Focused Review Meeting of KEK B-factory Project Joint Committee of Accelerator and Experiment

18 and 19 December 2025, Remote meeting

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1 Introduction

A joint review committee, consisting of six members from the KEKB Accelerator Review Committee or the KEK B-Factory Programme Advisory Committee, was convened by the Directors of the Institute for Particle and Nuclear Studies and the Accelerator Laboratory. The committee was charged with assessing whether the SuperKEKB/Belle II operation plan for the coming year is adequate with the following mandate:

> Assess whether the SuperKEKB/Belle II operation plan next year is adequate to achieve:
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> 1. the primary goal of accumulating a total integrated luminosity of 1 ab^{-1}
> 2. the secondary goal of reaching a peak luminosity of 1×10^{35} $cm^{-2}s^{-1}$ by next summer.
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> Our basic strategy is to increase the stored beam currents to achieve a higher luminosity while keeping 80% of the physics run time to achieve 1 ab^{-1}. Therefore, the review should focus on the measures taken to date, their results, and future plans including improvements to the beam injection quality and the operation efficiency. If the plan is deemed insufficient, please give advices to the project team to develop a revised plan that meets these objectives.

The committee met remotely on 18?19 December 2025 and received the following presentations:

> Accelerator operation issues and how they have been addressed
> Belle II operation issues and how they have been addressed
> Accelerator operation status

Accelerator operation plan
Mitigation plan for beam backgrounds and SBLs
Belle II operation status and plan

The presentations were followed by discussion, and follow-up questions which were addressed by SuperKEKB and Belle II experts. This report presents the committee?s response to the mandate, together with specific observations and recommendations concerning both accelerator and detector operation plans.

2 Response to the Mandate

The SuperKEKB operation in 2026 prior to the summer shutdown was originally planned to run until the end of May, corresponding to approximately 104 days of Belle II physics data taking. In order to achieve the primary goal of accumulating a total integrated luminosity of 1 ab^{-1} for the Belle II experiment within this period, an *average* daily integrated luminosity of ~ 4 fb^{-1} would be required.

It was presented at the meeting that the machine operation would initially aim to achieve a peak luminosity of 5×10^{34} $\text{cm}^{-2}\text{s}^{-1}$, followed by progression toward a target luminosity of 1×10^{35} $\text{cm}^{-2}\text{s}^{-1}$, with a machine operation efficiency exceeding 65 %. It was also reported that an unforeseen shutdown, required for the repair of the final focusing quadrupole magnet (QCS), necessitated an extension of the running period to the end of June. In the absence of this extension, the available physics data-taking period would be reduced to approximately 85 days.

The committee considers that a staged approach to luminosity increase should be adopted. Based on machine and detector operating parameters that have been achieved in previous runs, the committee recommends that, after successfully reaching a peak luminosity of 5×10^{34} $\text{cm}^{-2}\text{s}^{-1}$, a first operational stage should target a peak luminosity of 6×10^{34} $\text{cm}^{-2}\text{s}^{-1}$ with a machine operation efficiency of 80 % and a Belle II data-taking efficiency of 0.85.

It should be noted that a machine peak luminosity of 6×10^{34} $\text{cm}^{-2}\text{s}^{-1}$ has not yet been achieved. Reaching this goal will require a prioritised and well-focused effort. The committee considers improvement of the injection efficiency of the High Energy Ring (HER) to be the highest priority. In particular, this includes tuning of the RF gun to increase electron acceptance, successful implementation of two-bunch injection, and resolution of the emittance blow-up observed in the injection beam transfer line. These activities can be pursued largely independently of the tuning of SuperKEKB operational parameters. The committee therefore strongly recommends that sufficient dedicated time be allocated at the start of the run for optimisation of the injector complex. In addition, improved measurements of beam trajectories in the injection lines, as well as orbit measurements in the storage rings, would be important for further optimisation of injection and ring performance.

Once the machine reliably achieves an average luminosity of 5×10^{34} $\text{cm}^{-2}\text{s}^{-1}$, priority should be given to Belle II physics data taking in order to maximise integrated luminosity delivery. The Belle II collaboration must be prepared to sustain a data-taking efficiency of 85 % or higher. Machine development should continue, with particular attention to background levels and operational stability.

The next operational stage is expected to begin once the accumulated integrated luminosity approaches the 1 ab^{-1} goal, for example at the level of approximately 90 %. At this point, machine studies aimed at increasing the peak luminosity to 1×10^{35} $cm^{-2}s^{-1}$ and beyond, with a machine operation efficiency of 65 % or better, should take priority in order to address the secondary goal. This represents an important step toward achieving the ultimate objectives of the SuperKEKB programme. Realising this performance will require tighter beam focusing at the interaction point and higher beam currents, which in turn demand sustained high injection efficiency with low background levels and careful control of beam–beam effects. A global optimisation of machine parameters, encompassing both the injector systems and the SuperKEKB storage rings, will be necessary. This will require close collaboration among groups responsible for the various accelerator subsystems. The committee recommends to undertake comprehensive beam-beam simulation studies that includes a realistic ring impedance model. Such simulations will be very relevant to understand the specific luminosity drop at high currents, and to guide collider optimisation in order to achieve new record peak luminosity. The application of artificial intelligence to improve simulation tools and to develop algorithms for global optimisation may offer new opportunities in exploring the complex parameter space of the machine.

At the same time, the Belle II detector must be prepared to implement strategies for stable operation under the background conditions expected at luminosities of 1×10^{35} $cm^{-2}s^{-1}$ and beyond. Close and continuous collaboration between the accelerator and Belle II teams is essential to understand the respective limitations of the machine and the experiment, and to develop effective solutions to overcome them.

The committee notes that if the run stops at the end of May, achieving these goals will be very difficult. Maintaining the originally planned running time is strongly recommended.

In the following section, the committee presents specific observations and recommendations for both the accelerator and detector aimed at achieving these challenging goals.

3 Particular Observations and Recommendations

3.1 Accelerator

Introduction of an operation performance score, which aligns with the committee guidance to focus first on the delivered luminosity, is encouraged. It is suggested that explicit operational milestones be set and achieved before increasing the stored beam current. Improving the injection efficiency is the first step. Higher stored beam currents are and will continue to be new territory for the accelerator. Higher currents aggravate the storage ring vacuum quality that, in turn, lowers instability thresholds and increases stored beam emittances affecting the specific luminosity. Higher-Order Mode (HOM) power also increases and that affects bunch-by-bunch cross-talk and transverse instabilities.

The committee suggests finding beam currents that can be maintained with acceptable backgrounds to the detector and high injection efficiencies. This, then, allows the accelerator team to concentrate on the machine tuning for improving beam-beam effect and increasing specific luminosities. At the same time, the stored beams will continue to scrub the rings and backgrounds should continue to decrease allowing collimator settings to open. This should improve the dynamic and physical apertures. As the machine performance improves at a specific beam current setting, the beam currents can then be slowly increased. The committee suggests to evaluate the possibility to install octupole magnets in suitable positions along the two rings. They can give additional handles in the operation to improve beam lifetime, background condition and injection efficiency, which are very relevant for high current operations.

Machine status

Machine stability has improved significantly, but remains fragile at higher current. A clear reduction in beam aborts and Sudden Beam Loss (SBL) events has been demonstrated in run 2025c relative to 2024c, consistent with expectations after the VACSEAL removal and collimator relocation. Faster abort schemes (especially in the LER) and improved collimator robustness represent operational progress. However, residual SBLs persist, and some occur without clear precursor signals. The SBL source around D11 remains not understood. Recovery from certain failures (abort-kicker malfunction, QCS cryogenic instability) still incurs multi-hour downtime, incompatible with sustained 80 % machine operation efficiency at higher current. There is an inconsistency in the beam-beam effect between simulation and the actual performance. The specific luminosity decreases with the increase of bunch currents. On the other hand, it remains high in the studies with a lower total bunch number (393 bunches). It might be interesting to see if reducing the stored bunch number to 1173, for example (half the current number of bunches), provides a significant improvement in specific luminosity, since luminosity gain goes as bunch current squared, while it is only linear with the number of bunches.

Injection efficiency

Injection efficiency, especially in the HER, is a major accelerator limitation. HER injection efficiency in 2025c is explicitly reported as < 50 %, with a well-quantified breakdown (vertical emittance, collimator constraints). Synchrotron injection for the HER was attempted and abandoned due to charge leakage into other RF buckets and repetition-rate limitations. Despite substantial injector and Beam Transport upgrades (new RF gun, ECS at design voltage, improved diagnostics), beam?beam limited injection remains unresolved at higher current. The operation plan relies critically on near-term injection improvement, but several key elements remain ?under investigation? and have yet to be demonstrated. The committee encourages substantial initial effort be made to improve injection efficiency.

3.2 Belle II Experiment

Care must be taken that the Belle II detector continues to perform well as the luminosity is increased, to ensure that the data taken remain good for physics. There is currently some headroom for increasing the luminosity while maintaining acceptable detector performance, but this will become increasingly challenging towards 10^{35} cm^{-2}s^{-1}, in particular for the CDC. This argues in favour of the strategy of limiting the initial increase of luminosity to the value that is required to integrate the target of 1 ab^{-1} while maintaining high efficiency, and then pushing further towards 10^{35} cm^{-2}s^{-1} as a second phase. Indicators of the background level in the detector must continue to be communicated to the machine operators and be taken into account by them as the accelerator performance is tuned. The background in the CDC is a particular concern, as care must be taken to avoid permanent damage to the detector. The effort towards studying the ageing of the CDC with a test chamber should be reinforced. Operation of the detector with some layers at reduced HV looks promising to avoid damage, but the implications on detector performance, including for particle ID via dE/dx, should first be understood thoroughly. Studies to find a suitable precursor signal of SBLs to enable a fast beam abort to protect the PXD should continue with highest priority. The efforts to understand the remaining SBLs and reduce their frequency and impact in terms of radiation dose at the interaction region (e.g. by optimisation of collimation) are also essential, so that a strategy can be defined for switching the PXD back on during data taking, balancing the residual risk against the physics gain.

General observations

The beam background conditions in run period 2024c, especially at the beginning, were worse than 2024b, and can be explained by the higher vacuum pressure. Occasionally a large radiation dose has been seen on the detector due to sudden beam losses (SBLs). Impact on detector performance started to be visible in Belle II operation from several issues related to beam background and beam losses at the interaction region, including frequent DAQ stops in 2024c, mainly due to SEUs. Effort has been invested to improve this issue, including automatic recovery; a large fraction of the DAQ stops are currently due to the TOP, where an improvement in the readout system has been developed to mitigate the issue but has not yet been deployed; its final validation is still ongoing. The injection trigger veto contributes to the DAQ deadtime, which currently is about 5% using an active veto. Current blow-up has been seen in the Central Drift Chamber (CDC), possibly due to the Malter effect, which is an irreversible chamber damage by high beam background, and long-term detector ageing effects in the Barrel PID counter (TOP) PMTs. Damage has been seen on the innermost Pixel Detector (PXD) due to huge beam losses at the interaction region following SBLs, leading to the detector currently being kept off during data taking. Performance deterioration and radiation effects in other subdetectors (SVD, ARICH, ECL, KLM) also started to be seen with high background levels, but in general their limits are well above the levels observed so far.

Specific detectors

A limit is currently set on the acceptable CDC current to control the beam background levels, of up to 260 μA/layer; this constraint will limit future increases in the machine beam current if the beam background remains high. By increasing the H_2O and O_2 concentration compared with 2024c, it is expected that the current chamber condition should be more robust against the Malter effect, and thus, when the beam background reaches the limit, further increase will be explored gradually by carefully monitoring the stability of the chamber currents, unless frequent spikes are seen in the chamber current which could indicate development of the Malter effect. In parallel studies are being made of the impact of reducing the detector HV, with two sets of special runs (~ 1 fb^{-1}) taken with (1) all layers and (2) SL0 and SL1 at 50% gain, and reduced CDC threshold so that the TRG-L1 performance was basically unchanged. From studies of the first data sample significant deterioration of the CDC tracking is observed, as expected. A recalibration of the CDC-hit filters recovers this degradation in part, while it remains noticeable. The loss in particle yields is not dramatic, thanks to the recovery of the tracks by the SVD tracking. Further improvements in the CDC tracking performance (important for K_S reconstruction) will still be possible by tuning some of the algorithms and filters. Considering those preliminary results of the low HV in full layers, it is hoped that a condition with low HV only in two innermost superlayers (SL0/1) will be acceptable. These studies are encouraging, but the full implications of such a change need to be thoroughly investigated before implementation. Any relaxation of the current limit on the CDC should be performed with extreme care given the risk of permanent damage.

Following the replacement of degraded PMTs during LS1 no visible deterioration in the TOP PMT quantum efficiency has been seen yet in Run 2. At this moment, while the PMT hit rates (from single-beam background) are sometimes close to the current limit of 5 MHz/PMT, the limit can be increased to 7 MHz/PMT, so there is still some room to accept more beam background on TOP. However, a large fraction of the current beam background is believed still to originate from poor vacuum conditions due to opening of beam pipes during the shutdown, and should improve as the beam pipes are conditioned during beam operation.

The PXD detector suffered significant damage due to sudden beam loss events and was turned off on May 7, 2024 until more stable operation of the machine can be obtained and a mechanism has been developed to turn off the power to the detector quickly to avoid any further damage. A faster shutdown of the power to the detector is being developed, that could turn the PXD detector off within 30 μs, before beam losses could start damaging the detectors. This work on an active fast discharge board to drain the power from the PXD detector is progressing well, but depends on identifying a reliable signal that is an effective early indicator of an SBL or beam instability before a beam abort trigger. Three candidate signals are being evaluated: the beam pipe clearing electrode signal, the beam orbit fluctuation signal and the beam size blow-up signal. No signal has yet been certified for use. The electrode clearing signal was a promising lead, but recent SBLs during run 2025c did not show any anomalous signals on the clearing electrodes. Given the subtle nature of early warning signals, the use of AI methods is being investigated. The recent failure of the HER abort kicker system that resulted in the highest dose to date in the VXD diamond system, is a reminder of the urgent need to develop this fast power shutdown of the PXD.