SuperKEKB near-term (until 2021c) and long-term operation plan

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KEK Acc. Div.

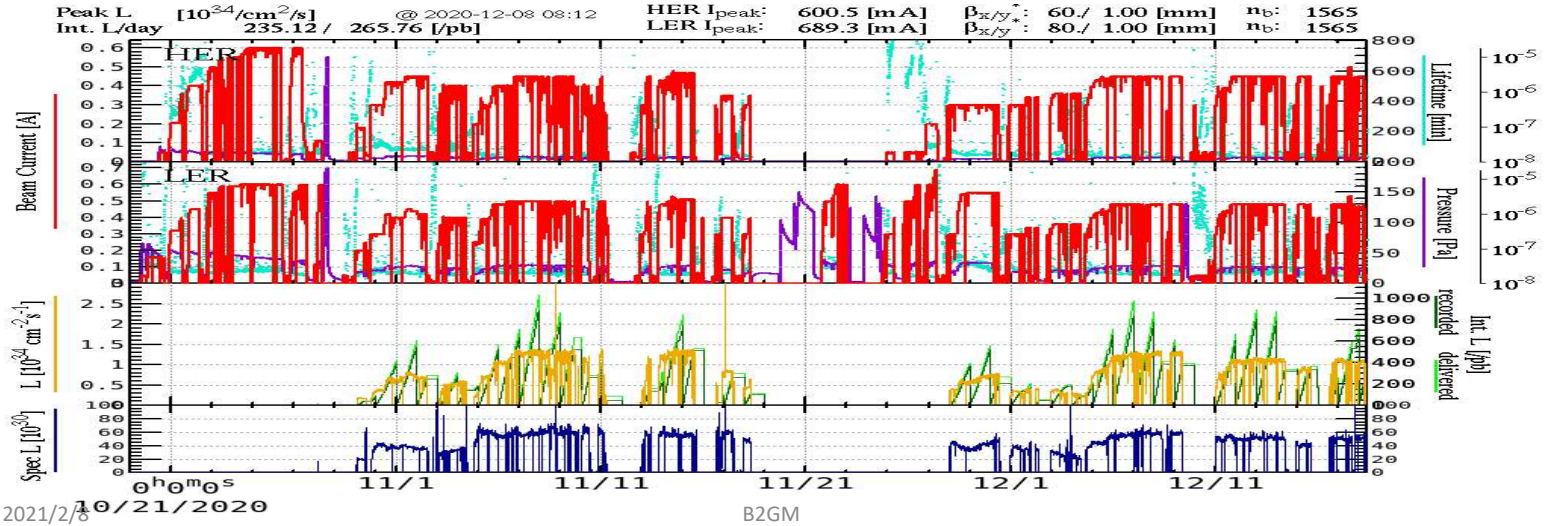
- Near-term (until 2021c) operation plan
- Long-term operation plan

Brief review of MR in 2020c run

- The 2020c run started on 19th Oct. and ended on 18th Dec., as scheduled.
- In summary, the 2020c run was very challenging one.
  - The operation condition has been far from that in 2020b run.
    - Imax(LER) = 690 mA (27th Nov.), Imax(HER) = 600 mA (24th Nov) during vacuum scrubbing.
    - Max. peak luminosity was 1.48E34 $cm^{-2}s^{-1}$ (14th Nov.).
    - Min. β_y^* was 1.0 mm.
  - Various challenges and limitations were revealed.

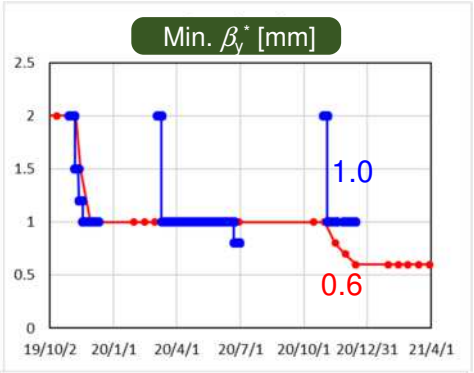
→ Details will be reported by Mitsuka-san later.

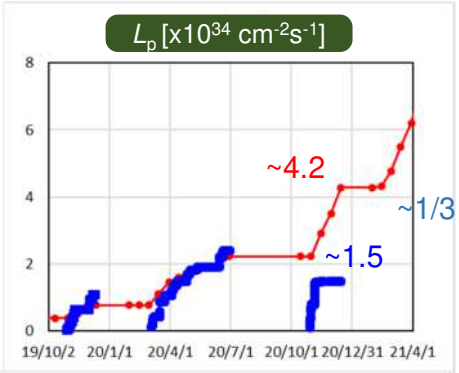
2020c run summary (2020/10/19~2020/12/18)

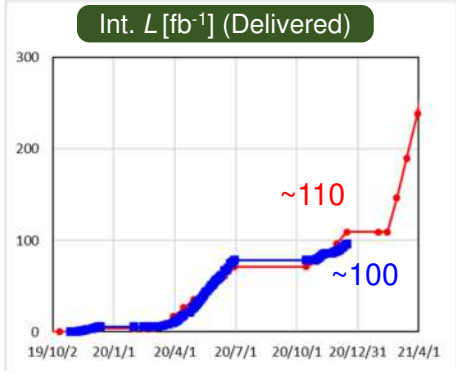


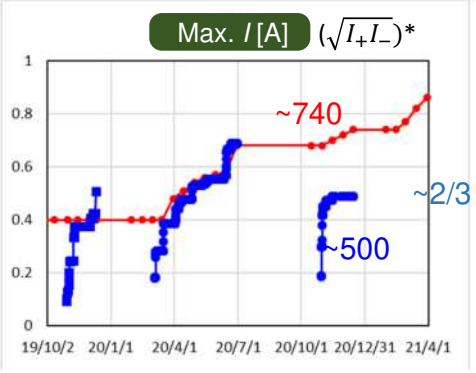
Brief review of MR in 2020c run

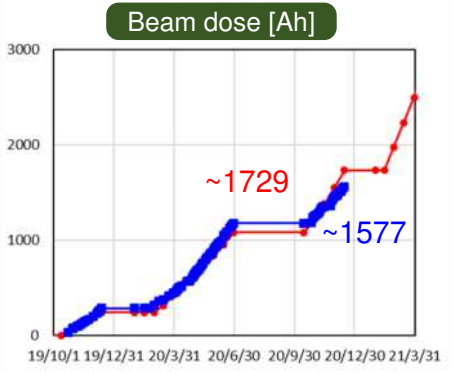
- Achieved luminosity and other major parameters











From 2019c run

- Original Plan
- Result until 2020c

	β_y^*	L_p	Int. L	I_{max}	Beam dose
Plan	0.6	~4.2E34	~110	~740	~1720
Result	1.0	~1.5E34	~100	~500	~1580

*Note: in the plan, the ratio of LER/HER beam currents are assumed to be 3.6/2.6, i.e., the ratio of the design currents.

Brief review of MR in 2020c run

- Main causes of the low luminosity
  - Lower beam currents than expected (~500 mA < ~740 mA)
    - Low injection efficiency
      - Unstable beams from BT and Linac
        - Time change (periodical change and drift) of beam orbits, energy spreads
        - Frequent break downs of RF-gun cavity
      - Low injection efficiency on HER (not “explosion” although still large)
        - Low physical aperture at injection points?
      - Short lifetime due to small physical and/or dynamic aperture in the ring
    - High background (especially background by injected beam)
      - Sometimes depended on optics.
    - Beam-size blow-up due to beam instability caused by collimator impedance in LER
    - Beam-size oscillation and/or blow-up due to beam-beam effect at high bunch currents
    - Hardware troubles -> limit max. beam currents.
      - Beam collimator, Cooling water system
  - Larger β_y^* than expected (1.0 mm at most > 0.6 mm)
    - Little time to try the low β_y^*. Even the condition of β_y^* = 1 mm has not been resumed.
- As a result, integrated luminosity was also lower than expected.

Operation plan for 2021 runs

- 2021 Run schedule
  - 2021a run will start on 16th Feb.
    - The first week will be only LER and will be dedicated to vacuum scrubbing and studies.
    - HER will start from 24th Feb.
    - The total operation period will be ~6.4 months this year, thanks to the support from our director.
  - The process for the FY2021 budget request is ongoing.
    - We will aim for 5.7 months' operation in FY2021 (taking account of the long shutdown for the PXD replacement from Jan., 2022).
- Major premise for 2021 runs
  - 2021 runs should be dedicated for the luminosity production.
  - Produce new physical results from enough data, over 424.18 fb^{-1} (final integrated luminosity of BaBar, NIM A726 (2013) 203) at least by the end of December, before the long shutdown.

  →Realize stable operation at a high luminosity.

Present plan

	2020									2021			
FY2020	4	5	6	7	8	9	10	11	12	1	2	3	
Present plan (20th Oct.)		2020b ~3M						2020c ~2M				2021a ~1.5M	Total ~6.5M/y
	2021									2022			
FY2021	4	5	6	7	8	9	10	11	12	1	2	3	
Plan (not fixed) [MEXT Road Map]	4/1	2021b ~3.1M		7/5	B2GM		10/7	2021c ~2.6M	12/23	PXD exchange			Total ~5.7M/y

Operation plan for 2021 runs

- Run strategy
  - Run strategy until 2020b run
    - Squeeze β_y^* and increase luminosity with moderate total beam currents within the limited background level, and then accumulate the data.
    - Suppress the increase in background resulting from β_y^* squeezing by adding or closing collimators.
    - Generally successful until 2020b
      - Achieved the world-record luminosity with moderate beam currents in 2020b at β_y^* = 1 mm.
  - 2020c run followed the strategy
    - Planned to squeeze β_y^* down to ~0.6 mm and improve luminosity further.
    - Add D03V1 collimator
    - However, lots of challenges were standing in the way before squeezing β_y^* down to less than 1 mm.
      - High background and low injection efficiency (unstable conditions of injection beam).
      - Strong beam instabilities (TMCI) due to high impedance of collimators
      - Strong beam-beam effects at high bunch currents
      - Beam currents of ~600 mA at most, as a result.
    - The situation would be worse if β_y^* is squeezed further in this condition.

Revise the strategy to achieve the goal of 2021 runs, through discussion with Belle II

Operation plan for 2021 runs

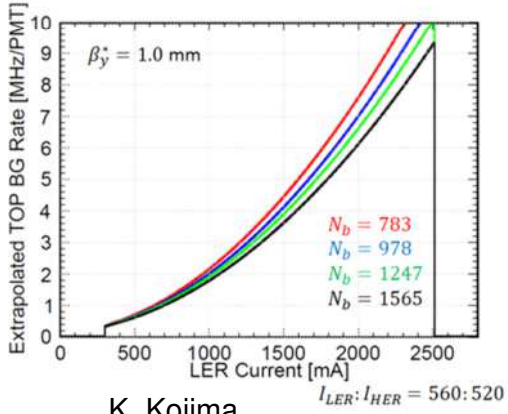
- Run strategy
  - Run strategy until 2020c
    - Squeeze β_y^* and increase luminosity with moderate total beam currents within the limited background level, and then accumulate the data.
    - Suppress the increase in background resulting from β_y^* squeezing by adding or closing collimators.

  - Revised run strategy for 2021 runs (proposal)
    - Put priority on (Int.) luminosity rather than background.
      - Relax the background limit, for example, the TOP hit rate, which has been sometimes a major limit of increasing the total beam current.
      - Open collimators within the tolerable range, which could increase injection efficiency and decrease the impedance
    - Aim at stable operation
      - Remove the high-impedance carbon collimator to avoid beam instability. → Done.
      - Use the proven optics with β_y^* of 1 mm.
      - Increase the total beam current by increasing the number of bunches and run within a moderate bunch current.
      - Establish stable injection condition (essential).
    - Of course, we will continue the effort to understand various issues, such as beam-beam effects, collimator damages, and to further squeeze β_y^* for the future.
    - We will be able to get experience at high current, too.

Operation plan for 2021 runs

- Basic run plan for 2021 run
  1. Resume the ring condition at β_y^*= 1 mm, which was realized in 2020b run.
     - The starting point. Peak luminosity of ~2.4E34 $cm^{-2}s^{-1}$ at ~700 mA, 978 bunches.
       - It will take one month (by the end of March)?
     - Establish stable beam injection condition.
     - Use the proven optics, which had been used when the maximum luminosity was recorded in 2020b (reduction of background by D03V1 will not be expected.)
  2. Gradually increase beam currents at β_y^* = 1 mm with 1565 bunches.
     - TOP could relax the limit on the background from 1.2 to 5 MHz/PMT, which allows to increase total beam currents.
       - Considering the possibility of replacing PMT in 2026.
       - 5 MHz/PMT, for example, corresponds to LER = 1.6~1.8 A.
     - The number of bunches might be increased step by step, depending on the machine condition.
  3. Option: Squeeze β_y^* down to 0.8 mm (and more)
     - If possible and if there is any indication to raise luminosity.
     - Note: We will not stop challenging lower β_y^* for the future.

Single beam backgrounds + constant injection backgrounds
(measured in the background study on May 9, 2020)

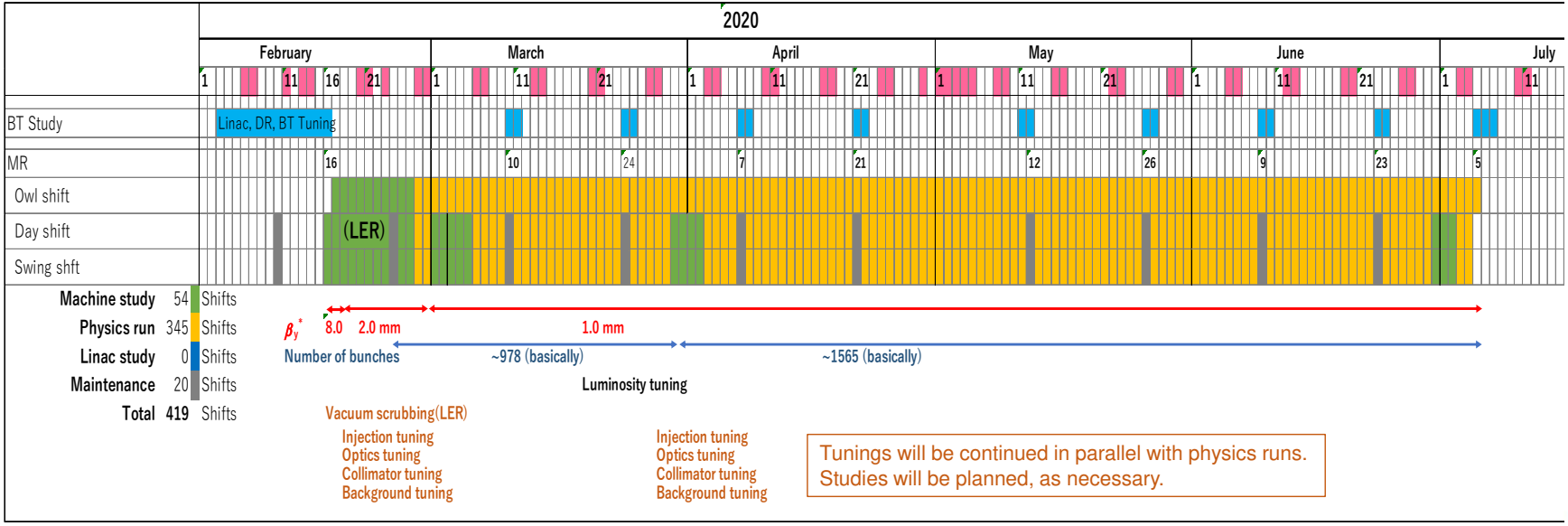


K. Kojima

Operation plan for 2021 runs

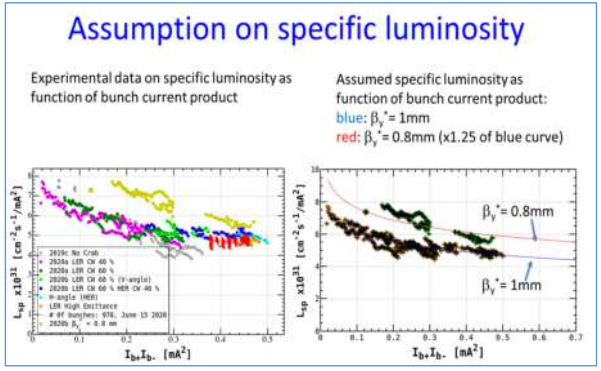
- Basic run plan for 2021a, b
  - Rough schedule (Draft)

SuperKEKB 2021a, b Operation Plan



Luminosity profile for 2021 runs

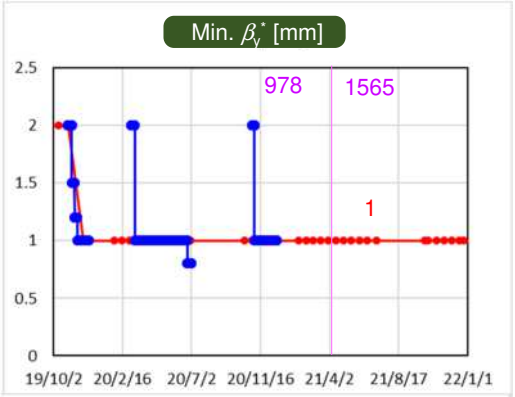
- The luminosity profile was re-evaluated based on the results of 2020c and following the strategy for 2021 runs.
- Assumptions for revaluating luminosity projection
  - Beam current ← Key point
    - Considering the results of 2020c run, it seems reasonable to assume that the beam current will be 1.1 ~ 1.2 A, although the TOP limit is relaxed.
  - Specific luminosity
    - Same level to 2020b run
      - Expected to be improved gradually by ~10%?
  - Others
    - The luminosity used for the calculation of Int. Luminosity is 0.65 times of the peak luminosity, which has been assumed to be 0.7 so far.
    - Physics run for 28 days per month basically.
    - Move to 1565 bunches from 4/1.
    - The Int. luminosity includes that during the off-resonance run.
      - ~1 week?
    - Reduction in d*P*/d*I* ~ 60% at 6000 Ah.
    - No long-term break
      - No trouble in collimators and other hardware (~1 week break in the case) -> ~10 fb^{-1} loss
    - No intervene by COVID-19

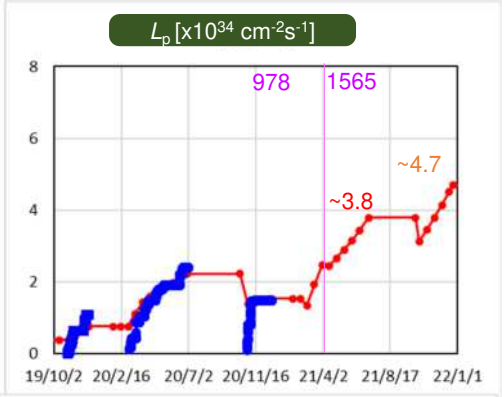


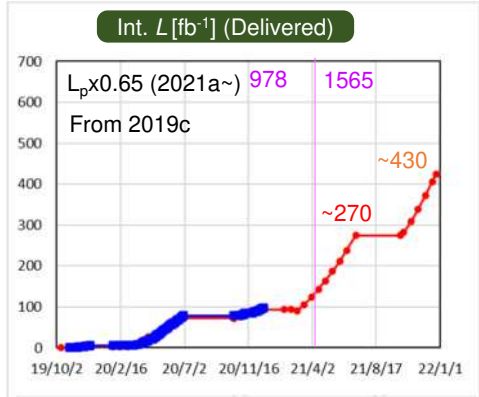
Y. Funakoshi

Luminosity profile for 2021 runs

- Base plan : Maximum beam current ~1.1 A by the end of 2021b.

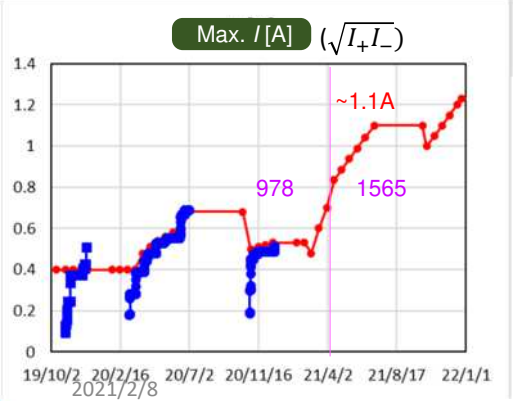


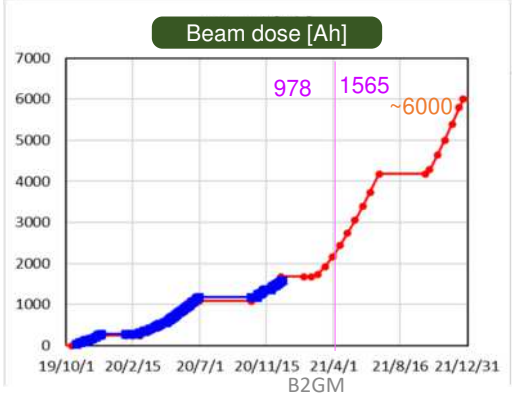


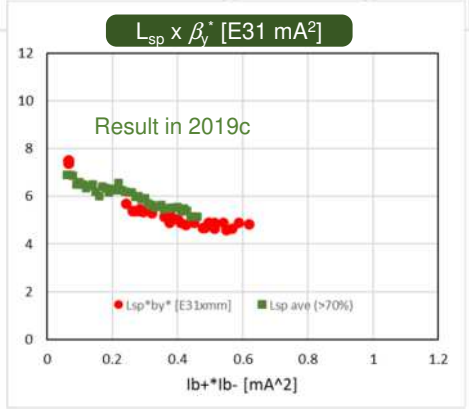


From 2019c run

- Revised plan
- Result until 2020c



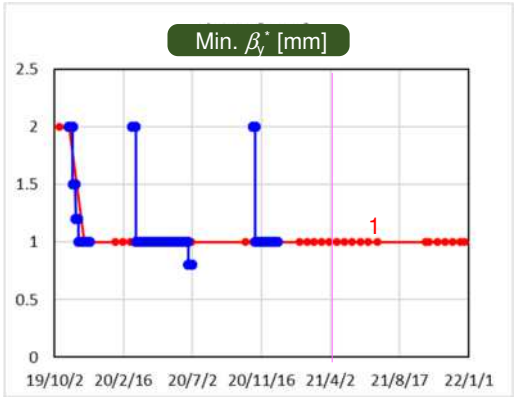


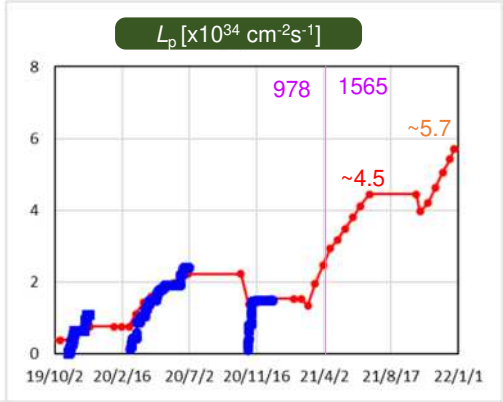


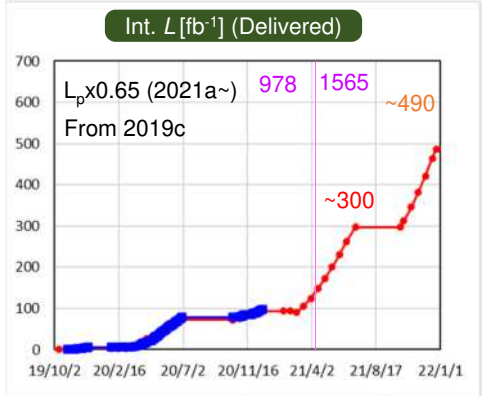
Note: Constant L_p was assumed even for $i_{b+} * i_{b-} >$ 0.6 [mA^2]

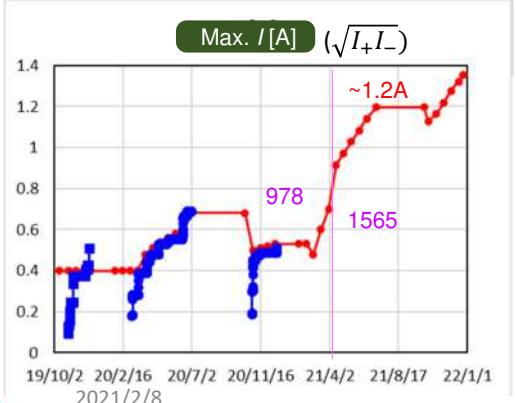
Luminosity profile for 2021 runs

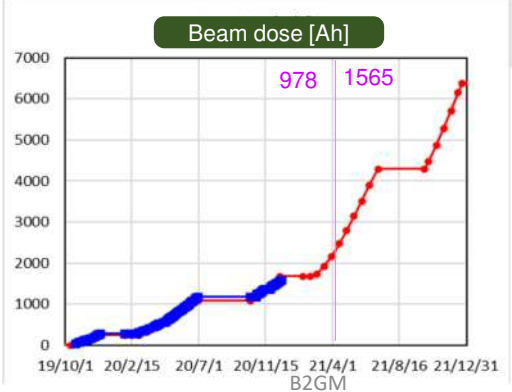
- Possible plan : Maximum beam current ~1.2 A by the end of 2021b.

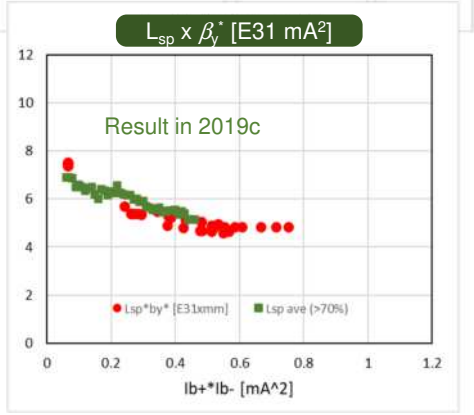












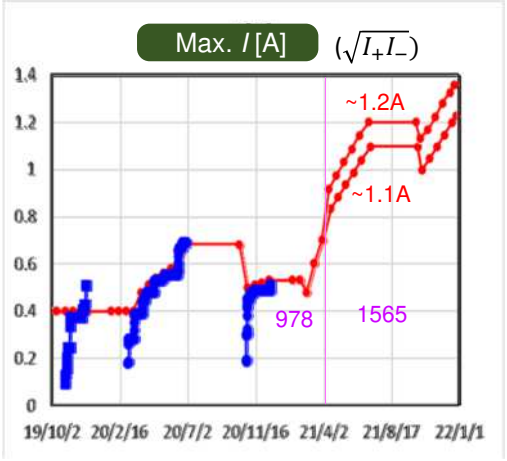
From 2019c run

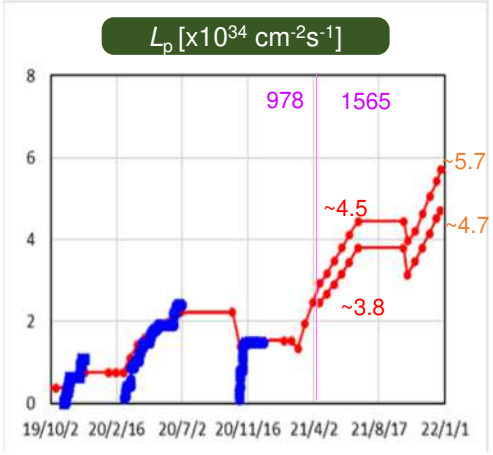
- Revised plan
- Result until 2020c

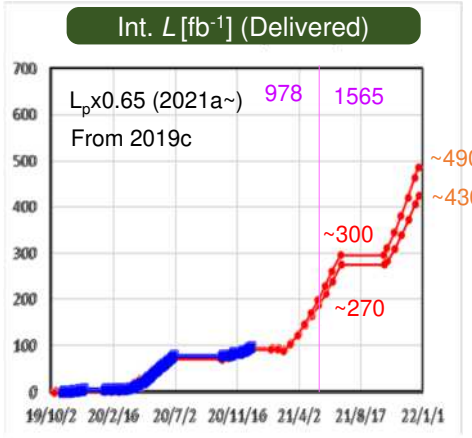
Note: Constant L_p was assumed even for $i_{b+}*i_{b-}$ > 0.6 [mA^2]

Short-term operation plan

- Summary
  - Run strategy for 2021 runs: Put priority on (Int.) luminosity rather than background.
  - Base and possible plans : Maximum beam current 1.1~1.2 A by the end of 2021b.







From 2019c run
- Revised plan
- Result until 2020c

- Key point to realize the plan
  - How much can we store the beam currents?
    - Can we keep the injection condition stable?
    - Can we control beam instability and beam-beam effect at high bunch currents?

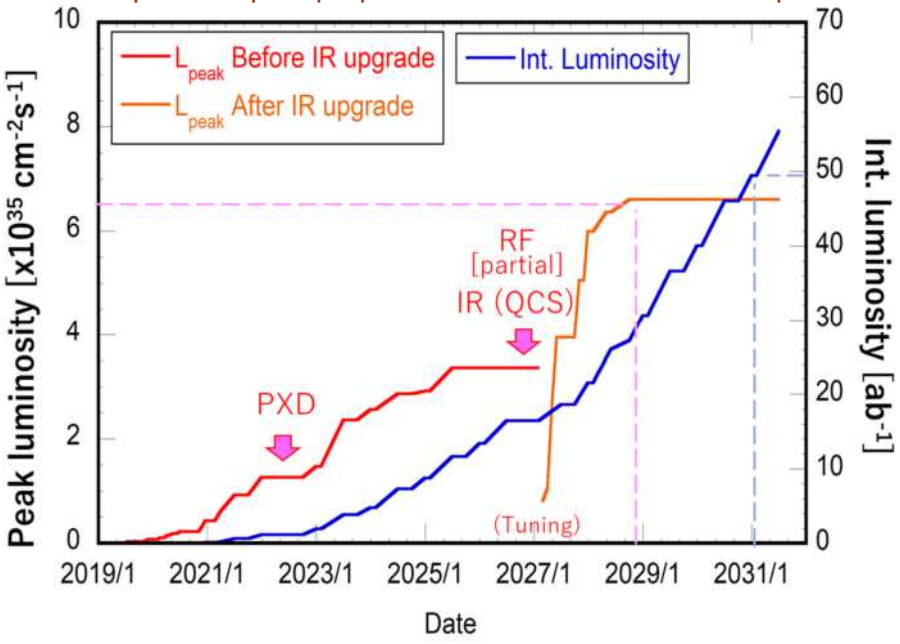
	β_y^*	L_p [E34]	Int. L [/fb]	I_{max}	
~2021b	1.0	3.8~4.5	270~300	1.1~1.2	1.5~2 fb^{-1}/day
~2021c	1.0	4.7~5.7	430~490	1.2~1.3	

- Near-term (until 2021c) operation plan
- Long-term operation plan

Long-term operation plan

- For MEXT Roadmap 2020, we proposed to update the previous long-term operation plan (2019) considering the actual situation and the results obtained until 2019c.

Operation plan proposed for MEXT 2020 Roadmap



- 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 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

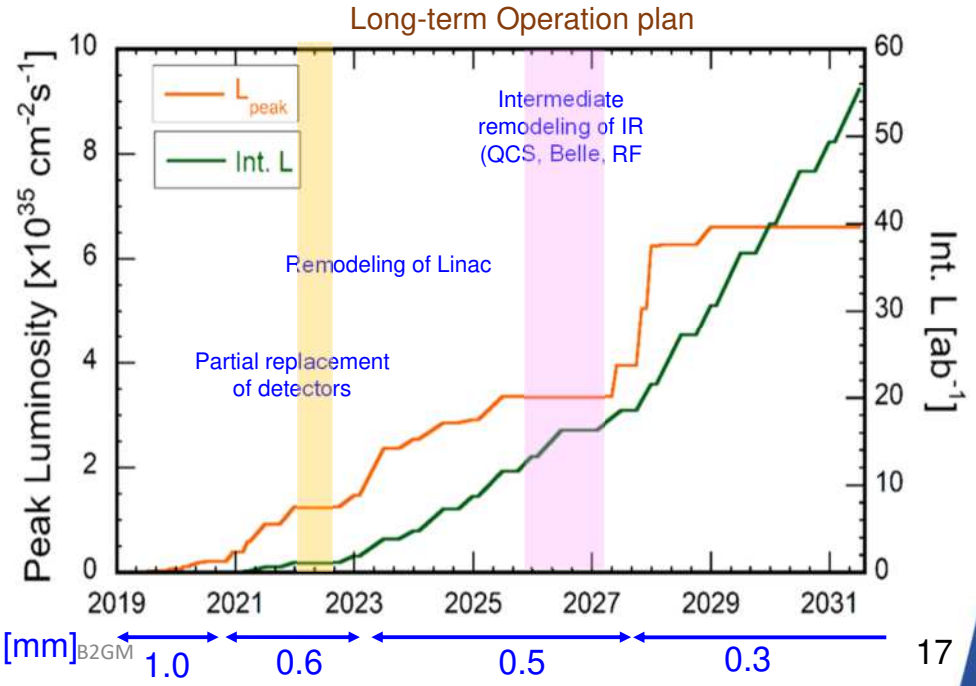
Long-term operation plan

- Key point : Intermediate upgrade of IR around 2026
  - 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.

- Improvement of
  - Background
  - Beam lifetime
  - Collision efficiency

- Boost up of luminosity
  β_y^* : ~0.5 → ~0.3 mm
  L_{peak} : ~3E35 → ~6E35 $cm^{-2}s^{-1}$

- Until the upgrade, β_y^* will be gradually squeezed, and the beam currents will be increased gradually.



Long-term operation plan

- Present status
  - The MEXT updated their roadmap 2020 in August, 2020.
  - The SuperKEKB/Belle II project was selected as one of 15 highest priority projects with an “AA” grade (the highest possible).
  - The actual plan will be finalized seeing the progress of the current luminosity improvement.
  - The plan was assessed by the external review committees (BPAC, 2020/6 and Accelerator Review Committee (ARC, 2020/7)).
  - Based on the recommendation from the review committees, “Long-term operation plan meeting” was launched in August, 2020.

Long-term operation plan meeting

- In the meeting, the following issues are discussed and examined in these 2 or 3 years.

- Is IR upgrade really required?
  - Examination of crab-waist scheme
  - Verification of the effect of rotatable sextupole magnets
  - Investigation of beam-beam effect
  - Understanding of background issue
  - β_y^* squeezing and luminosity
  - Understanding of beam lifetime
  - Collimators and their impedance issues
  - Injection efficiency
  - Examination of the base plan (with present QCS)

- Is IR upgrade really possible?
  - Making practical model of QCS magnet field configuration
  - Making practical beam optics
    - The range of remodeling
  - Examination of technical issues
    - Manufacturability、Materials of SC cables、Magnet alignment method
  - Examination of human resources
  - Conflict with Belle II detector
    - IP chamber, Connection mehode
  - Manufacturing schedule
  - Commissioning after the upgrade

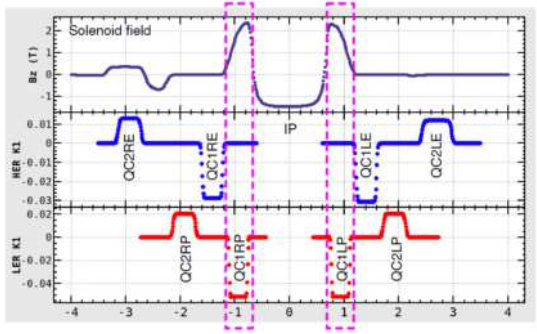
- Short-term commissioning plan
- Establish the performance model

- Four meetings have been held so far (~2021/2/4).
- In parallel, the issues of RF-upgrade, Linac and BT will be also discussed in the meeting.

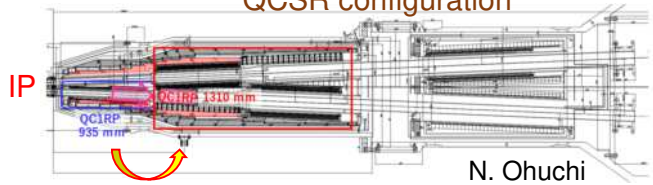
Some topics in the meeting so far

- Narrow dynamic aperture at high-bunch current regions due to strong beam-beam effect
  - A promising method to mitigate the effect was said to be the modification of QCS to avoid interference between the quadrupole magnetic field and the Belle II solenoid field for the LER.
  - Two ideas to relocate QC1P to places farther from IP were examined at first.
  - However, up to now, it was found that little improvement was expected even without beam-beam effect.
  - On the other hand, it was also found in a simulation that the effect will be cured using the rotatable-sextupole magnets installed in the local correction region at Tsukuba.
  - We will try it this during 2021 run.

Magnetic fields around IR



QCSR configuration



N. Ohuchi

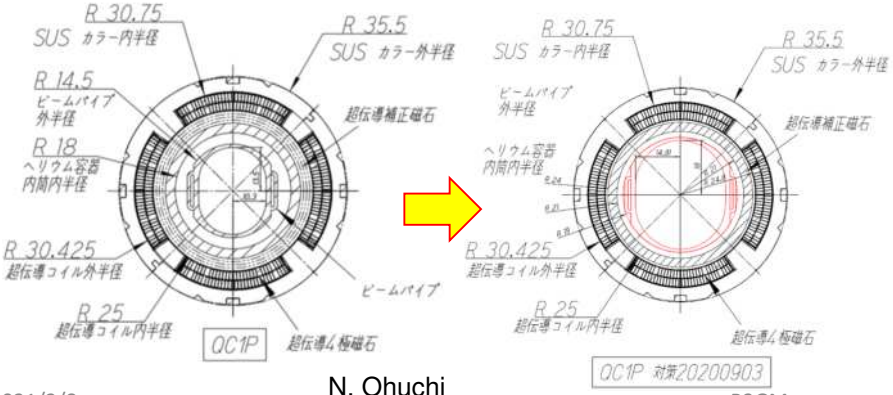
Rotatable Sextupole magnet

M. Masuzawa

Some topics in the meeting so far

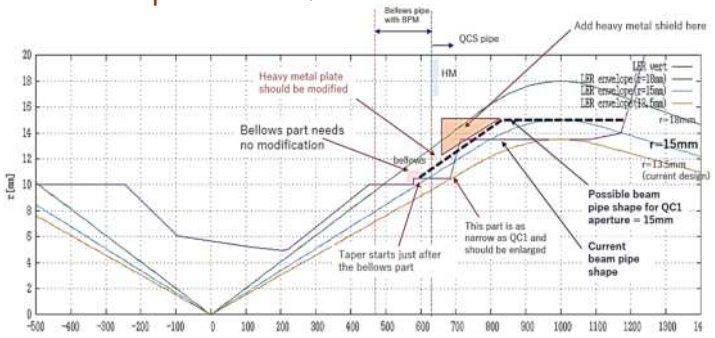
- Narrow physical aperture in the QC1RP -1
  - Enlargement of the (vertical) aperture of beam pipes in QC1RP has been discussed.
    - The enlargement is expected to increase the physical aperture and then increase beam lifetime, and also to reduce background.
    - Although little improvement in the lifetime determined by the dynamic aperture.
    - The aperture can be enlarged by relocating the correction magnets to outside of the main quadrupole magnets.
  - It will be possible to increase the inner diameter from 13.5 mm to 18 mm geometrically.
  - The range required for the modification was examined, and it was reported that the modification near to the BPM and bellows near to IP is also required.

Cross section of QC1P



N. Ohuchi

Aperture of QC1P and beam sizes

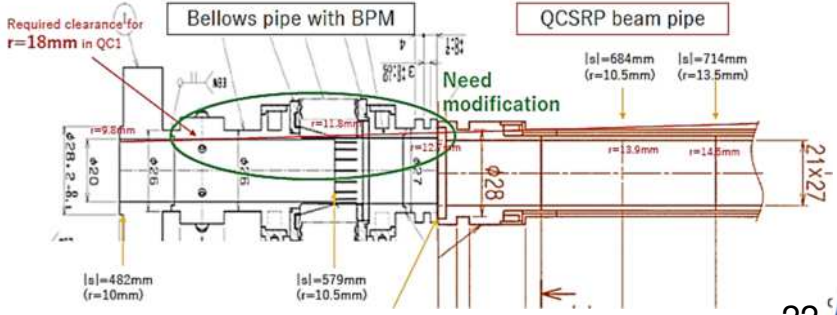


H. Nakayama

Some topics in the meeting so far

- Narrow physical aperture in the QC1RP -2
  - The R&D for the beam pipes, BPM and bellows has started.
  - Required R&D
    - Beam pipes for QC1RP
      - Remodeling of connection flange at IP side（RVC）→R&D and testing together with DESY group.
      - Change in the vacuum sealing mechanism between the QCSR cryostat and the beam pipe. (O-ring seal)
      - Manufacturing method of beam pipes and TiN coating method.
    - Bellows chamber with BPM
      - Change in the cross-section of bellows from circular one to an ellipse or a race-track one
      - Change in the flange at QCS side.

Bellows chamber with BPM at IP

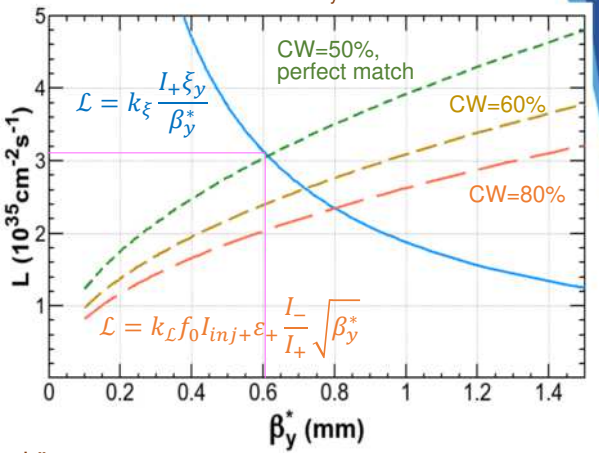


K. Kanazawa and K. Shibata

Some topics in the meeting so far

- Examination of the base plan (with present QCS)
  - The performance with the present QCS is being examined by a simulation including beam-beam effect.
  - Recently it was reported that the Touschek beam lifetime will be increased by 60% and a luminosity of around 3E35 $cm^{-2}s^{-1}$ could be achieved by introducing a “perfect match” and 40% of the crab-waist in LER.
    - ~3E35 $cm^{-2}s^{-1}$: Goal luminosity before the upgrade.
  - How to practically realize the “perfect match” using normal-conducting quadrupole magnets, for example, is being investigated.

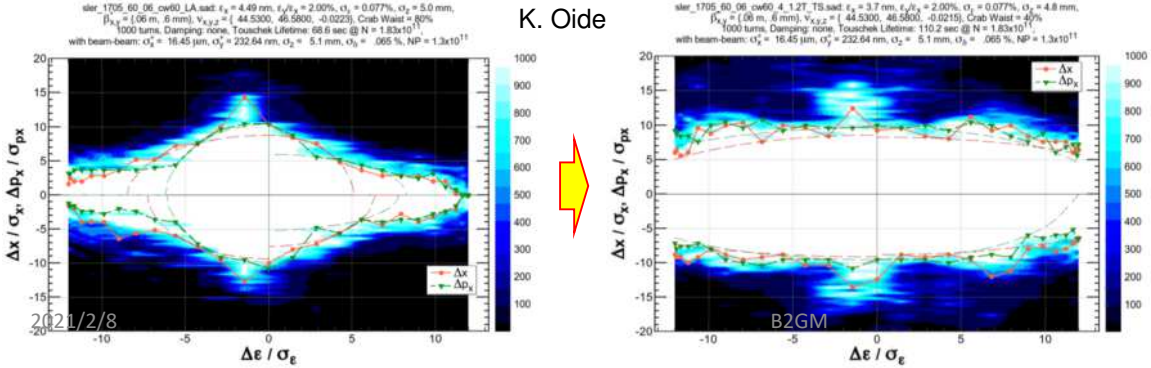
Luminosity vs β_y^* (K. Oide)



Dynamic aperture with CW=80%

Dynamic aperture with CW=40% + “perfect match”

K. Oide



“Perfect match”:

- Phase shifts between SLYTRP2/SLYTLP1 and IP are just 0.5 (x) and 0.75 (y).
- The values of β_x and β_y at the center of four SLY（SLYTLP1&2, SLYTLP1&2） are set to be the same, respectively.

Long-term operation plan

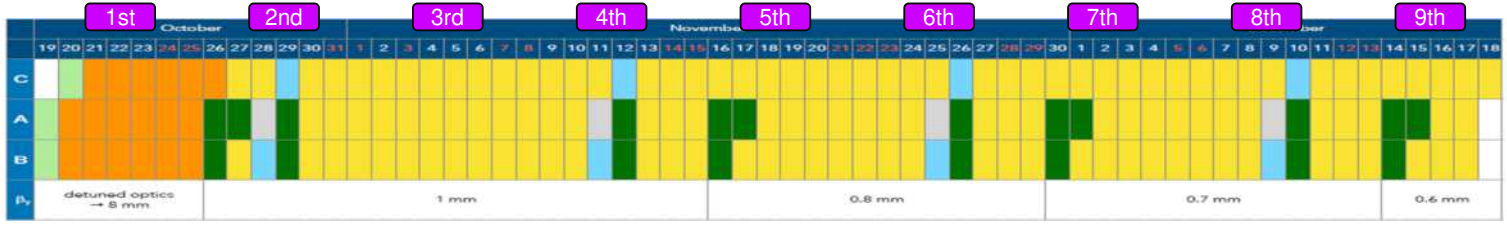
- Summary
- Updated long-term operation plan was proposed for MEXT roadmap 2020 last year.
  - Put the priority on the integrated luminosity, rather than the peak luminosity, and realize an integrated luminosity of ~50 ab^{-1} within a reasonable time period.
  - Modify the IR, especially upgrade QCS and its beam pipes around 2026, which should boost the luminosity and achieve the goal luminosity.
- "Long-term operation plan meeting" was launched based on the recommendation from the review committees to discuss the detailed and practical issues in the plan
- Four times meeting so far, and following subjects were discussed and investigated.
  - Relocation of QC1P to increase dynamic aperture
    - No clear improvement so far
  - Enlargement of physical aperture in QC1RP
    - R&D on beam pipes and bellows around QCS has started.
  - Weakening of Belle II solenoid magnetic field (for ex., 1.5T→1.2T)
  - Examination of the base plan (with present QCS)
    - Practical method to realize "Perfect match" is under investigation.
  - More major remodeling, including that of Belle II detectors.
- Some practical conclusion should be obtained in these two or three years, i.e., before the decision of whether the IR have to be upgraded or not around 2026.

Thank you for your attention

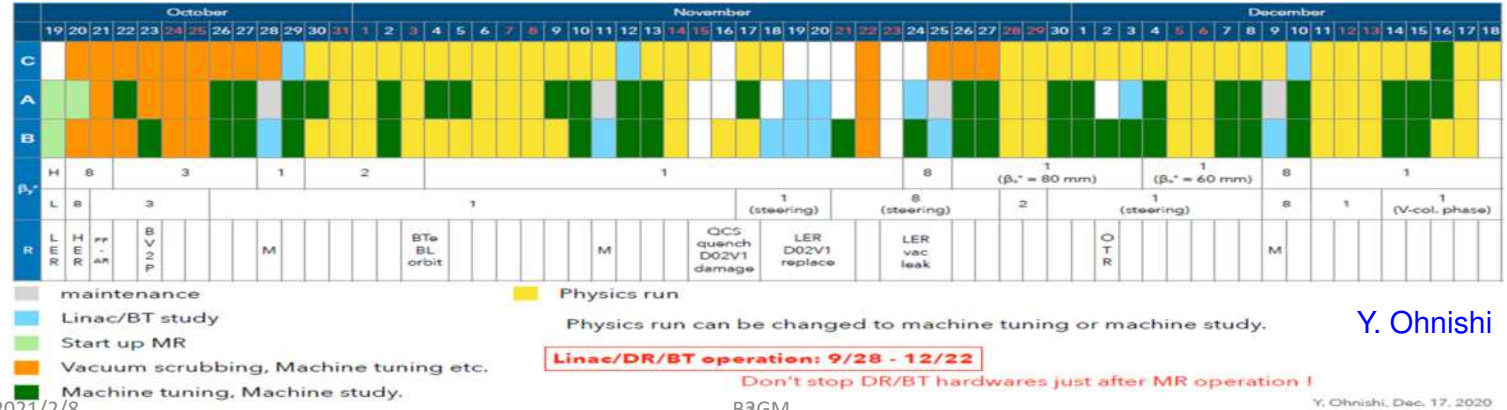
Backup

Brief review of MR in 2020c run

- Initial shift plan
  - 60 days (120 shifts) in total.



- Actual shifts
  - Most of day and swing shifts of weekdays were dedicated to beam studies and tunings.



Y. Ohnishi

Brief review of MR in 2020c run

- Challenges in 2020c run
  - Internal leak in a SC cavity of HER
  - Poor injection efficiency (through 2020c)
    - Many reasons, such as mis-setting of magnet parameters in BT, frequent break-down of RF-gun cavity, time change (oscillation and drift) of BT/Linac orbit and energy, narrow physical or dynamic aperture of the rings, beam instability, and so on.
  - Difficulty in squeezing HER β_y^* to 1 mm
  - High background by injected beams
  - Damage of D02V1 collimator jaw, and exchange work (~1 week break)
  - Big air leak from D02V1 collimator flange
  - Difficulty in resuming the LER/HER condition after the collimator trouble
    - High background by injected beam with new steering-magnet settings
  - Failure in cooling water pump
  - Coupled bunch instability in LER due to impedance of collimators
  - Strong excitation of TMCI with new phase-adjusted LER Optics
  - Vertical beam size oscillation and blow-up in HER due to beam-beam effect
  - Damage of D06V2 collimator jaw
  - Emittance growth at the latter part of the electron beam transport line
  - Etc.
- Some were solved, but some were not.

Operation plan for 2021 runs

- Main hardware work during 2021 winter shutdown for 2021a run
  - Replacement of D11D SC cavity to a reserve (HER)
    - The completion inspection and the issuance of completion certificate as a high-pressure gas device from the government agency, is expected in around mid of Feb.
  - Replacement of D06V1 collimator jaws (LER)
    - From 60 mm carbon to 5 mm tantalum
    - Reduction in the impedance is expected.
  - Replacement of D09V3 collimator jaws (HER)
    - KEKB type titanium jaw.
  - Replacement of D12V1 collimator drive mechanism (HER)
    - More precise positioning is expected.
  - *In situ* baking of D02V1 and D06V1 collimators (LER)
    - Reduction in the base pressure is expected.
  - Installation of a collimator in the Linac electron line (BTe SY3)
  - Replacement of aged 66 kV high-voltage power supply lines [by Facility Department]
  - Other maintenance works
    - Repairs of aged power supplies for magnets, etc.

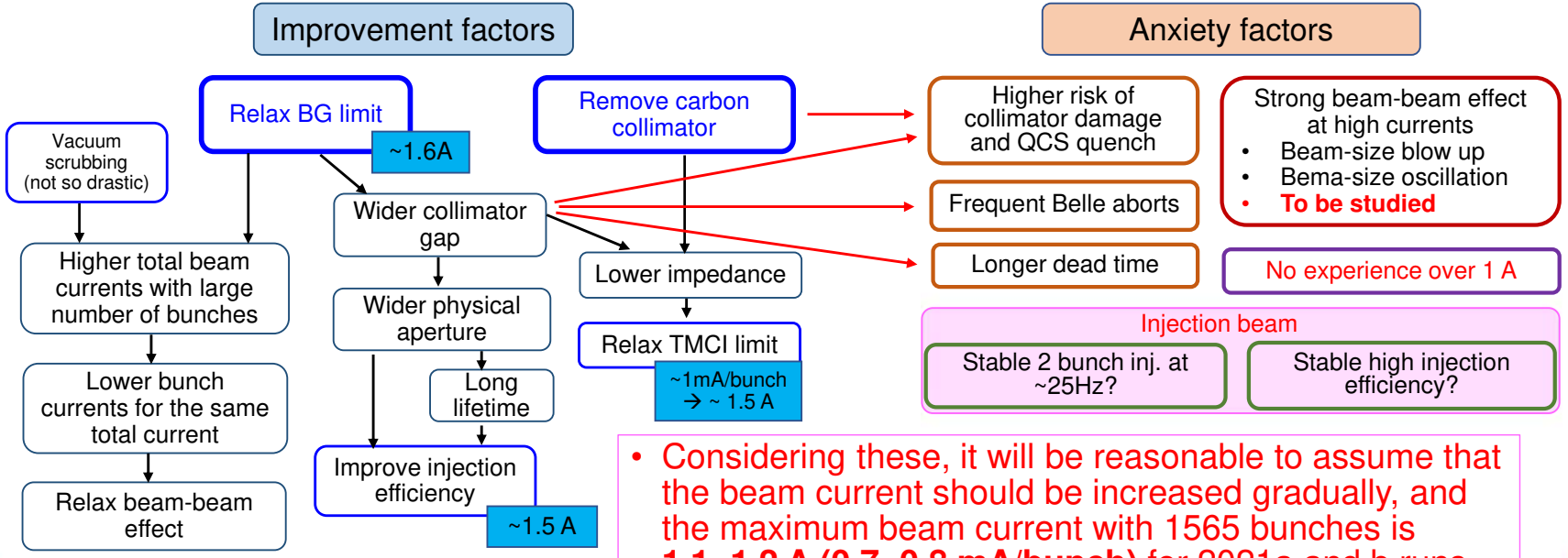
Operation plan for 2021 runs

- Other improvements for 2021a run
  - Prepare an interlock system in case of cooling water trouble for vacuum system.
    - Combined interlock with colling-water flow-meters and vacuum pressures.
  - Prepare an alarm system which indicates a possibility of collimator damage.
    - Combined alarm with pressure bursts and VXD signals.
  - Prepare a software to restore, check, and compare various setting parameters in BT (such as magnet settings) before starting run.
    - Discussion has started together with Belle II staff.

- Lessons not to follow the same rut
  - Do not forget beginner's mind even if it is a familiar work.
    - Use tooling as specified
  - Do not drastically change parameters at once, such as beam optics parameters.
    - Change them step by step while checking.

Luminosity profile for 2021 runs

- The luminosity profile was re-evaluated based on the results of 2020c and following the strategy for 2021 runs.
- Assumptions for revaluating luminosity projection -1
  - Beam current ← Key point

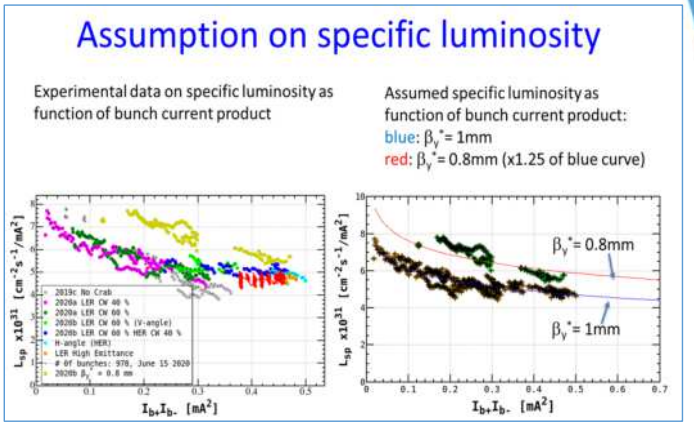


- Considering these, it will be reasonable to assume that the beam current should be increased gradually, and the maximum beam current with 1565 bunches is **1.1~1.2 A (0.7~0.8 mA/bunch)** for 2021a and b runs.

Luminosity profile for 2021 runs

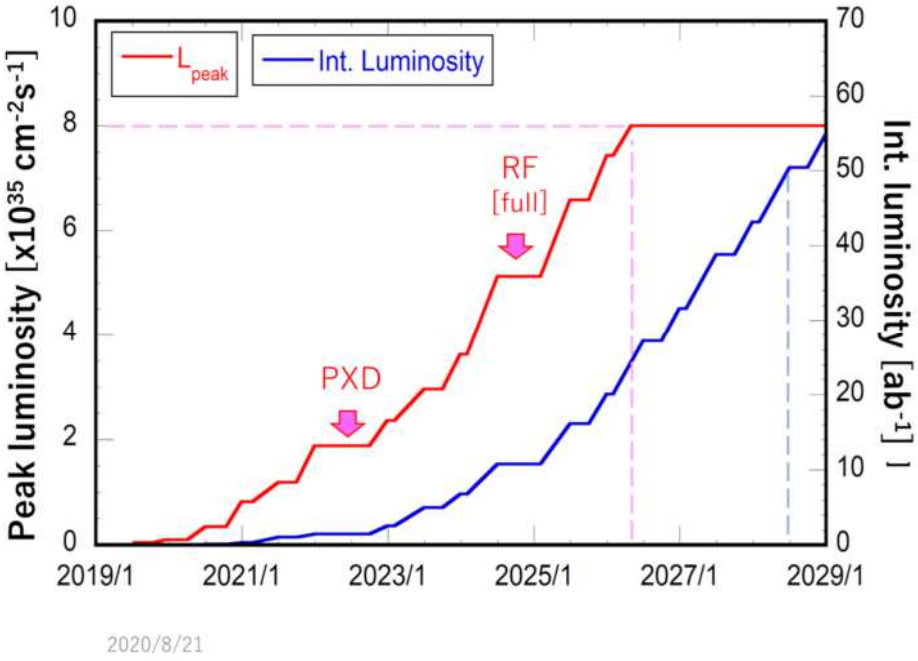
- Assumptions for revaluating luminosity projection -2
  - Specific luminosity
    - Same level to 2020b run
      - Expected to be improved gradually by ~10%?
  - Others
    - The luminosity used for the calculation of Int. Luminosity is 0.65 times of the peak luminosity, which has been assumed to be 0.7 so far.
      - Low reproducibility after run break
      - More tuning time will be required at high currents
        - Aging run before physics run, for example
      - But, no Linac study after maintenance day
        - Start physics run from night of the day
    - Physics run for 28 days per month basically. But,
      - First week after starting run has no physics run (4 days physics run between 2/16～2/28.)
      - Move to 1565 bunches from 4/1.
    - The Int. luminosity includes that during the off-resonance run.
      - ~1 week?
    - Reduction in d*P*/d*I* ~ 60% at 6000 Ah.
    - No long-term break
      - No trouble in collimators and other hardware (~1 week break in the case)
    - No intervene by COVID-19

Y. Funakoshi



Long-term operation plan

Previous plan (Revised based on the results until Phase-2) (2019)



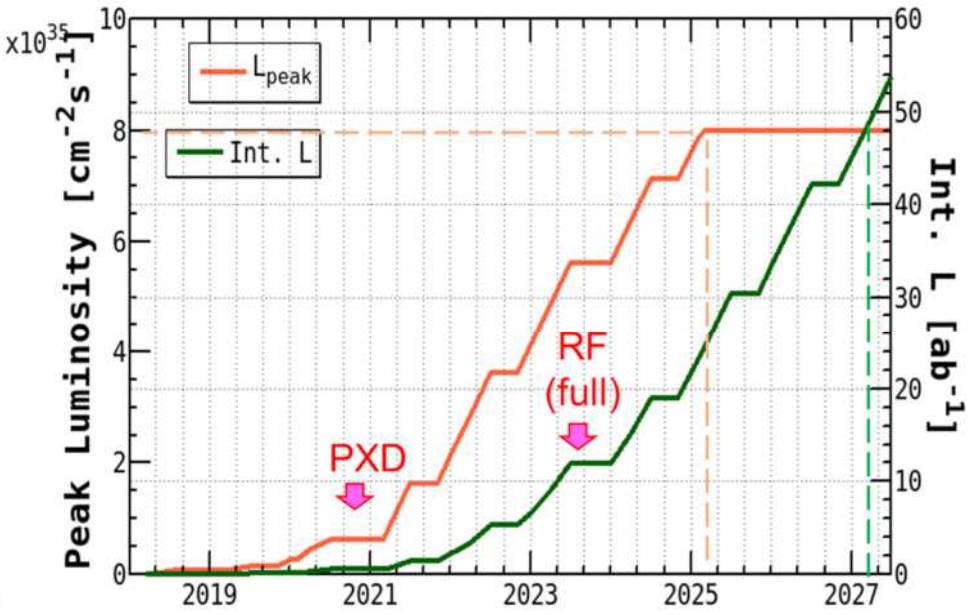
- Peak luminosity 8E35 $cm^{-2}s^{-1}$ in ~2026
- Integrated luminosity 50 ab^{-1} in ~2028
- b_y^* = 0.3 mm in 2021
- PXD exchange in 2021~2022
- RF full upgrade (4 stations) in 2024
- Max. beam currents: LER 3.6 A, HER 2.6 A (2500 bunches) in 2026
- Basically, 8 moths' operation per year.

[Investment in equipment]

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

Long-term operation plan

Original plan (~2018)



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

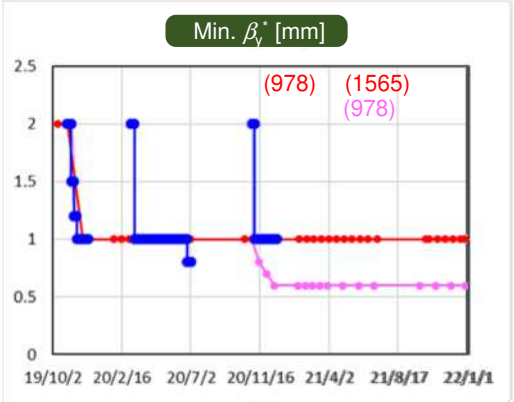
- Peak luminosity 8E35 $cm^{-2}s^{-1}$ in ~2025
- Integrated luminosity 50 ab^{-1} in ~2027
- PXD exchange in 2020~2021
- RF full upgrade (4 stations) in ~2023
- Max. beam currents: LER 3.6 A, HER 2.6 A (2500 bunches)
- Basically, 8 moths' operation per year.

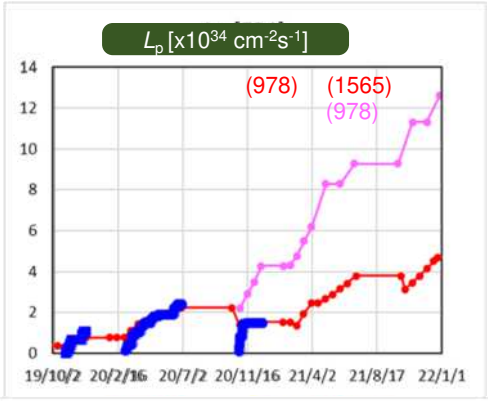
Investment in equipment

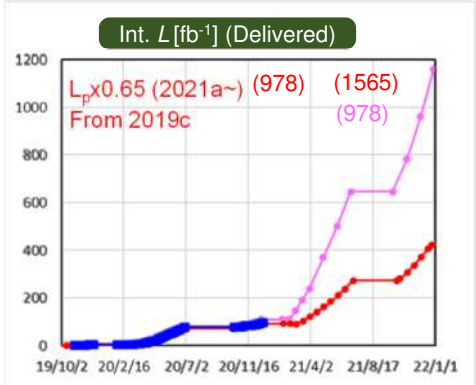
- Full-scale RF-power upgrade (4 stations)
- Beam collimator upgrade
- Linac upgrade
- Belle II upgrade

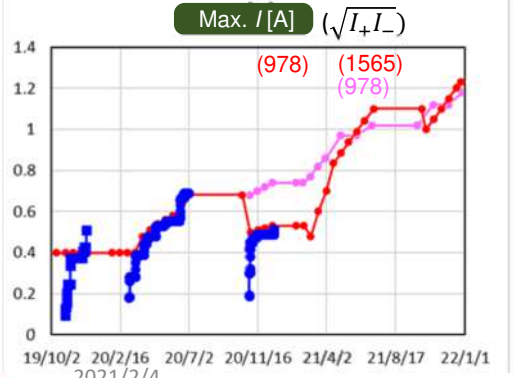
2021 and long-term operation plans

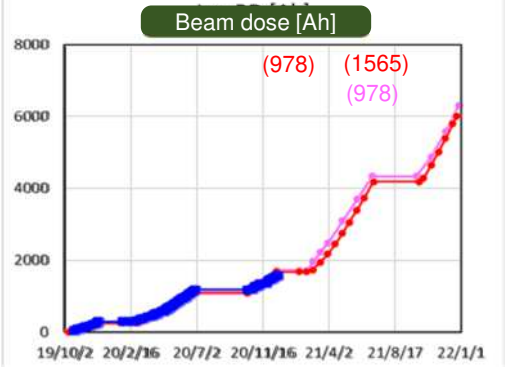
- Comparison of luminosity profiles in the revised 2021 plan and the long-term plan

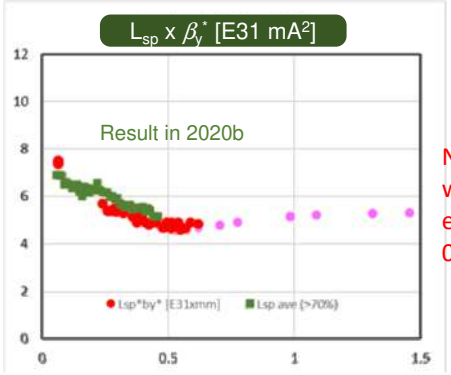












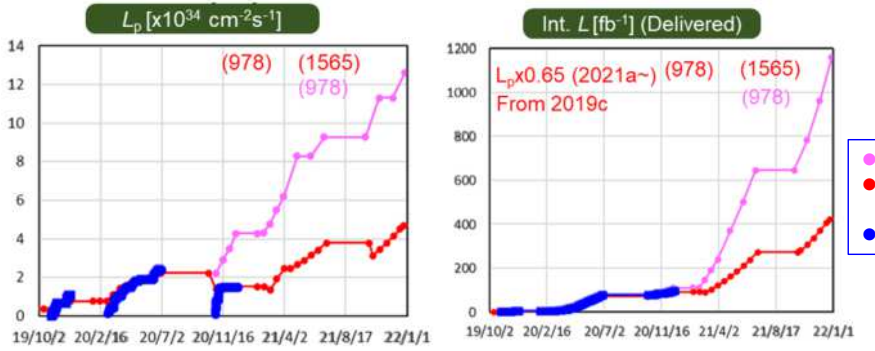
From 2019c run

- Long-term Plan
- Revised 2021 Plan (base)
- Result until 2020c

Note: Constant L_p was assumed even for $i_{b+} * i_{b-} > 0.6$ [mA^2]

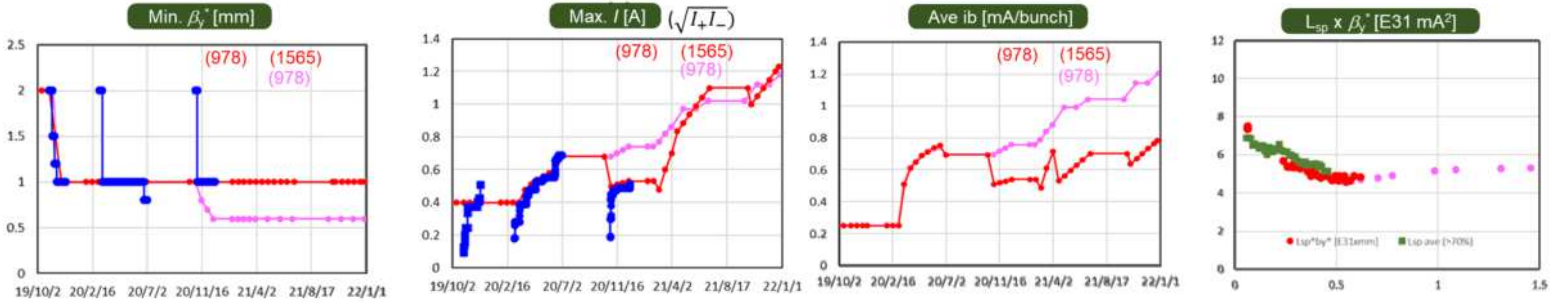
2021 and long-term operation plan

- The revised luminosity profile for 2021 runs is far from that for the present long-term one.
  - The peak and Int. luminosities at the end of 2021 are almost a half or one third of original plan.



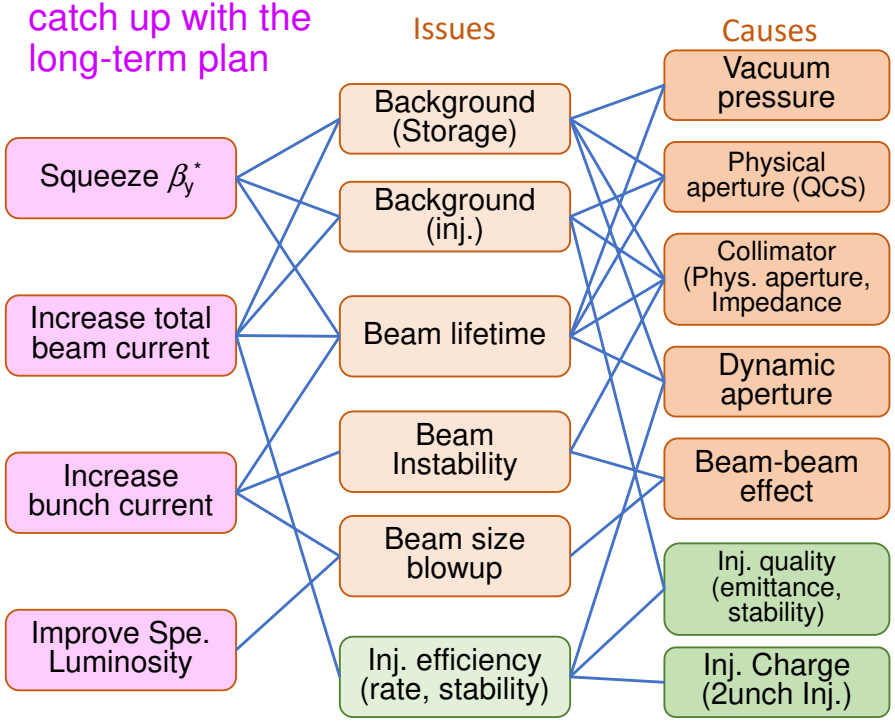
From 2019c run
- Long-term Plan
- Revised 2021 Plan (base)
- Result until 2020c

- Main Reasons:
  - Larger β_y^*
- Similar total beam current, but lower bunch current.
- The specific luminosities are almost the same.



2021 and long-term operation plan

- What to do to catch up with the long-term plan
- What to be improved
- How to improve (some possible measures)



~2021 2022~ 2026~

Vacuum scrubbing (not so drastic)

Add shielding

QCS beam pipe remodeling

Relocation, Optics optimization
Remodeling (low impedance, robust)

Rotatable Sx, Perfect match

QCS remodeling?

Understanding of the mechanism (Chromatic coupling)?
Improvement in optics measurement and correction

Understanding the reasons of low efficiency (especially on HER)
FB system in BT and Linac (orbit, energy)

Establishment of stable 2 bunch injection
Stable operation of RF gun

- Relaxation of the background limit should raise the limit of beam currents, although the actual effect should be examined in the next 2021a run.

Long-term operation plan

- Major reasons for the update:
  - Issues in the previous operation plan
    - Increase in the running cost (utility cost)
    - Challenges found in the initial operations (～2020a) ：
      (a) Strong beam-beam effects in high bunch-current region
      (b) Narrow physical aperture in the QCS
      (c) High background in Belle II
    - 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.

- Even if the design beam currents are realized 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.
- More utility cost will be required 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

Long-term operation plan

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

Long-term operation plan

- 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 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

Long-term operation plan

- BPAC Report (2020/6)
  - Based on the experience in operating SuperKEKB, the machine team has been developing ideas that could achieve the physics goal of the Belle II experiment with lower consumption of electricity . The committee understands that such an operation scenario over the next ten years was presented in the KEK submission to the MEXT Roadmap selection process, and finds this development timely and very attractive. Implementing such a plan requires an upgrade of the machine and detector. The BPAC strongly encourages a close collaboration between SuperKEKB and Belle II to further explore various ideas and conduct the necessary research and development work. Implementation of the necessary upgrade should then follow after positive evaluation of technical designs by the relevant committees. The BPAC is looking forward to hearing the progress in future meetings and strongly hopes for a positive outcome from the MEXT Roadmap selection.

Long-term operation plan

- KEKB Review Report (Long-term plan part) -1 (2020/7)
  - R7.2: Over the next year or so, perform beam measurements to determine if the proposed QCS upgrades with larger apertures are absolutely required to get to the design luminosity or, e.g., to half the design luminosity.
  - R7.6: Determine which technical studies (essential beam studies and QCS coil parameter studies) need to be carried out now, before a decision can be made, within about 2 years, on starting construction of new QCS quadrupoles.
  - R7.7: Determine the technical staffing and accelerator experts needed to construct the required hardware upgrades and examine if new technical staff will need to be trained or hired to design and execute these upgrades.
  - R7.9: Present a detailed SuperKEKB upgrade plan with underlying reasoning and data at the next ARC meeting.

Long-term operation plan

- KEKB Review Report (Long-term plan part) -2 (2020/7)
  - R7.8: Evaluate a backup plan to simply increase the luminosity with the existing hardware to about 2-3x10^{35} $cm^{-2}s^{-1}$ (with small upgrades but without major upgrades and the associated long installation downtimes and serious recommissioning) and then integrate luminosity for about 10-12 years at 7-8 months per year to obtain an integrated luminosity of 50 ab^{-1} by 2032-2034.
  - Detailed long-term upgrade plans should be finally decided once full performance with those upgrades is predicted within a quantitative performance model. This makes sure that the long-term quadrupole aperture is chosen wide enough, background sources and paths are understood, lower beam lifetime can be handled, impedance stays under control, and the collimator system is adequate.

Long-term operation plan meeting

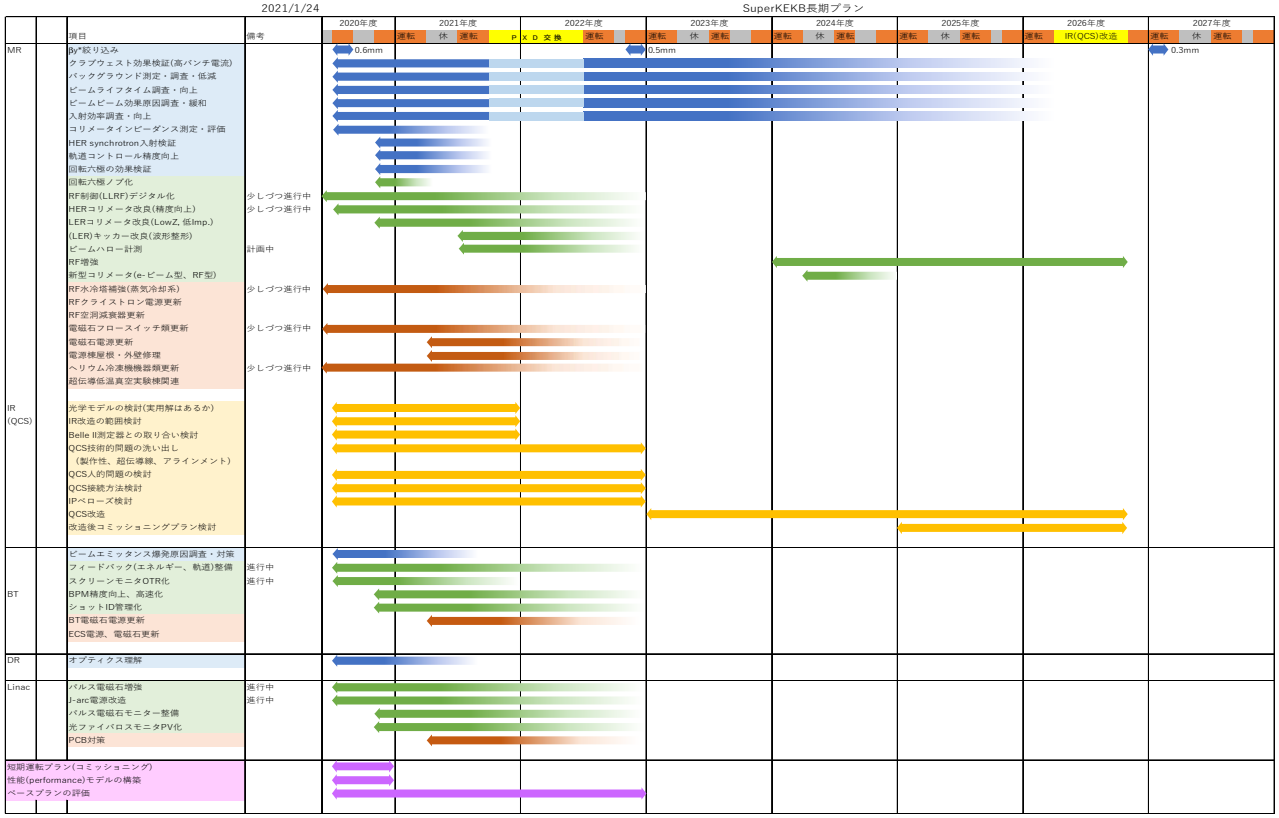
- Four meetings have been held so far (~2021/2/4)
- The first meeting on 2020/8/21
  - The process so far [Y. Suetsugu]
  - Present status of QCS update project [N. Ohuchi]
  - Future plan of this meeting [H. Koiso, Chair]
- The second meeting on 2020/9/3
  - Summary of the first meeting [H. Koiso]
  - Examination status of the optics for QCS upgrade [A. Morita]
  - Crab waist, dynamic aperture and beam lifetime [K. Oide]
- The third meeting on 2020/9/26
  - Effect of IR Model V-20-20A (large physical aperture in QC1) on the beam optics [H. Sugimoto]
  - Examination of QC0P (Permanent magnet) [A. Morita]
  - Luminosity and lifetime (update) [K. Oide]
  - Effect of the enlarged physical aperture in QC1P on MDI mechanical design and background [H. Nakayama]
  - On flange at the top of QCS cryostat [N. Ohuchi]
  - Dependence of the injection efficiency on β_y^* [Y. Funakoshi]

Long-term operation plan meeting

- The fourth meeting on 2021/1/22
  - Progress report on QCS of upgrade project [N. Ohuchi]
  - LER dynamic aperture and luminosity (update) [K. Oide]
  - Status, issues and future plan of BT and Linac from the view point of beam commissioning [N. Iida]
  - Middle and long-term outlook on injection efficiency and luminosity [Y. Funakoshi]
- The fifth meeting on 2021/2/17 (planned)
  - Long-term strategy of BT [M. Tawada]
  - Long-term strategy of Linac [K. Furukawa]
  - Long-term strategy of beam collimators [T. Ishibashi and S. Terui]

- We have been also discussing about IR upgrade on other meetings, such as IR technical meeting (hosted by N. Ohuchi) and MDI meeting (hosted by H. Nakayama).

Overall schedule



Parameters

Parameters		LER/HER	LER/HER	LER/HER	LER/HER
β_x^*	mm	60 / 60			
β_y^*	mm	1/1	0.8/0.8	0.6/0.6	0.3/0.3
N	10^{10}	16.1/11.6	20.9/15.1	18.3/13.1	15.0/10.8
N_b		978	750	860	1050
I	A	2.5 / 1.8			
ε_x	nm	~4.5 / 4.5			
$\varepsilon_y/\varepsilon_x$	%	1	2		
σ_z	mm	5.0 / 5.0			
σ_δ	10^{-4}	7.7 / 6.3			
CW ratio	%	80/			
τ_T	sec	137	101	101	52
ξ_y [a]		0.154/0.122	0.129/0.102	0.098/0.082	0.066/0.055
$\mathcal{L}_0$	nb/s	314	319	314	318
$\mathcal{L}$	nb/s	~ 250	~ 250	~ 310	~ 310

[a] incl. hour glass

- The luminosity lifetime due to rad. Bhabha is much longer (~1200 sec) than above.
- CW=60% is used in some cases,
- The bunch length above may be too optimistic, if the microwave instability matters.