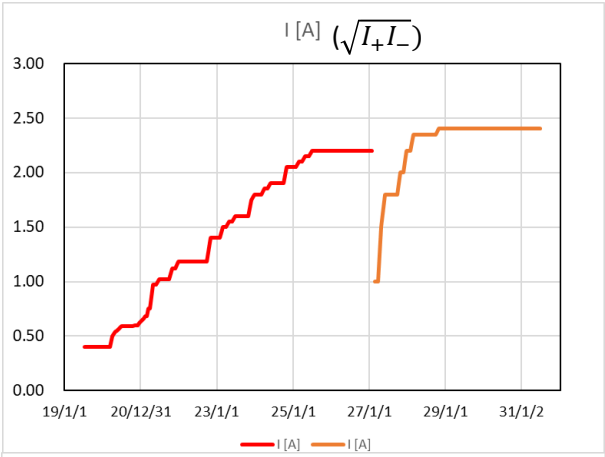


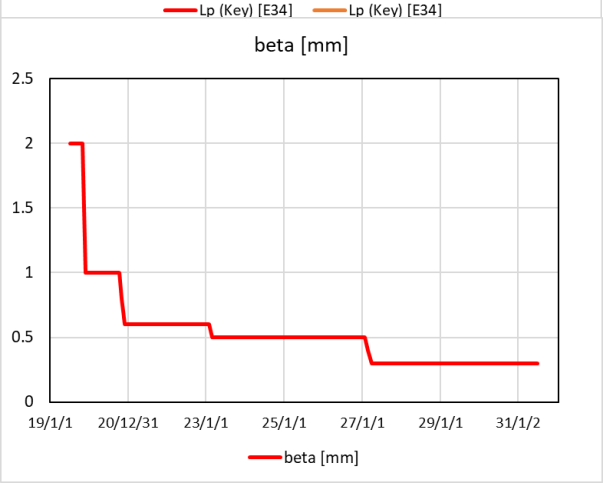
Updated luminosity projection (parameters)

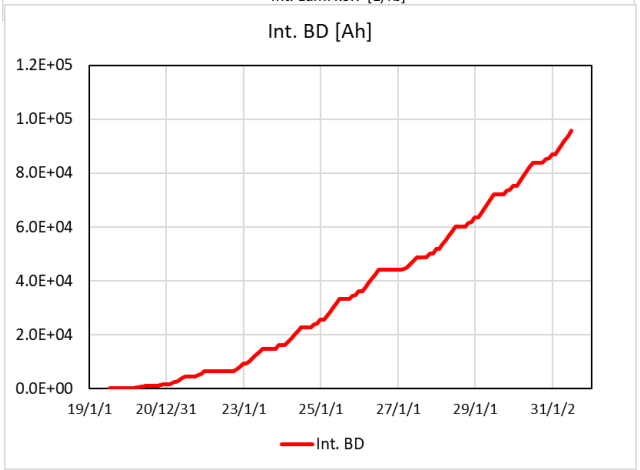
- Long term operation plan-1

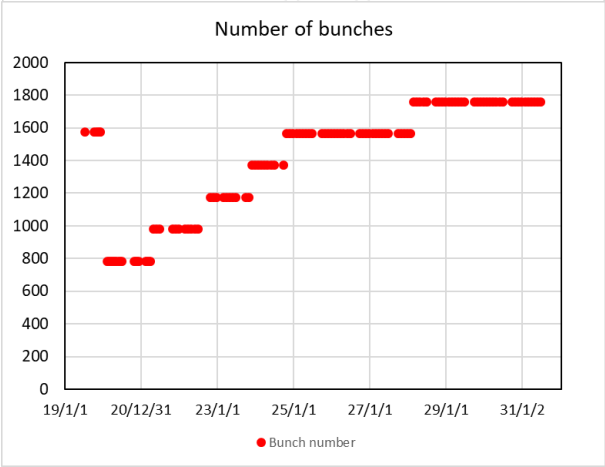






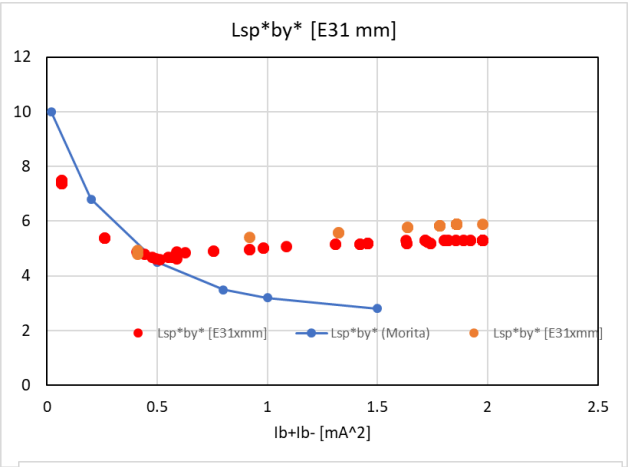


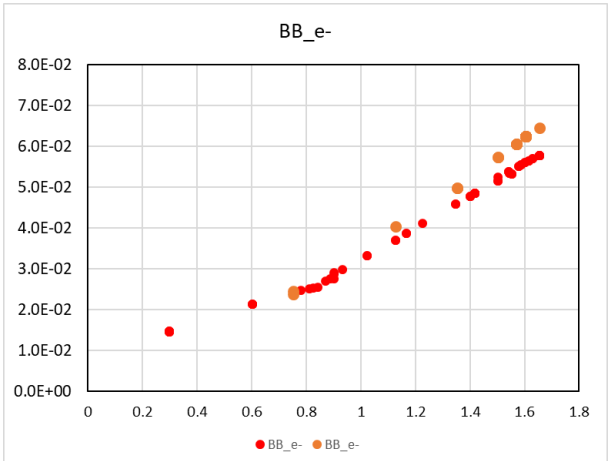


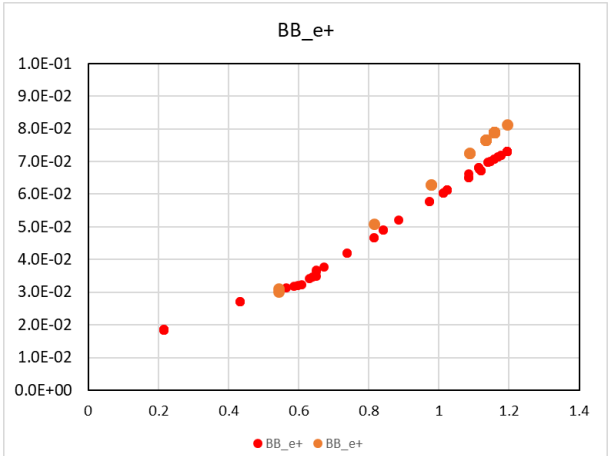


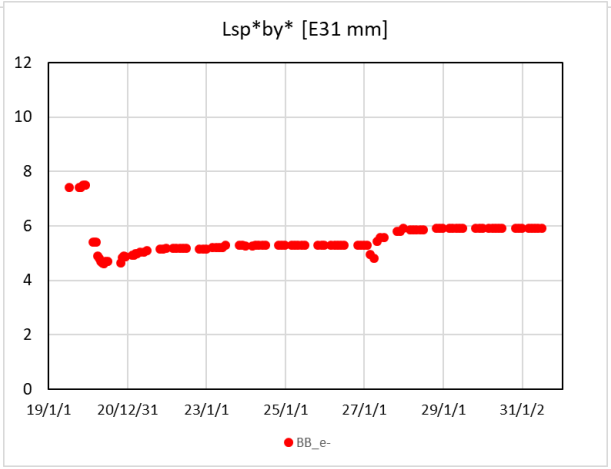
Updated luminosity projection (parameters)

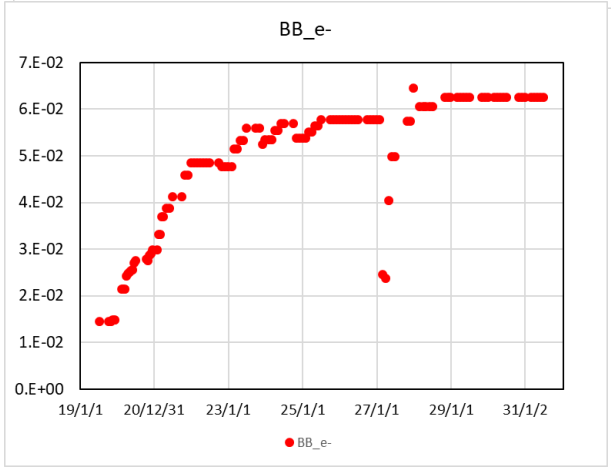
- Long term operation plan-2

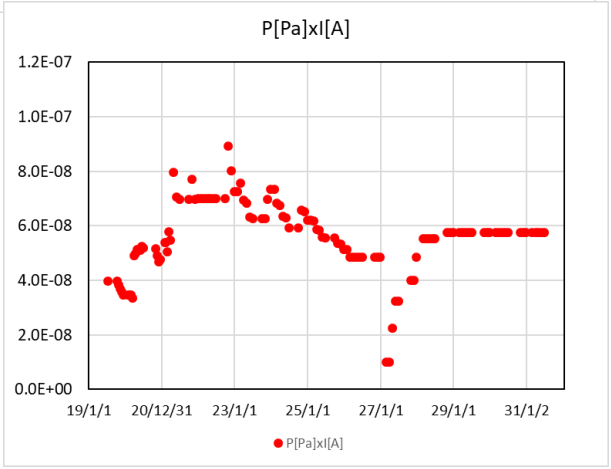






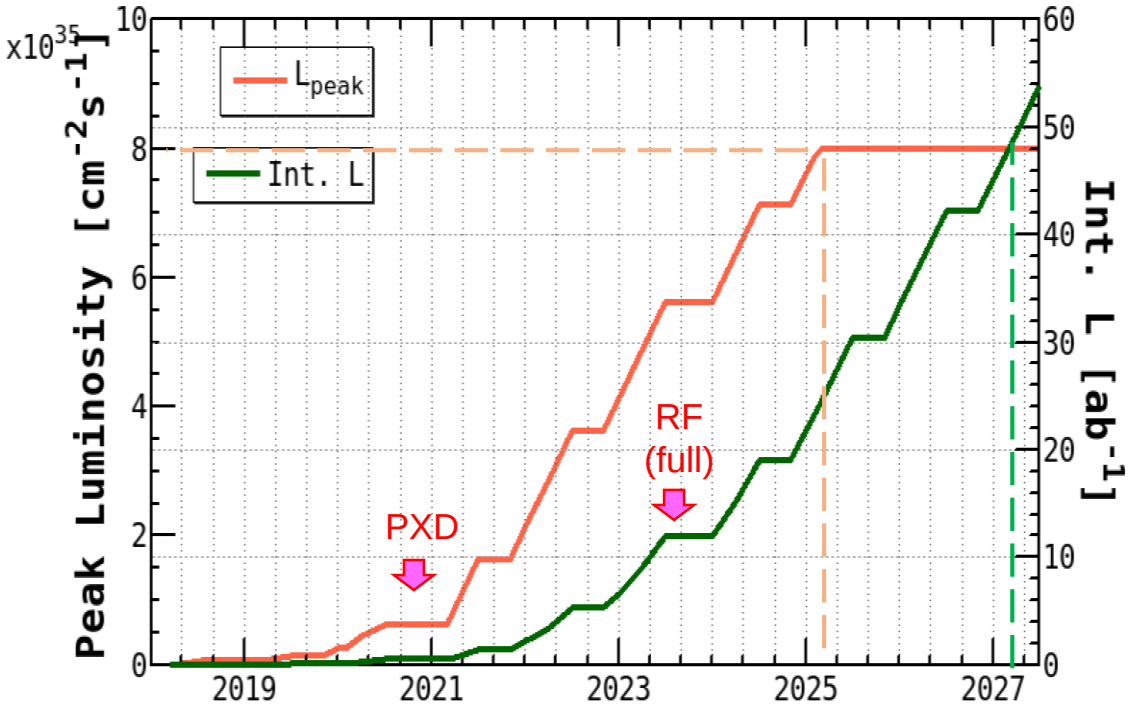






SuperKEKB Roadmap2020

- 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)