The Twenty-Eighth KEKB Accelerator Review Committee Report

February 26, 2025

Introduction

The Twenty-Eighth KEKB Accelerator Review Committee meeting was held on 14-16 January 2025. Appendix A shows the present membership of the Committee. 13 committee members attended the 28th meeting in person, and 2 others on zoom. The meeting was held in hybrid mode and featured two days of oral presentations by KEKB staff members, plus discussions between the Committee members, and a final half a day for another executive session, report drafting, and close-out.

The agenda for the meeting is shown in Appendix B. The slides of the presentations are available at **http://www-kekb.kek.jp/MAC/2025/** .

During its 28th meeting, the Committee has examined the progress of the collider operation through the end of run 2024c, the present challenges, the near-term plans and the longer-term upgrade strategy. As always, the high standard of the presentations impressed the Committee.

As highlighted in previous reports, the next generation is important for the success of the SuperKEKB operation over the coming decades. The ARC is pleased that the overall staffing situation for the SuperKEKB Accelerator appears stabilized, with approximately as many new recruitments as retirees, and a small but growing number of PhD students. The Committee would like to stress that the knowledge transfer from experienced staff and senior fellows to the new recruits is important in preparing for the future. The future success of the project will also require an increase in personnel to take on new challenges.

The most important recommendations of the Committee were presented to the SuperKEKB staff members, some Belle II physicists, and the KEK Accelerator Laboratory director before the close of the meeting. The Committee wrote a draft report during the meeting that was then improved and finalized by e-mail among the Committee members. The report is available at **http://www-kekb.kek.jp/MAC/2025/** .

Contents

A) Executive Summary

SuperKEKB successfully resumed operation in mid fall through the end of 2024. The emphasis of the run was in increasing the beam currents and luminosity. The ARC congratulates the SuperKEKB team on achieving a new world record luminosity of 5.1×10^{34} $cm^{-2}s^{-1}$. The β_y^* was kept at 1 mm, the β_x^* in LER reduced from 80 to 60 mm, while the beam currents were increased up to 1354 mA and 1699 mA for the HER and LER, respectively. The beam-beam tune shifts of about 0.03 remain 2-3 times lower than at the former KEKB.

In 2024, SuperKEKB operated with a nonlinear collimator. This was another world's first. The NLC improves the detector background. The new luminosity record was, however, achieved while the nonlinear collimation system was switched off, which might have been coincidental.

One new strong candidate cause for the sudden beam loss events has been identified, namely the vacuum sealant (VacSeal) intruding onto the inside of the vacuum chamber, where it is exposed to synchrotron radiation and to potentially high temperature.

During the early commissioning of the 2024c run, the minimum vertical emittance in the HER increased from 20 pm to a value above 50 pm, and stayed at that level even without collision and at low current. At the same time strong high order synchro-betatron resonances were observed in the tune scans, without collisions. Optics corrections could not recover the small vertical emittance, not even with a "relaxed" optics. The vertical emittance in the LER also increased by a factor of 2 from the 2024ab to the 2024c run.

Injection efficiency is a concern. It is worse than expected from the measured dynamic aperture and injected beam emittance, indicating that the phase-space distribution of the injected beam matters. At the record luminosity, the injection exactly balanced the losses.

The ARC reiterates that the SuperKEKB accelerator is a frontier machine and a world leader in Accelerator Technology, with ambitious goals for high peak and integrated luminosity. This accelerator is led by a highly dedicated group of experts who have encountered and overcome numerous technical obstacles, and who are encountering new issues as they approach the ultimate accelerator design goals. The achievements accomplished by this team and the KEK laboratory are already being incorporated into various future collider designs and the worldwide accelerator community is carefully watching the impressive progress of this very exciting enterprise.

The ARC has formulated recommendations on how to address the above issues, as well as various others, and supports the ambitious luminosity goals for the coming years and beyond.

B) Key Recommendations

Recommendations: The Committee has made recommendations throughout the different sections below. The most significant of these recommendations and a few more general recommendations are summarized here:

1. Consider the possibility to reconnect the BPMs, which were isolated in 2024, to the adjacent quadrupoles, and try to stabilize the quadrupole position by mechanical means. (R4.2)
2. Address the problem of emittance growth in the linac with a more systematic strategy, particularly for the electron beam, so as to identify and mitigate the causes of emittance growth. (R6.1)
   Identify sources of trajectory/orbit offset and jitter in the linac. (R8.1)
3. Continue the investigation of the sudden beam loss events ("SBL's") until one or more physical reasons and mechanisms have been found and verified beyond doubt. The model should explain why the LER has consistently experienced 5-7 times more SBL events than the HER, while both electrons and positrons are experiencing such SBL's. (R11.2)
4. Develop a set of accelerator conditions at which time Belle II can restore the use of the PXD during beam collisions. (R5.3)
5. Refrain from using VacSeal to leak tight flanges, particularly for those in direct view of the beam path. Define acceptable leak rates compatible with short term operation in a way to defer the vacuum intervention for repair during shutdown. Consider a temporary fix using clamshell-like tools to achieve primary vacuum around an identified leak. (R12.3)
6. Identify the flanges subjected to non-uniform synchrotron radiation heat load exposure and monitor their temperature to anticipate the risk of leak opening. (R12.2)
   For the actual wiggler sections carry out, and present, a modeling of synchrotron power impact and the resulting thermal gradients and temperatures. What is the power load and what is the asymmetry around the pipe both for LER and HER wiggler sections? What are the differences between HER and LER in the wiggler sections? Estimate the impact of having removed the wigglers in the LER OHO section on the local synchrotron loss patterns. (R11.1)
7. Carry out a systematic measurement of the tune shift along the LER bunch train. (R.1.1)
   Compare the bunch-by-bunch lifetime measured in the LER with this tune shift along the bunch train (R10.1)
8. Explore, by simulation, the possibility to shape the incoming beam phase space by using one or more non-linear magnets, such as octupoles, installed at a proper phase advance in the BT lines. (R10.7)
9. Consider local water cooling at the heat source for the power supplies instead of global air conditioning of the entire building(s). (R15.1)
10. Perform beam-beam simulations with the inferred residual linear coupling at the interaction point. Also, consider the lattice with vertical tilt angle of the detector (as presented by Oide san) to determine how such misalignment might affect the luminosity performance. (R20.8, R20.9)

11. Noting that the new and displaced envelope of the QCS will have an impact on the layout of the detector, possibly affecting the detector efficiency, ensure that the net gain in performance is worthwhile (R22.1).
12. Before embarking on the manufacture of tooling, study the possibility and implications of using a two-layer coil, and compare the manufacturing, cost and performance issues with those associated with the single layer coil design shown in the presentation. (R22.2)

C) Findings, Comments, Recommendations

1. Welcome

Findings & comments:

On 27 December 2024 SuperKEKB achieved a new world-record peak luminosity of 5.1x1034 cm-2s-1. This value, however, falls short of the 2024 target luminosity of >1035 cm-2s-1 and of the final target luminosity for after LS1 of 2.4x1035 cm-2s-1. It is planned to further increase the SuperKEKB luminosity towards the target values by: 1) Increasing total beam currents; 2) increasing the bunch currents; and 3) squeezing βy. Basic problems are: 1) Short beam lifetime; 2) Sudden Beam Loss events; 3) Low machine stability; and 4) Low injection efficiency. For the sudden beam loss events, a new candidate cause has been identified: Vacuum sealant inside the vacuum chamber. This is aggravated by extremely high synchrotron radiation levels. The collaboration between SuperKEKB and Belle II is ongoing and getting stronger. The elevated electricity cost remains a major concern. The big questions are how to achieve 1) current, 2) injection, and 3) squeeze. The drop of specific luminosity with current requires further investigation and mitigation.

Recommendations:

R1.1: Simulate the synchrotron radiation fans and impact points in wiggler and IR regions.

R1.2: Compare the synchrotron radiation level and local intensity at the chamber wall in the SuperKEKB wiggler section and Interaction Region with the synchrotron radiation levels at other facilities, like PEP-II, PETRA III, ESRF-EBS, and DAFNE.

R1.3: Explore or confirm if the drop in specific luminosity can be explained by the effect of space charge and/or determine which level of various optics aberrations would be consistent with the observation.

2. Status of Accelerator Laboratory

Findings & comments:

The Charge of this ARC meeting are: (1) Review and provide advice on beam operation, overall performance of the SuperKEKB accelerator including the linac. And (2) provide advices on the plans for the near future and LS2. The term of ARC membership is three years, JFY2022-2024. It is proposed to extend all ARC members for the next 3 year period, unless an ARC member asks to be replaced.

The Accelerator Laboratory consists of 6 Divisions and iCASA. Divisions III and IV are responsible for SuperKEKB and the Division V for the injector linacs. Together, these three divisions have a total of about 90 staff (roughly 30 each.). One new technical staff was hired in November 2024. One academic and two technical staff members will be newly employed from the beginning JFY2025. One graduate student joined in August 2024. Two academic and two technical staff will retire at the end of JFY2024, but will continue to be employed as Senior Fellows. The KEK Accelerator Laboratory has 66 technicians in total. SuperKEKB is also supported by about 40 company staff.

The ARC is pleased that the overall staffing situation for the SuperKEB Accelerator appears stabilized.

Shoji Uno (Professor of IPNS) has been appointed as new liaison of SuperKEKB and Belle II since October 2024. Some of Belle II members continue to contribute to accelerator operation and to investigate SBL and other accelerator issues together with the SuperKEKB team. The international collaboration with CERN, IHEP, etc. has been strengthened.

J-PARC is operating very successfully, and its performance is further improving. The J-PARC RCS delivers 1 MW in beam operation since April 2024. MR-FX runs at 810 kW (2.3 x10^{14} ppp), which is the world highest extracted ppp for physics experiments. The MR-SX achieves 81 kW (7.2x10^{13} ppp) with the world’s highest extraction efficiency of 99.6 %. The Tsukuba electron/positron beam campus includes the PF and PF-AR light sources. Their availability is ~ 99 % with ~3,000 users/year. iCASA includes ATF, STF, cERL, CFF and COI.

The ARC commends the outstanding and further improving performance of the J-PARC complex.

Recommendations:

None

3. Summary of 2024 Runs

Findings & comments:

The three beam runs in 2024 (a, b, c) for SuperKEKB started with three possible beam parameter sets characterized as "Plans A", "B", and "C" with luminosity goals from 8 to 10 x10^{34} $cm^{-2}s^{-1}$ using β_y^* from 1.0 to 0.8 mm. The final result was a very successful achievement, on December 27, 2024, of a new world-record luminosity of 5.1 x10^{34} $cm^{-2}s^{-1}$ using β_x^* of 60 mm, β_y^* of 1 mm, I_{LER} of 1.63 A, I_{HER} of 1.26 A, and n_b of 2346. The Belle II detector was not taking data at this moment.

The focus of runs 2024a and b was reducing β_y^*. The focus of the most recent beam run 2024c was on high current operation.

Many beam studies were carried out during the three short beam runs to increase the beam currents, increase the luminosity, to reduce detector backgrounds, to improve injection, as well as to provide adequate integrated luminosity to Belle II. During these beam runs, several accelerator issues were observed that affected achieving higher luminosity, which are discussed here.

Recently a β_y^* of 1 mm has been used for operations. Values of β_y^* of 0.9 mm and 0.8 mm have been tried, but are associated with background and injection concerns, so that, for now, these would provide less integrated luminosity. A β_y^* of 0.3 mm is the final goal.

The CW in HER was increased from 40% to 60% without any difference in dynamic aperture.

The goals for beam currents are about a factor of two above the present values to reach the ultimate luminosity. To accomplish these higher currents, beam lifetimes need to be improved, injection made more efficient, more RF stations added, Sudden Beam Losses (SBLs) reduced and controlled, and higher backgrounds managed.

As stated, the Sudden Beam Losses (SBL) need to be reduced further and controlled. These losses occur over two to three ring turns with no (or very little) beam centroid motion but substantial vertical enlargement. SBL can cause large backgrounds, radiation damage to Belle II, damage to collimators, and IR SC magnet quenches. The vertical enlargement is likely due to "dust particles' (~50-200 μm size) entering (falling into) the beam from the various vacuum chambers around the ring. Efforts have been successful in identifying several sources of in-vacuum particles, such as, collimators, ceramic-electrode chambers, grooved aluminum chambers, and VacSeal contamination.

VacSeal exposure to synchrotron radiation in the wigglers and interaction regions is perhaps a source of the Sudden Beam Loss (SBL) events. The combination of "MO flanges" with VacSeal was used only in SuperKEKB, and this could be part of the reason why this effect has been observed only at SuperKEKB.

Injection of both beams has been inefficient in the past. Fortunately, solid gains have been made to improve injection through work on the linac, damping ring, and transport lines, but more remains to be done. The two injected bunches have slightly different parameters.

There is a tune shift change along the bunch trains in the LER, possibly related to the longitudinal transients near the abort gaps or to residual electron-cloud build up. This tune shift along the LER train, with a lower tune at the head of the train would be unusual for a standard impedance, but, indeed, it is a typical signature of the electron cloud effect. Efforts to improve the consequences of the tune shift are underway. The team is also trying to understand the source of this effect.

In Run 2024c the vertical emittance of the HER degraded by about a factor of two consistently, after about 2 weeks of scrubbing. Studies to find the cause are ongoing. There is some evidence that this is related to stronger synchrotron-betatron resonances.

The new non-linear collimators (sextupoles) used to reduce backgrounds are working, but require the beam to be placed with an accuracy of about 10 μm inside these sextupoles. This requires special orbit control, as the orbit shifts with increasing beam current, due to chamber heating from synchrotron radiation and higher-order modes (HOMs).

In the HER, at high current, local synchrotron radiation causes heating which moves the vacuum chamber with attached beam position monitors (BPM), causing global beam orbit shifts. The orbit is particularly sensitive at the strong sextupoles near the IP, used for crab waist corrections. As a result of the orbit changes, the beam quality is degraded.

During collisions at high beam currents the beam-beam effect increases the emittance of both beams. At low currents the specific luminosity closely matches the value expected from computer simulations. By contrast, during operation at higher current, the luminosity observed is about half the prediction. Active investigations are underway. The cause(s) could be stronger synchrotron-betatron resonances, changes in the IR optics due to high-current orbits changes, the limited quality of IP luminosity tuning, single beam emittance blow up, choice of the betatron tune, tune changes along the bunch trains, or perhaps others. A recent success was a deliberate change of β_x^* in the LER from 80 cm to 60 cm which helped obtain the new luminosity record.

Recommendations:

R3.1: Carry out a systematic measurement of the tune shift along the LER bunch train, and determine if the tune of the early bunches is shifted onto a harmful resonance.

R3.2: Determine if the LER RF gap transients can be adjusted using LLRF and longitudinal feedback to perhaps improve the tune variation along the bunch train to improve the lifetime of the head of the train.

R3.3: Continue work on reducing the orbit changes in the IR from vacuum chamber distortions caused by heating by the HER beam current.

R3.4: Continue the study of the vertical emittance growth in the LER with higher beam current.

R3.5: Recheck if there is any ECI effect in LER leading to adverse effects along the bunch train. Clarify if the observed tune shift could not be caused by electron cloud.

R3.6: The ARC committee suggests studying the “SBL-like near-misses”, where a smaller scale vacuum burst does not trip the accelerator but could provide valuable data on the location of the source of SBL events.

4. Ring Optics Issues

Findings & comments:

There were some optics changes in the collider such as: LER IP β_x^* reduction from 80 to 60 mm, LER injection point β_x^* increase from 100 to 160 m and reduction of β_x^* at the non-linear collimation sextupoles to improve background.

IP β_y^*=0.8 mm was not tried in 2024, due to higher priority assigned to SBL and intensity studies.

One very significant change in the machine configuration is the isolation of some BPMs from quadrupoles. This was done to avoid unwanted movements of yeh quadrupoles when the vacuum chamber heats up. Nevertheless, this decouples the BPM center from the quadrupole magnetic center, which may complicate orbit control with respect to the magnet.

A critical observation in the 2024c run, not seen in the 2024a and b runs, is that the HER vertical emittance increased from 20 pm to 50-100 pm after two weeks of vacuum conditioning. This problem appeared during or after scrubbing at high intensity when the vacuum chamber heated up. Many mitigation measures were tried: magnet initialization, IP orbit angle tuning, rollback of magnet settings, orbit cleaning, optics corrections and going back to a relaxed optics. In particular, during the orbit cleaning, closed orbit deviations and orbit corrector strengths were reduced, slightly improving emittance. Yet, the emittance did not reach the 2024a/b run value or the value from the start of the 2024c tun. Even with relaxed optics (large β_y^*) the emittance was still 40-50 pm or higher (compared to 20 pm earlier).

Scanning vertical emittance versus vertical tune revealed large synchro-betatron resonances along with a high baseline value above 50 pm. Simulations neither predict one of the resonances nor their width.

A beta-beating correction performed in December 2024 improved the luminosity performance significantly. The single-beam emittance was not studied at that moment, but the measured beam sizes in collision were improved, corresponding to higher luminosity and specific luminosity. It is possible that this beta-beating correction also improved the HER single-beam vertical emittance.

The Quad-to-BPM alignment of the Quads isolated from the BPMs was not checked. This is another candidate for a source for emittance growth as Quad magnetic centers could have drifted from the nearby BPMs.

Some manufacturing errors exist in the skew sextupole and octupole cancel coils of the IR region. These errors are expected to generate significant amplitude detuning. Measurements of amplitude detuning, however, do not match the model predictions for the expected errors. Skew sextupoles could be used to change the amplitude detuning; yet the best value was obtained with the nominal settings.

In general, the nonlinear optics model for the SuperKEKB interaction region is not realistic and requires an update. The magnet team is providing new magnetic field descriptions as input.

Recommendations

R4.1: Devote time to recovering the small vertical emittance in the HER.

R4.2: Consider the possibility to reconnect the BPMs which were isolated in 2024 to the adjacent quadrupoles, and stabilize the quadrupole position by mechanical means.

R4.3: Develop efficient tools for the robust measurement of coupling and amplitude detuning. Turn-by-turn data techniques have been demonstrated to be very efficient for coupling measurement including with beam-beam collisions (e.g. at the LHC). Adequate BPM turn-by-turn measurement accuracy, and using BPM pairs with about pi/2 phase advance to construct the complex signal and remove calibration errors would be very important, as is reported e.g. in https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.17.051004. LHC tools with GUI are already working for the SuperKEKB data and have been used by the CERN and CEA collaborators.

R4.4: At the start of the next run, a thorough optics commissioning should be performed to avoid that better optics corrections are found later in the run.

R4.5: Continue with the implementation of the nonlinear IR optics model.

R4.6: Compare readout from temperature probes along HER before and after beam scrubbing, after which the vertical emittance growth was observed. This might help to sort out faulty elements if any, such as bellows for instance, which might be inspected.

5. Belle II status

Findings & comments:

The Belle II collaboration has collected over 500 fb^{-1} of integrated luminosity and has taken data when the accelerator was delivering up to $4.7x10^{34}$ peak luminosity. This is a rate of more than 2 fb^{-1} per day. The Belle II data collection efficiency is in the range of 85 to 90%.

The Belle II detector collaboration has worked very hard to get as much physics as it can from the delivered integrated luminosity. This includes using the dataset from Belle I whenever the added statistics can improve the result. In addition, The Belle I dataset has, in some cases, been enhanced through the use of some of the improved analysis tools developed for Belle II. The team has also used LS1 and the summer downtimes to improve the robustness of the detector hardware against machine backgrounds. The Data AcQuisition system has also been improved and the efficiency of the DAQ and detector on-time is approaching the desired level of 90%. Injection backgrounds are still significant and represent an appreciable fraction of the total beam aborts induced by the detector.

Last May 2024 it was decided to turn off the PXD vertex detector. This detector consists of two layers of pixels located next to the inner Be beampipe at the center of the detector. The PXD experienced two Sudden Beam Loss (SBL) events that noticeably damaged some parts of the PXD. The overall damage is currently low (a few %) but it is very difficult to replace parts of the PXD. The collaboration has noticed a high correlation between SBL events that quench the local QCS magnets and those that produce high radiation levels in the PXD when the PXD was on. So, while the PXD is turned off, the collaboration is monitoring the QCS quench rate as a measure of the SBL events that might have damaged the PXD.

The detector collaboration has significantly contributed to improving the detection of beam instabilities and in speeding up the abort system as well as to identifying particular injection bunches that produce higher backgrounds in the detector.

Recommendations:

R5.1: Continue the great collaborative effort of Belle II with the accelerator team in tracking down and identifying the sources of the SBLs and reducing injection-related backgrounds.

R5.2: Continue to jointly work on shortening the time between identifying an unstable beam and initiating an abort signal.

R5.3: Develop a set of accelerator conditions at which time Belle II can restore the use of the PXD during beam collisions.

6. Injector Status (1)

Findings & comments:

Simultaneous top-up injection for four rings has been conducted successfully at a repetition rate of 50 Hz, marking a significant operational achievement. Over the past three years, the injector's availability has consistently exceeded 98%, showcasing remarkable reliability. However, most of the injector failures are due to breakdown events in the RF gun. To address this issue and ensure more stable electron beam operation, a new RF gun is under development. This upgrade is expected to provide (even) stabler electron beam operation, thereby minimizing injector failures and improving overall system performance.

The electron beam has exhibited a satisfactory performance, with the laser system and its position feedback functioning without notable issues. A stable bunch charge of 2 nC has been delivered to the BT end, supported by bunch charge feedback, although this charge is still under the specification of 4 nC. The primary limitation in achieving higher charges is the degradation of beam quality at increased charge levels. For example, the emittances in both X and Y planes for the two bunches consistently exceed the specified values. In addition, the reproducibility of the beam quality remains a challenge. Expanding machine learning-based automatic beam tuning and leveraging big data analysis could mitigate these issues.

The positron beam generation system, including the flux concentrator, power supply, and DC solenoid, has performed reliably. Machine learning-based automatic tuning has successfully increased the positron bunch charge to 4.2 nC at the linac end, surpassing the design goal of 4 nC. However, the damping ring's stored current is limited to 35 mA due to radiation losses, a limitation that should be removed in the next operational run. Despite the advances, the horizontal emittance in the transport line remains well above 100 mm mrad, presenting an ongoing challenge.

Significant progress has been made in infrastructure and technology upgrades. A three-year plan (2023–2025) for the production of S-band structures to replace the oldest RF structures in the linac is advancing smoothly. The availability of pulsed magnet controllers has been substantially improved by moving to a Linux-OS/EPICS IOC-based system. Additional developments include enhancements to the fast kicker to control the second bunch, a beam diagnostics line with pulsed magnets, beam tuning programs, big data analysis, and the HER BT energy compression system (ECS) to remove the residual energy chirp from the linac. These upgrades aim at enhancing beam operation quality and reproducibility. The adoption of machine learning technologies is expected to further improve beam quality and operational efficiency.

Recommendations:

R6.1: Adopt a systematic approach to controlling linac emittance growth. That is, address the problem of emittance growth in the linac with a more systematic strategy, particularly for the electron beam. This should include in-depth analysis and targeted solutions to mitigate emittance growth in the different parts of the injector, identifying the causes of emittance growth and then developing models to be used in simulations. As mentioned in the slides, the use of advanced tools such as machine learning, big data analysis and refined beam-tuning techniques could play a key role in achieving this goal.

7. Injector Status (2)

Findings & comments:

The KEK injector complex supports several beams for the photon factory as well as for SuperKEKB. The SuperKEKB electron beams originate from a Laser system and RF gun with photocathode while the electrons used for positron production come from a thermionic source. The various laser systems are state of the art and comprise fiber oscillators, fiber amplifiers, and Nd:YAG amplifiers. The laser systems incorporate wavelength conversion and spatial shaping, with transfer optics to deliver two pulsed laser fields to the RF gun cathode. The history of this system is long, and the sophisticated development and laser complex performance is key to the success of SuperKEKB.

In 2024, the DOE (Diffractive Optical Element) has worked well without any significant trouble. The Ir_7Ce_2 cathode is being used with an infinite lifetime and without contamination or pollution issues because it does not require any evaporation. The QE is high enough (10^{-4}) at room temperature. The cathode is inactive in air and can recover by heating or laser cleaning. The Ir_7Ce_2 cathode is the best choice for long time operation at high charge of 5 nC for SuperKEKB. The two-laser beam injection, in both directions, with inclined laser irradiation, leads to a better emittance and increases the QE by more than a factor of 2.

DOE for laser beam homogenizer (spatial shaping) was adopted for the low emittance beam at high intensity. A new large-area DOE (fully covering the 8 mm cathode area) was installed in January 2024. The bunch charge was increased to 6 nC out-put from RF-Gun and 4 nC at the LINAC end.

Emittance from the gun is below 50 μm for horizontal plane and below 100 μm for vertical plane at 5.25 nC charge. But the emittance increased to over 150 μm along to the BT section for a charge of over 4 nC. The emittance along to the BT section is kept below 50 μm for 3 nC.

After serious discharge at the RF-gun, the gun klystron power was reduced from 14 MW to 9 MW in November 2024. The operating power level has not been fully recovered, resulting in low voltage operation. The 2 nC operation has been restored with the reduced voltage. The emittance at the B sector is below 50 μm even with the low voltage operation. However, the emittance increased up to 100 μm along the BT and the variation of emittance is becoming large. The frequent variation of emittance is similar to the amplification of fluctuation of beam parameters, such as beam position and angles.

The current RF-Gun cathode cell was designed with a choke structure to allow cathode thermal cleaning. The choke structure may introduce discharge because of a high surface field of ∼ 0.7Emax and causes a high dark current. A new QTWSC RF-Gun is under preparation. The QTWSC (Quasi Travelling Wave Side Couple) design provides a strong focusing electric field with a short drift space. The new RF-gun has an optimized electric field E∼0.4Emax at the cathode plug to reduce the surface field. The simulation result for the new gun with a triplet shows an emittance of 7 mm mrad. The new gun also allows a higher voltage to avoid cathode plug discharge and lower dark current.

The issue of RF-gun laser window degradation was investigated. A vacuum ion pump was installed between the laser window and the RF gun cavity with an extension vacuum duct for the 1st line laser in the summer maintenance of 2022. The installed ion pump did mitigate the laser window degradation according to the operation data.

An X-band linearizer cavity to reduce non-linear energy distribution is proposed and under design. However, there was no explanation or backup slide to motivate this second cavity system, to show how useful it would be, and the resulting improvement in the beam produced.

Recommendations:

R7.1: The emittance increase and its variation along the J-arc to the BT become substantial even at a charge of 2 nC. J-arc and/or the other parts may act as an amplifier of the fluctuations from the gun. Perform a start-to-end simulation with jitter sources to determine the requirements for the RF-gun and the other parts like J-arc in order to mitigate the emittance variation.

R7.2: Perform beam dynamics simulations including the longitudinal and transverse wake field in the RF gun area and compare the results with actual measurements in sectors A and B.

8. Injector Upgrade Plan

Findings & comments:

The injector upgrade plan encompasses several critical advancements aimed at enhancing beam stability, diagnostics, and overall performance.

A fast kicker system has been developed to correct the trajectory of the second bunch. Achieving identical injection efficiency for the first and second bunches requires the same beam orbits, which already differ after the electron RF gun. The displacement and trajectory jitter of the second bunch were measured at the linac end in beam tests with the kicker. These tests confirmed that the second bunch could be stably controlled. The installation of fast kickers will proceed where necessary. Additionally, the kickers are used as separators for measuring the two bunches simultaneously on the same screen.

A beam diagnostics line with pulsed magnets has been introduced to periodically (at rates of ≤ 1 Hz) direct the beam to the dump line for diagnostics, even during HER injection. The diagnostic line is utilized for tasks such as analyzing the beam during injection into HER, diagnosing bunch length through energy chirp applied by accelerating structures, and conducting test experiments using the beam dump. The strategy is to use this diagnostic line on a full scale for the operational runs in 2025.

Beam tuning programs employing machine learning, specifically Bayesian optimization, have been developed and are actually improving the beam performance. These programs have demonstrated significant benefits, such as achieving the highest positron beam transmission rate to date and enabling emittance reduction in the BT for the electron beam, while performing non-destructive monitoring. Continuous efforts are being made to refine these tuning programs. Systems are being implemented to monitor their correct functioning and ensure they do not interfere with other tuning or feedback processes. The development of these programs also requires identifying parameters that significantly impact beam emittance, stability, or in general beam quality and reproducibility.

Big data analysis has also advanced, with synchronized data output from the injector to the ring. This feature enables detailed analysis and exploration of key parameters, exploiting machine learning to improve operations.

One strategy to increase the electron beam current and injection efficiency will be to reduce the residual energy spread from the linac. For this scope an energy compressor system is under development, with construction and installation in HER BT progressing smoothly. This system is critical to reduce the residual energy spread from the linac and will help achieve the desired increase of the electron bunch charge.

Recommendations:

R8.1: Identify sources of trajectory/orbit offset and jitter in the linac. While using fast kickers to correct the orbit of the second bunch, it is also essential to identify the sources of the trajectory/orbit offset and jitter. This can be achieved by exploiting the beam synchronous data feature in the injector to perform correlation analysis. Understanding these sources of jitter will allow targeted solutions to reduce jitter at the origin, improving overall beam stability.

R8.2: Minimization of emittance in the HER BT was successfully done only in the horizontal plane by utilizing the beam tuning programs with machine learning. Investigate why the beam tuning failed for the vertical plane.

R8.3: Analyze optimization results to identify key parameters. A detailed analysis of the results of machine learning-based optimizations to improve beam performance is recommended. This analysis should focus on identifying the most critical parameters involved in the optimization process and compare them with those used in manual tuning methods.

9. Beam Transport Line

Findings & comments:

The beam transport line has seen significant advancements and refinements, focusing on improving the ring injector kickers, diagnostics, and magnetic elements.

For the main ring injector kickers, a notable improvement was achieved by reducing the LER kicker self-firing rate from 2.4 events/month to 2 events/month. This was accomplished by changing the trigger (G1) from a DC primed to a pulsed trigger method.

Additionally, vertical kickers were installed in the HER in spring 2024 and in the LER in autumn 2024. These kickers are used to measure the vertical dynamic aperture of the rings. Their characterization has been conducted through simulations and laboratory measurements, ensuring readiness for deployment.

Diagnostics in the beam transport line have also seen upgrades. An additional Synchrotron Radiation Monitor (SRM) has been installed at the BT line for continuous electron beam size monitoring. The Optical Transition Radiation (OTR) screen underwent an overhaul in pre-, during, and post-measurement treatment, improving accuracy, robustness, and usability. Consistency between different diagnostic tools has now been achieved. Several new applications for the OTR screens have been developed. These include tools for automatic data logging and plotting at rates exceeding 1 Hz, monitoring two bunches simultaneously on a single screen after transverse separation using kickers, and conducting Q-scans with enhanced accuracy and methodologies. These applications now enable real-time measurement of beam trace, peak intensity, transverse size, peak position, and center of mass position. The improvements have resulted in emittance measurements from the Q-scan and wire scanner agreeing within approximately 10%. A larger emphasis on analyzing substantial quantities of data has improved study accuracy and provided additional insights. Issues related to radiation-affected camera networks have been identified and addressed, while the BPM signal isolation improved the reading of the position of the two positron bunches.

The beam transport magnetic elements have undergone realignment, particularly in ARC1 for the positron line. A first important result of the magnet realignment in the positron BT line was that the vertical emittance growth in ARC1 disappeared, and the shielding effect of CSR was no longer visible.

Dipole magnets in BT were found to have vertically asymmetrical poles due to spacers inserted in the upper pole to strengthen the magnetic field during the energy increase from 3.5 GeV to 4 GeV. Tracking simulations suggest that the multipole components of these dipole fields may contribute to vertical emittance growth. Sequential replacement of the dipoles is planned during the 2025 shutdown period.

Emittance measurements conducted using the quad scan method revealed discrepancies between the model and real magnet for some quadrupoles. These differences have affected the measured emittance values. Tests will be extended to other locations, and problematic magnets will undergo further investigation to resolve these issues.

As a general comment, these developments and improvements reflect a commitment to enhancing the beam transport line's performance and reliability, in line with operational goals and future requirements.

Recommendations:

R9.1: Establish a time plan for future activities. Given the extensive list of activities outlined for the BT line, it is recommended to define a comprehensive time plan. This plan should prioritize tasks based on their impact on the overall injector performance and align with the broader operational schedule. Clear timelines will help optimize resource allocation and ensure timely completion of critical upgrades and investigations.

R9.2: Re-measure emittances along the injector (also related to R6.1). Perform systematic re-measurements of emittance in X and Y along the injector, giving special attention to the quadrupoles with discrepancies between the model and real magnetic.

R9.3: Replacement of the dipoles in BT. This replacement could be fundamental to avoid the vertical emittance growth in the beam transport line.

10. Injection Tuning

Findings & comments:

New variables have been introduced in order to describe quantitatively, and without ambiguity, the injection efficiency. Raw Injection Efficiency (RIE) is defined as the charge measured after 100 turns normalized to the bunch charge at the end of the injector. Injection Efficiency Margin (IEM) is defined as the raw injection efficiency minus the required raw injection efficiency. IEM rapidly drops as stored currents increase, which represents a major limitation in improving collider performances in terms of luminosity and background on the detector. Background is evaluated using diamond detectors installed at the QCS and central beam pipe in each ring.

During operations in 2024, injection was performed at 12.5 Hz in both rings. The injection rate was almost halved with respect to 2023 operations. Lower injection rate was adopted to cope with limitations in the injection efficiency, background shower on the detector, and to limit the negative impact of the frequent SBL events. Two bunches per burst are efficiently injected into the LER, which had not been possible during previous runs. On the contrary only one bunch per burst was injected into HER due to problems afflicting the RF gun.
Injection efficiency for the LER profits from switching on the bunch-by-bunch horizontal feedback, which indicates the need to enhance damping of the beam horizontal oscillations. In this regard it might be useful to decrease the LER horizontal damping time by increasing the wiggler magnetic

field. This modification might be useful since implementing non-linear collimators had led to the removal of some wiggler sections in the positron ring.

The fast kicker, which might mitigate some of the injection problems, especially in the LER, has been successfully tested. Unfortunately, it will not be installed before 2026.

The source of the emittance growth in the e+ injection line has been understood.

Recent studies outlined that the e+ beam emittance blowup of the order of ~40 micron measured after e+ linac was caused by a residual dispersion, of about 0.1 m, in the LINAC itself which has been corrected. Moreover, the difference in the horizontal emittance between the first and the second bunch in the same burst was induced by a different bunch orbit, originating in the DR, and propagating through the LINAC. These effects are enhanced by the X-Y coupling in the BT1-BT2 section. As a result, at the end of the injection line the horizontal emittance for a bunch carrying a 3 nC charge is about a factor 2 higher than the design one evaluated for a bunch charge of 4 nC. This large horizontal emittance represents a major limit for RIE.

Strong X-Y unidentified coupling was also detected at BTe-arcs 1&3 in the e- injection line, which coincided with a huge increase in horizontal and vertical beam emittance measured for a single bunch carrying 3 nC charge. In fact, horizontal and vertical e- emittance at BTe2 are 153.4 μm and 167.3 μm, respectively. These values must be compared with the nominal values, for 4 nC bunch charge, which are 40 μm and 20 μm, respectively.
Concerning contributions from CSR to emittance growth, which had been outlined during the previous ARC meeting, it was discovered they did not play any role as far as e+ injection line is considered. On the contrary, there remains a non-negligible CSR contribution to the emittance growth in the arcs of the e- injection line.

Several considerations, supported by simulations and experimental observations, have been presented aiming at reassessing how injection efficiency and Dynamic Aperture of the colliding rings depend on β_y* and on the beam-beam kick, and how these rapidly degraded for shrinking β_y*. To avoid this effect a rather complicated cure is proposed to minimize the horizontal envelope of stored and injected beam at the ring entrance using a pulsed kicker, and implementing a complicated bunch-by-bunch feedback trigger able to skip the injected bucket. Such a method requires non-trivial hardware developments, and time to be implemented and commissioned. In the meantime, it might probably be useful to revise the present ring optics in order to increase DA, and to explore by simulation the possibility to shape the incoming beam phase space by using one or more non-linear field magnets in the BT line.

Recommendations:

R10.1: Compare the measured bunch-by-bunch lifetime measured in LER with the tune shift measured along the batch.

R10.2: Evaluate the potential benefits and drawbacks coming from reducing damping time in the LER, using the optics model.

R10.3: Consider and investigate, by numerical simulations, the possibility to use IR octupole correction coils or to install octupole magnets in the LER, in order to add Landau damping and try to improve injection.

R10.4: Continue the effort to correct X-Y coupling in the BT1-BT2 section.

R10.5: Understand and cure the anomalous x-y emittance growth in BTe2

R10.6: Revise ring optics trying to achieve a larger DA.

R10.7: Explore by simulation the possibility to shape the incoming beam phase space by using one or more non-linear field magnets installed at a proper phase advance in the injection line (e.g., as for "octupole tail folding" in an LC final focus).

11. Sudden Beam Loss

Findings & comments:

Sudden beam losses start occurring within 1 turn (10 μs) and a significant percentage of beam is lost before the abort trigger extracts the beam. Therefore, damage to collimator and accelerator components, quench of SC magnets, large background, … can occur. Before the summer shutdown there were 19 SBL events in HER, 144 SBLs in LER, and 7 of these events were leading to QCS quenches. After the summer shutdown 19 SBLs were observed in HER and 95 in LER. The frequency of SBL events increases with beam current. Many simultaneous vacuum bursts were observed in the wiggler section. However, loss monitors downstream of the wiggler section did not see beam loss. It was found that the vertical beam size increases when SBLs occur.

Several approaches were tried to find the root cause of the SBLs.

1) Under the assumption that falling dust particles create the SBL's, it was tried to mechanically trigger the release of such dust particles, the so-called "knocker study". Three locations were tested: 1) a beam pipe with a clearing electrode in the wiggler section, 2) an aluminium beam pipe with grooves in a bending magnet and 3) a normal drift chamber. By knocking on the beam pipes, the team could create some beam losses similar to SBLs, but those had some characteristics which may have differed from standard SBL events (current dependence, vacuum behavior, …). After the knocking campaign a lower rate of SBLs was observed but it did not go to zero.
2) During the summer shutdown it was tried to flip the beam pipes with clearing electrodes, moving the ceramic insert from the top to the bottom. No significant improvement was observed.

3) Finally, it was tried to clean the wiggler section D10. At this attempt an unexpected black stain was discovered near the flange. The TiN coating was found not to be affected.

From the statistics side, it was shown that LER is much more affected than HER. Many SBL events correlate with bursts of vacuum pressure at D10L02/L03. Bellows in between were opened, and black stains were found. It was shown that the main component of those stains was silicon vacuum seal. The locations were cleaned up and after that no SBLs with pressure burst were found here. The SBLs at D04 started again (pipe had been turned, no vac seal applied here). The pipe was knocked again, and the status improved but the SBL events later reappeared. Pressure bursts without SBLs were checked. The effect of flipping the vacuum pipe is not clear while the positive effect of bellows replacement is obvious. The beam size was checked with a CMOS camera for LER SBL against normal: a much blown-up vertical beam size was found during the SBL, and also checked bunch by bunch.

The ARC notes that the run 2024ab (2024/1/30-7/1) lasted for almost twice as run 2024c (2024/10/9-12/27), which to some extent indicates that the incidence of SBL increased in 2024c (possibly due to higher current) , despite the countermeasures adopted to keep it under control.

In a second part of the talk the efforts to speed up the abort trigger were summarized. In LER an optical fiber had been introduced in 2022 in the effort to build a system that sends the abort trigger and safely extracts the beam as quickly as possible. It was decided to install a similar system in the HER at a collimator. The LER reaction time was further reduced by not routing the cable through the central control building but through a local D7 master.

The committee is impressed by the careful and detailed study that is being executed on the Sudden Beam Losses. While the physical mechanism is not yet clear, more and more mechanisms are being characterized and various possibilities are excluded.

The committee notes that a serious origin of SBLs seems to be in the wiggler sections of LER where the synchrotron line heating is highest. It notes that the LER OHO wiggler section has been modified and wigglers have been removed for installation of the non-linear collimation NLC. It also notes that synchrotron loss maps for the wiggler sections have not been presented, and neither for the modified OHO section. The paper by Suetsugu et al (J. Vac. Sci. Technol. A 30, 031602 (2012); doi: 10.1116/1.3696683) mentions 14 kW/m for 3.6 A positron current in the LER wiggler section.

The committee supports not flipping more chambers, it also supports the cleaning of additional flanges (where VacSeal has been applied, e.g. in the wiggler section) to improve the statistics before/after cleaning and it supports the continuing work on faster abort triggers.

Recommendations:

R11.1: For the actual wiggler sections show a modeling of synchrotron power impact and resulting thermal gradients and temperatures. What is the power load and what is the

asymmetry around the pipe both for LER and HER wiggler sections? What are the differences between HER and LER in the wiggler sections? Estimate the impact of having removed the wigglers in the LER OHO section on local synchrotron loss patterns.

R11.2: Continue the investigation of the SBLs until one or several physical reasons and mechanisms have been found and verified beyond doubt. The model should explain why LER has consistently 5-7 times more SBL events than HER, while both electrons and positrons are driven to SBLs.

R11.3: Clean more of the black stains and improve the statistics on the apparent improvement.

R11.4: Improve the sensitivity of the BOR detection system, e.g., by deploying it around the ring.

12. Vacuum System

Findings & comments:

A detailed status, evolution and studies performed for the Vacuum System since the last review were presented to the ARC. All recommendations were received and addressed. The continuous effort led by the vacuum team to maintain the vacuum system at a performance level required by SuperKEKB is still ongoing.

At the end of 2024c period, the achieved beam currents are 1.70 A and 1.35 A in the LER and HER, respectively. Vacuum scrubbing is still ongoing, reaching dynamic pressures below 10^{-7} Pa/A and 10^{-8} Pa/A in the LER and HER, respectively, giving enough margin for further beam current increases. Following the summer shutdown, the vacuum quality had decreased, but could be recovered rapidly (within 1-2 weeks).

During the run 2024b, following the actuation of beam pipe knockers located in D06 beam pipe and wiggler LER sections D10 and D11, SBL (Sudden Beam Loss) like events were produced. In the same period, collimator heads were damaged (LER: D02V1, D05V1 and HER: D09V1), anomalous pressure rises attributed to HOMs, false gauge readings attributed to leakage current and vacuum leaks were detected (at flanges, feedthrough and welds).

During the summer shutdown all the above issues were tackled systematically. Collimator heads were repaired or checked. RF screens to mitigate HOM heat loads were installed at vacuum gauges in the D05 NLC (non-linear collimator) section and near the D09V1 collimator. Temperature sensors were installed to monitor abnormal pressure rises, desiccant was attached to some cold cathode vacuum gauges and ion pumps feedthrough to prevent corrosion leaks, D04 & D10 wiggler vacuum chambers were realigned to avoid beam heating induced leaks and leaks were repaired. In addition, beam pipe inspections revealed the presence of significant quantities of vacuum sealant (i.e. VacSeal) at D04 and D10. VacSeal at only D4 was partially removed but the vacuum chambers cleaned from dust. Finally, to mitigate beam-dust interactions, knockers were actuated before beam operation resumed.

During the 2024c operation period, leaks appeared at LER D04_L8, LER D10_L5 and HER D05_H19 but were successfully solved by additional tightening of the flange without using VacSeal. In the LER, SBLs with QCS quench were observed with D04 and D10 pressure bursts. Hence, during a short intervention, VacSeal was removed from D10 to mitigate SBLs. Pressure rises at some RF screened vacuum gauges were still observed. A detailed analysis of the VacSeal behaviour in the accelerator environment and cooling improvement of bellows located in the wiggler section are ongoing.

Present plans for this shutdown foresee the complete removal of VacSeal in vacuum chambers and bellows, IR beam pipe inspections, installation of additional gauges, repair of collimator heads and upgrade of the bellow's cooling.

Recommendations:

R12.1: To guarantee machine availability, continue to monitor, analyze and document vacuum scrubbing, pressure bursts and beam dumps due to vacuum. E.g. try to determine if the pressure bursts are a result of the beam loss or a pre-cursor, and/or to categorize the type of losses with regard to pressure bursts. Pursue the development and implementation of automatic tools to perform the daily monitoring of the vacuum system. Consider documenting any tunnel interventions in reports and/or a database.

R12.2: Identify the flanges subjected to non-uniform synchrotron radiation heat load exposure and monitor their temperature to anticipate the risk of leak opening.

R12.3: Refrain from using VacSeal to leak tight flanges, particularly for those in direct view of the beam path. Define acceptable leak rate compatible with short term operation in a way to defer the vacuum intervention for repair during shutdown. Consider temporary fix using clamshell like tools to achieve primary vacuum around an identified leak.

R12.4: Consider inspecting, removing VacSeal (if any), and cleaning the vacuum chambers in regions where pressure bursts were observed during 2024. Take actions to minimize the risk of damaging the components and introducing dust during each vacuum intervention.

13. Beam Instrumentation

Findings & comments:

The status of the SuperKEKB collider diagnostics has been given by a comprehensive and very clear report. All the recommendations coming from the previous review have been received and addressed in depth during the presentation.

A summary of the faults occurred during operations was shown, and all the interventions undertaken for maintenance and to recover from faults have been presented in detail.

All the faults experienced are pretty much in the category of the ordinary problems occurring running a collider.

In the SuperKEKB specific case maintenance of the beam position monitors is particularly demanding, since several different systems are used: narrow band BPM, Libera modules, and gated turn-by-turn BPMs.

During the summer 2024 shutdown, a general campaign was undertaken to check all the BPM connections. As a consequence, several loosely tightened N- connectors have been discovered and fixed. In the LER ring 79 out of the 445 connections had at least 1 loose connector, and 250 out of 445 had 2–4 loose connectors. In the HER ring 34 out of the 467 connections had at least 1 loose connector, and 68 out of 467 had 2–4 loose connectors.

A major problem has been confirmed affecting the six LIBERA modules installed in the collider rings and used for turn-by-turn beam orbit measurement, which return inconsistent readout at low current. A fault at the level of the internal attenuator is suspected. The experts are discussing whether to repair the 15 years old equipment, implying high costs and long lead time, or to replace the LIBERA modules with narrow band devices. It is worth outlining that in case LIBERA would be replaced the present capabilities of the collider ring diagnostics will not be affected.
More BOR devices and Beam Loss Monitors have been installed in both rings. They have been efficiently used to study SBL in general, and more specifically to identify different SBL event categories.
The R&D activities conducted in collaboration with the SLAC laboratory and aimed at developing RFSoC based BOR is going on. Recent tests on a RFSoC BOR prototype showed it has the same performances as a iGp12 BOR in detecting an artificially induced instability.
DCCT vacuum chambers were replaced with straight beam pipes, and fast analysis of DCCT readout is under development in order to improve beam injection efficiency, which can now also be optimized by a machine learning based procedure, which however still requires further developments.

Recommendations:

R13.1: The ARC supports maintaining and expanding diagnostics capabilities at a high level. In this context, the faulty LIBERA modules can be replaced by updated devices, if their performance cannot be recovered by the procedure sketched in the following R13.6.

R13.2: Strive to minimize the number of different systems to maintain and to develop.

R13.3: Maintain, expand and strive to improve turn-by-turn BPM diagnostics for advanced optics studies, including coupling and nonlinear topics.

R13.4: Develop and expand turn-by-turn bunch-by-bunch diagnostics to diagnose SBL events (e.g. from FBCK system, RFSoC, SR monitors, ...)

R13.5: Continue the maintenance work of all kinds of beam monitors during the upcoming shutdown time.

R13.6: For the LIBERA systems, check the contact of the flanges of the vacuum chambers close to the BPM buttons, or other possible disconnections and discontinuities, which may impact the adjacent BPMs.

R13.7: The ARC supports installing more BORs to localize the SBLs, if the budget and human resources are available.

R13.8: Continue developing Machine-Learning applications for the on-line analysis of data from different monitors.

14. Control System

Findings & comments:

The control system for SuperKEKB is a critical component of the machine. Essentially every aspect of the collider is controlled, monitored, and logged through this system. It is a legacy system, which means that it is being incrementally upgraded and expanded to accommodate new features and systems. It also means that obsolescent computer hardware and software has to be judiciously replaced over time. Keeping the system running while adapting it and adding new functions takes skill and care. The SuperKEKB accomplishments would not have happened without the skilled control system team.

For the 2025 MAC several upgrades and additions were presented. In 2024 several shortcomings in the existing timing and abort system were repaired and improved, specifically

- Time stamp slippage at D11
- Issues with aborts that do not get logged with sub-system request source (4 from vacuum, 1 QCS)
- Software improvements for the backend database (allowing abort summary searches and better characterization of aborts), including Keyword search (software log searches). The core database functions have been developed, but the user interface is in progress. The Belle-II/MDI group is participating in this web-based user interface.

There has been attention to the overall control system stability/robustness. Some newly integrated linux/mini PC consoles (intended to replace legacy functions) have been erratic, rebooting sporadically and there are some small hardware issues that have been fixed. There are some software issues with Radeon system drivers that are being sorted out. Work-arounds have been developed to keep things running.

One important computing aspect is the increased computing and storage requirements for the large amount of abort and diagnostic system files that are required by the new AI/machine learning configuration, tuning and diagnostic tools. The processor and memory requirements of these expanding new applications have exceeded the expectations and capacity of the existing system. The group has a budget request to expand the capacity. However, the direction and extent of these new functions requires something that is more like an AI server farm than the original control architecture. The exciting new machine learning and big data tools require greatly increased computing power and data storage.

The experience with the SBL diagnostics and other measurements that require synchronization and abort control have led to the design and development of a new low latency abort system. This is an extensive effort that includes the SKB-BT, SKB-control, and Belle II/MDI groups.

The new design shortens the path length between an abort signal source (in a loss monitor, for example) and the abort kicker trigger on the kicker power supplies. This reduction in latency is important to minimize the time beam loss is occurring and potentially damaging detector and beam line components.

The upgrade includes new abort sensors, re-routed direct fiber optic paths, and has been shown to reduce the latency. The log shows the benefits of the changes, since November 2024, 18 of 24 recorded aborts are faster by 10 μs (a full turn).

Plans for 2025 were detailed:

With coordination from MDI collaborators

- 20 New CLAWS sensors
- New hardware platform for "abort launcher" (red pitaya based, a commercial FPGA platform), the goal is < 100 ns delay in this function

LER Upgrade Plan -

- Add more CLAWS sensors
- A free space laser for signal transmission in the tunnel. A "structured low divergence laser" is in design and development in conjunction with CERN. This will be prototyped in 2025-2026.

The HER upgrade plan is similar, with more CLAWS sensors and the use of the low-latency signal distribution.

An upgraded Timing System and Injection Control function was commissioned in 2024, also more sophisticated dual threshold and trigger control to generate aborts from monitor signals. The added flexibility is very significant to allow more sophisticated data acquisition on faults and anomalous beam conditions.

The system implements two bunch injection diagnostics to allow current equalization. The flexible timing system allows injection efficiency measurements, looking at the injected current and the loss rate, and schedules the choice of future bunch injections through a bucket selection system.

The group is planning timing system technology upgrades and improvements. Results were shown from a more flexible and sophisticated data acquisition trigger. This general trigger function allows multiple sources and linked systems to co-trigger

- Two synchronization modes are supported, for injected and stored beam.
- 7 unique data sources can be flexibly triggered and data acquisition synchronized

An example was shown for a fast loss monitor and synchronized data acquisition from multiple sub-systems to test/measure fast beam loss. (a synchronized kick from vertical kicker, synchronized acquisition data taken from the TbT-BPM and TbT loss monitor (CsI scintillator+PMT)).

There is an R&D effort to develop timing functions on the White Rabbit platform, as a joint development and testing program with IJCLab. This is an excellent path to leverage software and hardware with amortized development that is shared. The White Rabbit platform is being considered for possible use to combine and synchronize fast luminosity, vibration and beam position monitor data.

A collaborative work between Belle II and SuperKEKB is underway to construct a large GPU farm for machine learning.

Recommendations:

R14.1: The SuperKEKB team should further coordinate with Belle II on storage and processor upgrades. Plans for eventual future growth could also be considered during the next phase of implementation.

15. Magnet & QCS

Findings & comments:

The committee noted that the management of the Main Ring magnet and QCS group had been modified to take into account retirement. The work of the magnet and QCS group covers a fairly wide range of areas, including the normal conducting and superconducting magnets themselves, their installation, alignment, cryogenics, power supply, cooling water, etc., so that there are not enough people at present.

Following the recommendation of the previous ARC meeting, many of the decades-old control power supplies in some old magnet power supplies will be replaced this winter.

Studies are underway to reduce the use of liquid N2 (LN2), as the present system uses about 3500 liters per day, by adding a new heat exchanger.

In December 2024 the rotatable sextupoles were used to measure the strengths of the IP synchrotron-betatron resonances. The rotation did not affect the orbit significantly.

Recently, the IP QKARP magnet was shifted vertically by ~1.9 mm to align with the beam orbit. This has reduced the horizontal orbit variation that occurs during IP knob tuning as expected.

Several aborts were caused by magnet power supply failures, mainly due to high ambient air temperatures. These problems were addressed by the use of air conditioning. However, air conditioning of the entire power-supply building may not be the most efficient way to remove the heat. An example of a different approach is the new local cooling of each cabinet at the big data center at IJCLab Paris.

A plot was shown how the tunnel has shifted over 25 years. Parts of the tunnel have moved a total of 40 mm which is about 1.5 mm per year. The movement does not appear to be tailing off with time. So far compensation using magnet correctors has been sufficient to make up for this movement.

The QC SC magnets in the IR have quenched 36 times in 2024. For 2024c, there were 16 SC magnet quenches due to SBL and 2 due to kicker failure. As the beam current is increased the quenches have increased.

The SC magnets were built so that managed quenches do not damage the magnet coils. However, the radiation doses to the coils from SBLs may ultimately degrade the coil mechanically.

Recommendations:

R15.1: Consider local water cooling at the heat source for the power supplies instead of global air conditioning of the entire building(s).

R15.2: Complete the study of whether the radiation doses to the SC magnet coils due to SBLs, other beam aborts, and accumulated backgrounds will ultimately degrade the integrity of the SC magnets.

16. MDI

Findings & comments:

The MDI group has three main subgroups. One group is dedicated to the study and mitigation of stored beam backgrounds and injection backgrounds. The second group is concentrating on the Sudden Beam Loss (SBL) events and on ways of reducing the time between a beam instability detection and a beam abort. A third group is forming that will concentrate on improving machine performance through the use of Machine Learning (ML) and big data analysis. These MDI groups have members from all of the main teams (SuperKEKB, LINAC and Belle II). This effective set of collaborations has shortened the abort time, installed new diagnostics for the detection of SBL sources, tuned the abort signals from the detector, optimized collimator settings for best running conditions, applied ML techniques to improve infection efficiency and collected dedicated background information from either main ring.

The strong collaboration of detector, collider and injector teams has been very effective in tackling these very challenging issues and we encourage the MDI group to maintain this combined effort.

Recommendations:

R16:1: Continue to improve, and devise new, diagnostics and detectors in the two main rings (HER and LER) in the hunt for SBL sources.

R16.2: Continue to work with the LINAC team to improve injection capture efficiency.

R16.3: For backgrounds associated with long injection durations, it is essential to identify which injected particles are lost in phase space and, if feasible, design specific collimators for the BT to address this issue.

R16.4: The ARC recommends that the MDI group not only focuses on mitigating beam background, but also provides potentially useful beam information to the accelerator team.

R16.5: The ARC suggests extending the machine learning (ML)-based injection tuning approach by incorporating the objective of reducing detector backgrounds. This effort should involve optimizing not only the linac and transport line, but also explore the inclusion of additional tuning knobs in the ring.

17. Radiation Shield for NLC

Findings & comments:

A clear analysis of the radiation issue in the NLC (Non Linear Collimator) region with present mitigations and future plan was presented to the ARC.

In the Oho region, beam losses in the collimator D05V1 are a factor 10-20 larger than the design value. This may limit the SuperKEKB operation due to radiation doses above 1.5 μS/h in the experimental area, machine room and shutter area. Following this year's beam intensity increase and the radiation field analysis, mitigations were put in place. Working areas were declared as radiation-controlled areas with restricted access, 10 cm thick polyethylene was installed along the existing 5 m long lead shielding and concrete blocks were placed in front of the shutter.

Following a detailed analysis of the radiation fields, plans for better radiation shielding to be installed during this shutdown were presented. They consist of extending the existing lead shielding from 5 to 10 m, adding a 10 cm thick polyethylene shield, adding a lead shielding around the collimator and adding a concrete shielding between the so-called "Mongata" concrete shield and the side wall. This would leave the radiation to leak only through the (empty) RF waveguide vertical shaft and the cable trays positioned on the side wall. Doing so, it is expected to reduce the radiation dose in the concerned radiation-controlled areas by about a factor 10. As countermeasures in case beam loss largely exceeds expectations an extension of the radiation-controlled area is considered by placing fences outside the Oho experimental hall.

Recommendations:

R17.1: Consider inserting removable shielding stones in the vertical shaft.

R17.2: Consider minimizing the source of radiation by reducing the losses on the collimator by e.g. adapting the material and length of the collimator (while complying with the impedance budget) and placing absorbers close to the radiation source.

18. RF System

Findings & comments:

The RF systems have operated well during the last year with low downtime and stable operation. All recommendations from the last review have been addressed as far as the budget has allowed. Good news is that one spare klystron that had been in storage for 10 years was tested and is still good. Another will be tested during this year, ensuring an adequate number of spares for the upcoming runs. Canon is still willing to rebuild existing tubes, which is also good news, though the cost may be high.

RF system hardening is progressing well with many legacy issues being corrected. This will pay off in terms of reliability for the long-term future. Repairing the klystron test stand was not possible last year because of budget limitations, but it is hoped to resume operation in the coming year. This is important to allow continuation of high-power testing of the HOM absorbers in advance of higher current operation. The replaced ARES cavity with a 0.7 mm flange gap (which had concerned the committee last year) was instrumented with thermocouples at the critical vacuum joint and also compared with two other cavities. No abnormal temperatures were seen during commissioning or high-power beam operations, and the repaired station did not trip during the last run. The SCRF systems suffered several piezo failures last year, but these were replaced with spares. The failed units were installed in 2018 and were the oldest in service. However, the exact cause of the failures is not known. New spares will be procured to replace those used.

Overall trip rates in both ARES and SCRF systems are low and seem to be consistent over the runs. However, the beam currents are still well below the design values. The systems will be stressed more as currents are increased in the coming runs. Most ring RF systems are running legacy analog LLRF systems that are no longer supported. The digital LLRF systems developed 15 years ago are functioning well, but these too may become difficult to maintain as electronic components become obsolete. Spares are limited.

Looking to the future, it would be prudent to plan a gradual migration to new state-of-the-art digital LLRF systems. Such systems are in use or under development at many labs. It may be fruitful to survey these activities and form collaborations to minimize the effort required by KEK staff. Budget and schedule will not likely allow upgrading all systems at once. So, a phased plan will be more realistic. Gradual conversion of stations will free up analog spares to support the remaining legacy systems, ensuring continued availability until all stations are eventually converted. New systems will ensure reliability, but will also provide new capabilities for real-time diagnostics and fault finding.

Recommendations:

R18.1: Continue the good work of RF system hardening in anticipation of future higher current operation.

R18.2: Make a plan for implementing new digital LLRF systems in place of legacy analog systems that are no longer supportable. This plan might look at several options. One path might be to collaborate with another lab that has developed a similar LLRF system or to jointly develop an architecture useful for several machines.

19. IR misalignments, Model-Independent Orbit Analysis, Dynamic Coupling

Findings & comments:

SuperKEKB elements should be well aligned to about 100 μm. However, the IR orbit seems to have problems as there is synchrotron light shining onto the detector and a special orbit was required to avoid this. The source could be an important misalignment of the detector.

Putting a 1 mrad vertical tilted misalignment in the solenoid gives 71 pm vertical emittance. However, optics correction brings this value down to 16 pm for the HER. The LER appears more sensitive. The tolerance on the solenoid vertical tilt is about 0.7 mrad, aiming for a vertical emittance of less than 20 pm after correction for both rings.

A horizontal tilt of the solenoid is easier to correct and should not be a concern.

Past studies of the beam spot X-Z tilt angle reported discrepancies between the value calculated from the machine and the value from the detector at the level of 1-2 mrad.

Using a MIA analysis of orbits excited from outside the IR the contribution of the external components to the IR closed orbit can be removed. The intrinsic residual is large (~ 0.5 mm) and points to a vertical angle in the HER of 0.66 mrad. This is close to the tolerance computed above.

Data for different values of β_y^* is available, but not yet analyzed.

It has been observed that transverse coupling is generated when beams are put in collisions. Residual lattice coupling at the IP in combination with the beam-beam interaction can explain this. Thorough analytical derivations are presented in the slides.

The IP coupling should have been corrected by maximizing luminosity. However, this correction was not complete, since the required corrector knob setting indeed the maximum knob strength, leading to residual lattice coupling at the IP and hence also to dynamic coupling. This coupling could have also affected the luminosity vertical offset scan. Maybe the QCS alignment problems reported in the previous talk are linked to these coupling observations.

In summary, alignment and coupling issues in the IR remain an important potential source of the limitations observed in SuperKEKB.

Recommendations:

R19.1: More quadrupole-to-BPM beam-based alignments in the IR should be done with special focus on the resolution and accuracy of the analysis, in order to be able to assess the impact of the residual misalignment.

R19.2: Explore ways to further correct the IP coupling to avoid leaving a residual coupling after the coupling knob maximum strength is reached. Mechanically tilting the IR (or nearby) quadrupoles could help.

R19.3: Is the residual lattice IP coupling strong enough to deteriorate the luminosity performance in simulations?

R19.4: Consider further survey of the IR alignment, including Belle II detector.

R19.5: Allocate scientific manpower to make the beamstrahlung diagnostics operational, in order to enable its use for X-Y coupling studies during future runs.

20. Beam-Beam Simulation

Findings & comments:

It is encouraging to observe that new members have been assigned to investigate this critical topic. In July, 2025 a beam-beam simulation working group was formed in order to understand the operation issues where the beam-beam effects are important.

The challenges associated with injection efficiency in collision require further investigation and better understanding. The weak-strong approach was used to study the tune dependencies of injection, as well as the off-momentum injection scheme.

A strong-strong model was used in studies of the specific luminosity. Although some important features are reasonably well modelled, a significant discrepancy remains between the ideal simulations and the real machine performance. The beam-beam tune shift is significantly lower than for KEKB. Addressing this issue should be the highest priority for related research.

During the 2024 run, it was observed that reducing βx^* effectively suppresses the horizontal instability and clearly mitigates the horizontal beam blowup. In studies with colliding beams in June 2024, as the bunch current increases a clear drop in specific luminosity was observed in case of identical vertical tunes for the two beams, but not with different tunes. Simulations also reveal a similar luminosity drop when symmetric vertical tunes are used, and that this effect can be mitigated by employing asymmetric tunes. However, no clear dipole oscillations were detected in the experiments. It remains unclear whether a vertical coherent beam-beam instability (TMCI-like) occurs in the actual machine. Studies of the interplay of the beam-beam effect with the single-beam collective behavior require the correct transverse and longitudinal wakes to be taken into account in the simulation.

Recommendations:

R20.1: The ARC recommends the further development of realistic and comprehensive simulations of beam-beam effects as a focus for the international scientific collaboration between KEK and its partner laboratories.

R20.2: Further efforts should focus on more realistic simulations of beam injection during collisions, aiming to optimize injection schemes and minimize beam loss at injection.

R20.3: Achieving high luminosity will require smaller βy^* values. However, reducing βy^* introduces numerous complex optics-related challenges. At this stage, it is recommended to prioritize addressing the discrepancies in beam-beam performance between simulations and actual machine behavior.

R20.4: Although the SuperKEKB team is under significant pressure to achieve high luminosity, a prudent starting point may be to investigate the discrepancies observed at low bunch currents.

R20.5: A further step involves analyzing performance during weak-strong collisions, where one beam operates at high current (normal status) and the other at sufficiently low bunch current. In the absence of coherent instabilities, such experiments are expected to help identify the distinct limiting factors of the two rings.

R20.6: Horizontal beam-beam instability could serve as a valuable benchmark for comparing simulations with actual machine performance. It is suggested to consider longitudinal impedance, local transverse impedance, feedback, and chromaticity both independently and in combination.

R20.7: To achieve a comprehensive analysis, strong-strong beam-beam simulations should incorporate lattice effects, impedance, space charge, feedback etc., step-by-step. Try to evaluate the tolerance of linear errors (referring to the most-frequently used luminosity tuning knobs) to facilitate comparison with tuning experience in the real machine.

R20.8: Perform beam-beam simulation with the inferred residual IP coupling.

R20.9: Use the lattice with a vertical tilt angle of the detector (presented by Oide-san) to determine how such a misalignment might affect the luminosity performance.

21. Near-Term Plan

Findings & comments:

The history of the SuperKEKB project was concisely and well-reviewed, especially the Phase 3 commissioning. During the runs of 2024ab & 2024c, the luminosity target was not achieved, but still the new luminosity record of 5.1×10^{34} $cm^{-2}s^{-1}$ was obtained. A revised long-term plan is now being developed and the proposed luminosity evolution is under review. The LS2 is shifted from 2027 to around 2032 compared with the original plan. The luminosity projection is also modified with the foreseen beam current increase due to the reinforcement of RF power and the IR upgrade. 50 ab^{-1} is assumed to be achieved by 2042 after continuous operation. Milestones for both integrated luminosity and peak luminosity, which are targeted before LS2, become the premise of the run plan 2025.

Partly due to the budget issue, a 10-month shutdown from the beginning of 2025 has been implemented, which means the 2025ab run will be skipped, while the 2025c and 2026a runs will be conducted, as shown in the 2025 run plan presented. Works related to the preparation of the next run and the improvement of some hardware systems in this 10-month shutdown are being arranged. The commissioning plan of the runs of 2025c and 2026a is to be finalized.

The ARC understands the current budgetary situation which KEK is now facing, and supports the strategy made for the further commissioning and operation of the SuperKEKB.

Recommendations:

R21.1: The ARC encourages the installation of more BORs and Claws diagnostics for SBL studies and for faster beam aborts during this long downtime.

R21.2: The ARC encourages upgrading the IR for further luminosity increase. Develop the strategy of IR upgrade carefully, and evaluate the relevant technologies needed.

R21.3: Prioritize the works in the 10-month shutdown, in order to secure the machine operation and commissioning studies in runs 2025c and 2026a.

22. Plans for LS2 (IR Upgrade)

Findings & comments:

In order to reduce $\beta^*_{x,y}$ to increase the luminosity it is planned to move the closest magnet towards the interaction point. This calls for a new magnet with increased gradient, together with corresponding adaptations to the iron yoke and surrounding compensating solenoids. Details of the magnet were shown. It is based on the use of Nb_3Sn superconductor together with a plan for executing the corresponding R&D, in collaboration with Fermilab, with Furukawa for the conductor, and with the help of students from Sophia University. It is planned to complete the R&D on the magnet by the end of fiscal year 2027, so as to start production of the two series magnets together with all the other components (yokes, solenoids, etc.) in fiscal year 2028. Fermilab will play an important role in the endeavour, as it will be responsible for reacting the coils, and for the supply of a mirror yoke for prototype testing of a coil quadrant.

Recommendations:

R22.1: The new and displaced envelope of the QCS will have an impact on the layout of the detector, affecting the efficiency of the detector. Ensure that the net gain in performance is worthwhile.

R22.2: Before embarking on the manufacture of tooling, study the possibility and implications of using a two-layer coil, and compare manufacturing, cost and performance issues with those associated with the single layer coil design shown in the presentation.

R22.3: Check the synchrotron radiation detector backgrounds with the quadrupole moved closer.

23. International Collaboration

Findings & comments:

A pillar of the international collaboration is the US-Japan collaboration on High Energy Physics, which has supported R&D for SuperKEKB with SLAC since 2002, the development of the SuperKEKB Interaction Region Nb_3Sn Quadrupole Magnet with FNAL, and the development of superconducting magnets and quadrupole field vibration measurement system for SuperKEKB upgrade with BNL, as well as contributions to the SuperKEKB commissioning such as the development of dithering-based IP feedback with SLAC and ANL, the development of high speed bunch-by-bunch X-ray beam size monitor diagnostics (XRM) with U. Hawaii and SLAC, studies of beam collimation and electron cloud Instability, the development of the Large Angle Beamstrahlung monitor with Wayne State U., and accelerator physics in general. The work on the new QC1s (Nb_3Sn) is carried out together with FNAL.

Other collaboration exists in the frame of the KEK Multi-National Partnership Project on R&D for high luminosity colliders (MNPP-01) – CERN, CNRS/IN2P3, SLAC, IHEP-Beijing, INFN – The project provides for visa support (where needed), daily life support etc. – Many contributions come from IHEP, CERN, LAL/IJCLab and SLAC. LAL/IJCLab developed a fast luminosity monitor (LumiBelle2). CERN participates in ring commissioning, and optics measurements, amongst others. IHEP is engaged in hardware design, optics, and simulations.

KEK welcomes the international collaboration to improve performance of the SuperKEKB accelerators. The KEK team would be very grateful to anyone who could visit KEK and help.

An invitation program has been set up, with the following possibilities:. KEK short term invited fellow (14 days – 90 days); KEK long term invited fellow (3 months – 1 year); and Guest Researcher Program (14 days – 1 year). A normal invitation program with partial support (such as daily allowance only) is also negotiable.

Recommendations:

R23.1: International cooperation is encouraged while focusing on specific technical studies that emphasize mutually important topics, for example, specific luminosity degradation at higher beam currents.

Appendix A: KEKB Accelerator Review Committee Members

Frank Zimmermann, Chair	CERN
Ralph Assmann	GSI
Vincent Baglin	CERN
Paolo Craievich	PSI
John Fox	Stanford University
Andrew Hutton	JLab (excused)
Heung-Sik Kang	POSTECH
Catia Milardi	INFN-LNF
Evgeny Perevedentsev	BINP
Qing Qin	ESRF
Bob Rimmer	JLab
John Seeman	SLAC
Michael Sullivan	SLAC
Tom Taylor	CERN (ret.)
Rogelio Tomas	CERN
Yuan Zhang``	IHEP
Tadashi Koseki	KEK, Director of Acc. Lab., Ex Officio Member
Kyo Shibata	KEK, Head of Acc. Division III, Ex Officio Member
Makoto Tobiyama	KEK, Head of Acc. Division IV, Ex Officio Member
Hiroyasu Ego	KEK, Head of Acc. Division V, Ex Officio Member

Appendix B: Agenda of the 28th KEKB Accelerator Review Committee meeting

January 14 (Tuesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:10	Welcome	S. Asai
09:10 - 09:25	Status of Accelerator Laboratory	T. Koseki
09:25 - 10:15	Summary of 2024 Runs	Y. Ohnishi
10:15 - 10:45	Ring Optics Issues	H. Sugimoto
10:45 - 11:15	Belle II Status	K. Trabelsi
11:25 - 11:45	Injector Status (1)	M. Satoh
11:45 - 12:05	Injector Status (2)	M. Yoshida
13:25 - 13:55	Injector Upgrade Plan	F. Miyahara
13:55 - 14:25	Beam Transport Line	D. Oumbarek Espino
14:25 - 14:45	Injection Tuning	T. Yoshimoto
14:45 - 15:15	Sudden Beam Loss	H. Ikeda
15:25 - 16:05	Vacuum System	M. Yao
16:05 - 16:45	Beam Instrumentation	G. Mitsuka
16:45 - 17:15	Control System	A. Morita
17.15-18:05	Magnet(s) & QCS	S. Nakamura
18:05 - 20:00	Executive Session	
January 15 (Wednesday)		
08:30 - 09:00	Executive Session	
09:00 - 09:30	MDI	H. Nakayama
09:30 - 10:00	Radiation Shield for NLC	Y. Sakaki
10:00- 10:50	RF System	T. Abe
11:00 - 11:30	IR Misalignments, Model Independent Orbit Analysis. Dynamic Coupling	K. Oide
11:30 - 12:10	Beam-Beam Simulations	Y. Yamamoto
13:20 - 13:50	Near Term Plan	K. Shibata
13:50 - 14:30	Plans for LS2 (IR Upgrade)	Y. Arimoto
14:30 - 14:50	International Collaboration	M. Tobiyama
14:50 - 17:50	Report writing	
18:50 - 19:20	Executive Session	
January 16 (Thursday)		
08:30 - 11:00	Executive Session	
11:00 -12:00	Closing	

Appendix C: Required and achieved SuperKEKB parameters and comparison with KEKB

parameter	KEKB w Belle		SKB 2022b		SKB 27 December 2024		SKB design	
	LER	HER	LER	HER	LER	HER	LER	HER
E [GeV]	3.5	8	4	7	4	7	4	7
β_x* [mm]	1200	1200	80	80	60	60	32	25
β_y* [mm]	5.9	5.9	**1.0**	**1.0**	**1.0**	**1.0**	0.27	0.30
ε_x* [nm]	18	24	**4.0**	**4.6**	**4.0**	**4.6**	3.2	4.6
ε_y* [pm]	150	150	**~50**	**~50**	**~70**	**~70**	8.6	12.9
I [mA]	1640	1190	**1321**	**1099**	**1632**	**1259**	3600	2600
n_b	1584		2249		2346		2500	
I_b [mA]	1.04	0.75	0.587	0.489	0.696	0.537	1.44	1.04
ξ_y	0.098	0.059	**0.0407**	**0.0279**	**0.036**	**0.027**	0.069	0.060
L_{sp} [10^{30}cm^{-2}s^{-1}mA^{-2}]	17.1		**71.2**		58		214	
L [10^{34} cm^{-2}s^{-1}]	2.11		4.65		5.1		80	

The beam-beam parameter is computed without the hourglass factor or geometric factor for the luminosity.

Appendix D: Ordered list of priority items

1. Acquiring or producing vacuum clamshells to avoid use of VacSeal during the next run
2. Installing more BORs for SBL diagnostics around the LER, and at least one in the HER, in particular RFSoC with bunch-by-bunch capabilities
3. Additional laser-based (?) IR survey (misalignment/tilt of Belle-II detector w.r.t accelerator)
4. Further development of improved IR magnetic model
5. BT dipole magnet replacements (for LER)
6. Further realignment of both BT lines (since realignment of ARC1 e+ proved effective in reducing the emittance growth)
7. Improve and extend turn-by-turn BPM reading capability for both HER and LER
8. Routine recording of emittances or beam sizes measured by SR monitors
9. Installing two or more nonlinear magnets, such as octupoles, in each of the two BT lines, once the potential beneficial effect for injection efficiency is confirmed by simulations
10. Explore and, if deemed possible, implement a local water cooling at the heat source for some power supplies, to save energy and not only to rely on air conditioning