B-factory Programme Advisory Committee
Complete report for
Focused Review Meeting

31 October and 1 November 2022 Remote Meeting

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1 Short summary

This focused review meeting of the B-factory Programme Advisory Committee (BPAC) took place, as a remote meeting, with the following questions posed by the director of the Institute of Particle and Nuclear Studies:

- Long Shutdown 1 (LS1) schedule
  Is the proposed schedule for LS1 appropriate? Point out if there are any particular concerns in the preparation and execution of the detector replacement work.
- Yearly Plan
  Are the operation and study plans for machine and detector in the coming months reasonable to achieve maximal integrated luminosity?
- Selected items
  - Progress in understanding the Central Drift Chamber (CDC) and photon detectors (PMT) for the barrel particle identification system (TOP) lifetime.
  - Improvement plan of data production and processing.
  - Analysis strategy toward winter conferences.

In this section, a short report is given with more detailed descriptions in the following sections.

The LS1 work appears to be mostly progressing well. The production of the new beam pipe, which was reported to have met a serious setback during the last focused review in June, is now on track again with a few weeks of delay and is expected to be completed by the end of November 2022. One major concern now is the delivery of a new Pixel Detector (PXD2) with two complete layers. While the ladder construction and assembly of the half-shells of PXD2 had been successfully completed, mechanical damages occurred during the pre-commissioning of a half-shell at DESY, where two ladders of the first layer were bent. A dedicated BPAC review meeting of experts took place on October 19th. A detailed presentation on the accident was given by the PXD team, and a written report by the BPAC expert group was distributed to the full members before this meeting. The most likely cause of the mechanical damage of the ladders was identified to be a thermal expansion when the sliding mechanism failed to act correctly. A plan to prevent this to happen again was presented, but further investigations are needed to ensure the safe operation of PXD2. The PXD2 group has also started to make a plan for replacing the damaged ladders. Here too, further work is needed to establish a safe procedure, since some ladders from the second layer have to be temporarily removed. The number of spare ladders is limited and there is no room for mistakes in this repair work. The experts' report calls for a very careful approach, not pushed by the overall LS1 schedule. The original plan was to start the Japanese Fiscal Year (JFY) 2023 run in October. This has now been deferred to the beginning of 2024. Modification in the PXD2 design or an accident in the repair would further delay the start of the run. The JFY 2023 ends in March 2024. The committee takes note that the Belle II collaboration is now developing two installation scenarios. The original one is to replace the setup of the current interaction point by a new one with the new beam pipe, PXD2 and current micro-strip silicon detector (SVD), and the alternative scenario to continue using the current set-up without extracting it from the Belle II detector. The second option would allow the run to start in October 2023, and the PXD2 would be installed some years later, before serious radiation damage of the PXD, requiring a one-year shutdown. Although the second option would allow a reasonable amount of run time in JFY 2023, there is a clear risk that the performance of the current Vertex Detector (VXD) would not be adequate for the future SuperKEKB luminosities and beam backgrounds. It should be noted that the current PXD is equipped with only a few ladders in the second layer and has been exposed to radiation for several years. A further concern is the availability of experts in the PXD group for such an extended period. The Belle II collaboration should prepare a detailed risk analysis by monitoring the progress of the PXD2 work as well as the realistic JFY 2023 run time based on the funding availability and the development of the electricity cost.

The committee was impressed by the progress being made by the SuperKEKB and injector machine group in overcoming the various problems to increase the luminosity. The group is now focusing on two major issues, the instability of the beam injection and catastrophic beam losses in the rings. Although there are still several open questions, the LS1 work plan presented by the machine group looks promising. The committee highly appreciates the close collaborative effort among experts of the injection system, SuperKEKB, and the Belle II collaboration.

The slow but steady loss of gain of the CDC remains a major concern, and may be an indication of ageing of the detector. The committee encourages the CDC group to fully exploit the LS1 and to consider a wide range of interventions together with an appropriate risk analysis. The committee is pleased to see the progress being made for implementing and operating a laboratory set-up to study the effect of ageing in a controlled environment. Stable operation of the CDC requires a team of experienced physicists. The Belle II collaboration is encouraged to build up such a team for the coming runs.

The committee acknowledges the work in progress to understand the behaviour of efficiency drops due to ageing for the TOP PMTs. Laboratory tests of unmounted PMTs from the Slot-16 will provide important information, and in-situ testing with cosmic rays will contribute further interesting comparisons. Of the two replacement strategies currently considered, the one involving rearrangements of all PMTs to enhance the overall optimisation is quite interesting. However, the time needed for such an operation has to be carefully assessed.

The committee observes continuous efforts to improve the efficiency of data production for the real and simulated events. While a further reduction in the time needed for (re-)calibration and validation is desirable and increased participation by detector and physics analysis groups is encouraged, the overall progress and plan for future activities are good.

The committee is very impressed by the wealth of physics results published in journals or presented at various conferences. The dark sector searches are unique. A number of ICHEP contributions with very interesting results are a great preparation for high precision journal papers. With a total sample of $424\,\mathrm{fb}^{-1}$ of data collected prior to the start of LS1, about half of the Belle data sample, the Belle II collaboration is preparing physics results of high precision on a very broad range of topics. The ambitious plan to fully exploit the data for beauty and charm physics is convincing. The preparation of physics publications for the full data set is in an early state, but with the extended LS1 and the past preparations, the committee expects very significant publications. However, the most recent data might be impacted by large beam injection backgrounds. The committee stresses again the importance of run-dependent MC simulation becoming available as fast as possible.

In addition to the responses to the questions, some important observations by the committee are given here. The KLM (K-long muon detector) group has responded well to the problem of the efficiency loss in the RPC detectors. The cause of the problem is understood and the proposed improvements in software and hardware to monitor the detector operation should prevent similar incidents in the future. A dedicated RPC test-bench has been installed in Tsukuba Hall to reproduce and test efficiency recovery strategies.

After some experience in operating the detector and taking data, LS1 is a good time to review and consolidate the detector control and monitoring, as well as the whole operational scheme during the data taking. The committee fully supports the new organisation, specifically the Detector Control System (DCS) group, who has started to review and document the current control system. Case studies must be made to assure that the control system guarantees at any incident the safety of the experiment. It is recommended to extend these activities to cover also the data-taking system. It is expected that the DAQ group will play central role with strong participation of detector groups. The Belle II management needs to pay attention that adequate resources are allocated to these activities. Although there are some major concerns, such as the PXD2 installation and the CDC gain loss, the overall status of the Belle II detector and physics achievements has been good. The committee urges that adequate resources will continue to be provided for the Belle II experiment and machine operation.

2 Machine and machine detector interface issues

2.1 SuperKEKB and injection complex

2.1.1 Status

The SuperKEKB machine performance significantly improved over the last two months of running. The luminosity record is now $4.65 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, up from the May 2022 record of $2.49 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Without Belle II taking data, the accelerator team has achieved a new record luminosity of $4.71 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. These records are almost within a factor of two of the luminosity of $1 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, a remarkable step forward in accelerator accomplishments. The beam currents are now well over 1 A (1.46 A for the LER and 1.14 A for the HER). The ring vacuum pressures are improving and with these higher beam currents, the scrubbing of the beam pipe will accelerate and the dynamic gas pressure will continue to decrease, allowing for the storage of more beam current.

A significant number of issues have been uncovered and addressed, further improving machine performance. Orbit deviations in magnets near the IR were postulated to arise from high power synchrotron radiation (SR) fans hitting beam pipe walls and generating heat resulting in displacements of the chambers. Residual magnetic fields in the superconducting final focus quads were causing a β-beat in the IR region. There was another β-beat source from some of the IP beam parameter settings that produced a local orbit deviation. Understanding the sources of β-beats is very important because they can change the actual β_y^* value at the IP. There has also been a good deal of work in improving the injection for both rings. Tuning of the timing and amplitude of pulses for the four injection kickers has been improved, thereby reducing the orbit non-closure. Two-bunch injection has improved and the total injection charge for the positron beam has increased to over 3 nC.

Full efforts has gone into examining and decreasing the time between the detection of an unstable stored beam and its abort. The timing sequence between detection and abortion has been carefully studied and unnecessary delays have been eliminated. In addition, optical fibres are being installed in critical signal paths which will further shorten the delay time. New sensors are being installed in locations that are designed to detect an unstable beam near collimators. They should be the first to produce a signal of instability. These locations are also closer to the abort dump and hence can produce an abort signal in the shortest possible time to dump the beams. Another BOR (Bunch Oscillation Recorder) is being installed with the intention of ascertaining whether there is a particular part of the storage ring where an instability begins. These sensors might indicate where a part of the vacuum chamber is either already damaged or is being damaged such that the stored beam is affected by the damaged section. Temperature sensors around each ring are being carefully monitored as well as vacuum pressure sensors.

2.1.2 Concerns

- Although much progress has been made, it was recognised in the presentations that there are still several outstanding issues that need to be addressed. The first is the unexpected, sudden catastrophic beam losses.
- Injection efficiency and stability has been improved but further improvements are still needed.

2.1.3 Recommendations

- Although some further understanding of the sudden catastrophic beam losses has been achieved (i.e. the empirical bunch current limit), it is still a mysterious issue. The accelerator team is making great efforts to avoid the damage by minimising the beam abort delay time and the committee fully supports these efforts.
- The injection efficiency and stability must be further improved in order to operate at the planned higher beam currents. As the stored beam currents and the luminosity increase the beam lifetimes will start to decrease. The committee fully supports the efforts of the accelerator and linac teams to improve the stability and reliability of the injector. This will require improvements of the orbits and kicker systems of the injection.

2.2 Machine detector interface

2.2.1 Status

This section is devoted to the status of the new beam pipe. The new beam pipe, currently being assembled, has completed many important steps and is on track to be finished with a delay of one to two weeks. Another beam pipe, with an inner coating of Cu, instead of Au, was being put together. However, it developed a vacuum leak sometime during the Cu sputtering and can no longer be used as a spare. The third alternative is to reuse the beam pipe still inside the detector.

2.2.2 Concerns

- There are still many important steps before the installation of the new beam pipe can be completed successfully.

2.2.3 Recommendation

- The committee recommends the development of a very carefully laid out plan for the full process: i.e. the extraction of the beam pipe assembly, removal of the SVD and PXD1 from the beam pipe, assembly of PXD2 and SVD on the new beam pipe, and insertion of the new beam pipe assembly. The plan must be written down in detail for every step and be reviewed by the experts doing the work and those overseeing the whole process.

3 Belle II Detector

3.1 PXD2

3.1.1 Status

The replacement of the current PXD1, which has an incomplete Layer 2, with PXD2, having full azimuthal coverage with two layers of DEPFET detectors, is a major goal for LS1.

Two complete PXD2 half-shells have been assembled at MPP and safely transported to DESY. After removing the first half-shell from the commissioning setup, two Layer 1 ladders were found to be bent. The PXD group promptly setup an effort to understand the origin of the failure, define corrective actions and develop a repair strategy. These topics were the subject of a special BPAC review on 19 October, 2022. Further developments have been presented at this review.

The current understanding is that the bending of the Layer-1 ladders is due to the concurrence of different events. Issues with the CO_2 cooling system resulted in too high a temperature during the electrical test; it has been shown that $T > 40°C$ may cause a weakening of the glue used in the joints between two modules of one ladder. The joints may therefore break if exposed to continuous stress. Besides that, the high temperature increased the overall thermal stress. The gliding mechanism that should have compensated for the thermal expansion failed because too high a torque applied on the module fixation screws prevented the mechanism from working properly under compression. This was worsened by the maximum asymmetric heating during the electrical tests, since only one azimuthal section of the detector was powered at a time.

The collaboration has undertaken actions to find a new working point for safe operation under the conditions expected after LS1.

It has been found that reducing the torque from 15 mNm to 5 mNm provides enough sliding capability without compromising the thermal contact between the ladder and the support. The reproducibility and long-term reliability of this working point for ladders assembled with the use of self-adhesive mylar foil are now being verified. The options of removing the mylar foil, or not using the self-adhesive one will be considered only in case all the half-shells need substantial rework.

The group is also preparing to replace the broken Layer-1 ladders. The operation will be performed at DESY, to avoid the risk of further damage by shipping the half-shell with loose parts. To minimise the handling of Layer-2 ladders that need to be dismounted in order to remove the Layer-1 ladders, an adequate number of intermediate storage devices is being manufactured at MPP. The current spare situation consists of at most five Layer 1 ladders and four Layer-2 ladders, including module pairs that are still to be assembled.

The delay due to the additional studies needed to recover from this accident has taken up all the contingency available in the schedule and triggered the analysis of further potential failure modes. The committee acknowledges the careful work performed by the PXD team to analyse in-depth the failure modes in a very short time. It also commends the collaboration for planning analyses of other possible failure modes.

Following the recommendation of the October 19 review, the Belle II Collaboration developed different LS1 scenarios, including the installation of the PXD2 in the 2023 fiscal year or postponing it to a later long shutdown. In the former case, the VXD removal is triggered by the successful integration of the PXD2 on the new beam pipe, after passing the acceptance tests and integration of the heavy metal shields expected by the end of January 2023. The VXD removal and reinstallation will require six months, followed by 3 months for the reconstruction of the Interaction Region. The earliest start of data taking could then be January 2024. The latter scenario may allow completing LS1 in October 2023. The choice between these two options depends also on the availability of the funding resources needed for running SuperKEKB. An informed decision may be taken in February 2023 with updates from the PXD2, beam pipe and funding situation.

3.1.2 Concerns

- The PXD2 is a keystone for the execution of the whole Belle II physics programme. Its completion has been affected by accidents that have exposed design weaknesses. Addressing these requires additional time that will result in a delay with respect to the original LS1 schedule. At the same time, the number of spares is extremely limited and any other failure may either be fatal to the PXD2 or may require more than an additional year to get components to assemble new ladders. A major concern is that operating under schedule pressure may increase the risk of such an eventuality.

- The Belle II Collaboration is facing different scenarios with varying levels of risks. Postponing the PXD2 installation until after LS1 exposes it to the risk that a single DEPFET layer, already exposed to irradiation for several years, will not be sufficient for the increased luminosity and background rates expected for the beam operation after LS1. In addition, critical expertise that is already stretched may not be available for a delayed installation. Prolonging the LS1 waiting for the completion of PXD2 may result in no new data before the fiscal year 2024. Taking the decision to start the VXD extraction only when the PXD2 has been integrated on the new beam pipe and fully tested is the safest from the point of view of the risks associated with the VXD removal, but maximises the impact on the LS1 schedule.

3.1.3 Recommendations

Most of the recommendations from the October 19 special review are still valid, and are repeated here for completeness. Others have been updated taking into account the progress and developments after that special review.

- The installation of a fully operational PXD2 should remain a top priority of the Belle II collaboration. The PXD2 safety must take priority over schedule issues.
- Have all actions (tests, measurements, etc.) to be made on the PXD2 reviewed by a small task force to ensure that the procedures are safe and meaningful. More than half the members of this task force should be non-PXD members so that the actions can be evaluated from multiple viewpoints.
- Verify that any further modification to the PXD2 design is safe, addresses a well-defined issue and does not cause any adverse effect on the PXD2. Verify any such modifications in a holistic manner when multiple changes are made, evaluating the system as a whole and not piece-by-piece, and revisit the implications of prior decisions.
- Establish a safe environment for storage and operation, for testing (temperature and humidity) as soon as possible; every effort should be made to keep these environmental specifications.
- Evaluate the PXD2 construction milestone that will trigger VXD extraction and disassembly, by minimising the risk for the SVD as well as the impact on the data-taking schedule.
- Estimate the impact on the Belle II physics programme of restarting data taking with PXD1 still installed and postponing the PXD2 installation to a subsequent shutdown. This study should be used to define a decision strategy about the time of PXD2 installation, depending on the evolution of PXD2 construction.
- Fully assess the possible failure modes during Belle II running before the PXD2 installation, because the loss of the tracking pixel layers will be irreparable.

3.2 TOP PMT

3.2.1 Status

The quantum efficiency (QE) projection of the TOP PMTs after LS1 depends on the beam background rate and run time. After LS1, the accumulated charge is expected to increase rapidly, due to the high background rate related to the expected increase of luminosity. The accumulated charge at the next summer shutdown will be close to the mean lifetime of the conventional PMTs, and it should be borne in mind that the projection is based on the lifetime test results using a small number of samples. The conventional tubes are therefore expected to significantly lose efficiency soon after LS1, before the next summer shutdown in 2024, even if they follow the prediction made assuming an average lifetime of $1\,\mathrm{C/cm^2}$ – the accumulated charge in Slot 16, for example, is expected to approach $1\,\mathrm{C/cm^2}$ by then, assuming a background rate of 5 MHz/PMT. The data taken so far seem to indicate an even shorter mean lifetime, more like $0.3\,\mathrm{C/cm^2}$.

There are currently 224 conventional MCP-PMTs installed in the detector to be replaced, and also 220 ALD PMTs, out of which about 30 currently look bad. 251 replacement tubes are available, ready to install: lifetime-extended ALD MCP-PMTs. Further production is in progress for LS2 replacement – 36 PMTs are already in acceptance testing and 60 additional PMTs have been ordered. The actual PMT performance needs to be investigated and the procedure and performance criteria for selecting the PMTs to be replaced need to be defined. The QE variation study has been updated using data taken up to LS1, including an updated correction for gain variation and hit selection. Further checks will be made of the analysis, as well as cross-checking with cosmic-ray data. Some strange behaviour has been seen, with the QE even appearing to increase at some point: checks are being made on the effect of beam background and tracking quality. Nevertheless, a significant fraction of the ALD tubes also seems to be degrading in a similar fashion to the conventional tubes.

It is planned to unmount the PMT modules in Slot 16 of the detector during November, to confirm their QE on the test bench at Nagoya, and also to check their PMT-filter-quartz connection. Getting access involves loosening the VXD cable fixture, opening two or three CDC covers, removing about 12 CDC frontend boards, and moving cables and cooling pipes. The current status of QE variation PMT-by-PMT was shown. Some bad board-stacks are misbehaving, and the corresponding PMTs will have little accumulated charge since their HV is off, which may help in understanding the cause. The dismounting will be done in units of PMT module (2×2 PMTs) to avoid the extra work required to remove their silicon potting. The candidate PMT modules to be replaced will be selected according to the number of their PMTs which start to degrade. Studies of the effect of photon loss on the TOP performance show that a loss of about half of the photons would lead to a significant effect on PID at higher momentum (above $2\,\mathrm{GeV}/c$). Due to the arrangement of the VXD cables, the PMTs in the upper slots of the detector are only accessible during a long shutdown, while it would be possible to access the lower part during a summer shutdown. There are possible risks of damage of the VXD/CDC/TOP cables and electronics, so the work on Slot 16 in November will provide essential experience on the feasibility of a more extensive intervention.

Two possible PMT replacement plans are currently being considered:

1. Replace the bad ALD PMTs, and use the remaining new PMTs to replace the bad conventional PMTs, while waiting to replace the rest in a future summer shutdown. This will minimise the number of currently bad ALD PMTs in the upper half, but the remaining conventional PMTs might fail before summer 2024. If the QE measurements confirm the monitoring results, then there is a significant risk of ALD PMTs failing before LS2 – even for PMTs where no degradation is yet seen.

2. Fill the upper half completely with lifetime-extended ALD PMTs, and fill the

lower half with the best remaining PMT modules, replacing these PMTs in future summer shutdowns as needed. This would minimise the risk from degradation of the QE of the ALD PMTs, but means that more slots would need to be accessed and far more PMTs modules would be moved around. The required working time is not considered to be very different, assuming one working day per slot.

3.2.2 Concerns

- The apparent loss of QE is still not understood and may have significant impact on the TOP performance – not only for conventional tubes but also some of the ALD tubes.
- The intervention to replace tubes is a significant perturbation to the detector, carrying risks. The time needed to replace tubes on the less-easily accessible slots may be longer than foreseen.
- The installation crew is small which may become a concern if the effort required at each slot is larger than estimated and the overall intervention takes longer than foreseen.

3.2.3 Recommendations

- Continue the investigation of PMT performance loss with high priority. It is unclear whether the loss of photon efficiency might be related to the photon angle at tube faces, but it would be useful to check that in the data. The removal of tubes from Slot 16 will be a very important test of the feasibility of more extensive replacements; the measurement of their actual QE in the lab should allow the effects seen in data taking to be better understood. A detailed report on the outcome of this work would be welcome at the next BPAC meeting, along with progress from the cosmic-ray tests, and the decision on the PMT replacement strategy.
- Overhauling the full set of PMTs (option 2. above) is attractive, as it would allow those which are inaccessible between long shutdowns to be fully replaced with lifetime-extended tubes, leaving the lower part populated with the best of the other tubes, which could in principle be replaced later (if necessary) during a summer shutdown; also all poorly functioning board-stacks could be fixed, and the optical cookies between PMTs and quartz replaced if necessary. However, this option involves substantial additional work on the detector, and a thorough risk assessment (both for the TOP and the other affected sub-detectors) should be carried out before taking the decision.

3.3 KLM

3.3.1 Status

The low efficiency of RPC BB2 was noticed in April 2022 when a new monitoring plot of the RPC efficiency of each layer was introduced. Looking back at the history, the trend began in June 2021. The original cause was the interruption of the gas circulation. After the recovery of the gas circulation at the end of April, the efficiency of RPC BB2 was partially recovered, however, its efficiency dropped again. The problem is understood to be due to the contamination of water vapour through the polyethylene tube for the gas inlet. Copper tube is widely used for the RPC gas tubes, however, an interference with the chimney of the solenoid magnet and RPC BB2 requires using a flexible gas tube, and the polyethylene tube has been used only on the RPC region.

To recover the operation condition, normal operation gas was circulated with a higher flow rate than normal, and the contamination of water vapour was monitored since May 2022. The contamination was reduced in the first month and saturated before the middle of June 2022. The efficiency of damaged RPCs remains lower than the others and there is a plan to recover the efficiency with a gas mixture including ammonium. The procedure will be tested and confirmed at the test stand in the KEK Tsukuba Hall.

The KLM group is reinforcing slow monitoring and data monitoring to find similar problems as quickly as possible. The gas flow of each inlet and outlet of individual lines will be monitored in a total of 832 channels. The new system will be ready before the end of LS1. The hit rate and the efficiency of each layer have been monitored in the framework of Data Quality Monitoring (DQM). The plots to show trends of relevant parameters are available and an automatic alert system is in place if algorithms spot unusual behaviour on these parameters. In addition to these, the infrastructure will be improved. A part of the polyethylene tubes for the BB2 RPC will be replaced with copper tubes. Water sensors for the chimney of the solenoid magnet and additional drain tubes will be installed.

3.3.2 Concerns

- The recovery method of damaged RPC was studied a long time ago. It is important to follow the same method and to check all procedures.
- Ammonium gas is corrosive to copper and should be treated carefully. The committee considers that introducing ammonium in the gas mixture to recover the damaged chambers appears to be a highly risky operation, which should be first studied in the laboratory with an RPC test chamber made of similar materials as the KLM one, and copper gas lines.

3.3.3 Recommendations

- As proposed by the KLM team, it is important to check the recovery procedure at the test bench before applying the method to the Belle RPCs. In case the cosmic ray tests indicate recovery of efficiency in the affected BB2 layers, one might consider continuing to flush the RPC chambers with a high flux of nitrogen for the duration of a few months.

3.4 CDC

3.4.1 Status

As was already reported during the BPAC review in June, a clear correlation between the degradation (mean, resolution) of the CDC dE/dx measurements and the beam background conditions has been observed in 2022 data. Gas recirculation rate of 4 l/min and H_2O content (1300 ppm) was rather stable in 2022ab runs. The effect of gain drop is especially prominent for less than 20 to 30 msec after LER beam injection, increases with time (run dependency) due to the higher beam background, and is also seen in two-track trigger efficiency plots (dependence is larger for LER than for HER). One of the possible sources of the gain degradation is the voltage drop across the HV divider; changing the resistor on the low pass filter with a lower value (1% or 10% of the current one) is being planned during LS1 to minimise gain reduction.

Apart from gain drop due to background, a slow drift of the signal gain by 5% was revealed during the period of four months in 2022 checking the data of cosmic runs. It is also observed in physics data of 2022ab and 2021ab runs. As the running condition is independent of the beam background in cosmic runs, it might indicate the onset of ageing effects. Therefore, further studies with cosmic ray data since 2019 should be performed. The inner CDC layers, where the effect is the most pronounced, has already collected the charge of about 0.1 C/cm per wire, which is non-negligible for the anode ageing appearance when operating with the hydrocarbon gas mixtures.

Still, the real reason of the slow gain degradation has not been well understood. Some suspicion exists that the gain drop comes from higher water content in the inner layers; the amount of H_2O in CDC measured with a water monitor does not match the quantity injected at the bubbler level (one order of magnitude difference). Another H_2O monitor will be used to cross-check the existing one, temporarily installed in a line that bypasses the CDC. Meantime, an attempt will be made to dry out chamber components during LS1.

A number of inner volume wires in the Layer-0-sector-1 (1/4 layer) has been turned off due to problems with HV supply in February 2020. Those wires would have seen therefore significantly smaller integrated charge. During LS1 and after the VXD is extracted, an attempt will be made to access them and to fix the HV line and later to take cosmic runs. If one sees a difference in gain between neighbouring Layer-0 sectors, this will unambiguously indicate gain degradation that depends on the accumulated charge.

The gas flow rate during the CDC operation remains at a very low level for a high-rate gaseous detector operation; one full CDC gas volume is recirculated every 25 hours and the fresh gas rate corresponds to one full volume exchange within approximately one month. CDC has eight inlet ports and eight outlet ports, while only half of them are currently connected to inlets and outlets. One should check if all four inlet/outlet lines have a homogeneous flow and if the 20 mm long plugs in the unused inlet/outlet CDC ports can be removed and more pipes can be connected to increase flow circulation. Space is very limited to access service points and some tests are being considered for better circulation. Installation of additional pressure monitors at the CDC outlet to measure chamber over-pressure, and to avoid significant stress on chamber wires, is also envisaged.

An ageing laboratory setup with a small chamber as well as proper equipment to analyse the chamber gas has been prepared at KEK. Clean-up and arrangement of the layout will be done in December 2022, gas cylinders, H_2O/O_2 monitors will be installed in January 2023 and first tests with a radioactive source and a gas flow are planned for February 2023. The aim is to reproduce ageing effects with a strong β source by irradiating the test chamber up to 1C/cm/wire as well as to develop and test different remediation strategies and additives for gain recovery.

3.4.2 Concerns

- The gas flow rate during the CDC operation remains low for long-term high-rate operation. Increasing the circulation flow rate is very important, but there is a concern regarding high pressure in CDC and associated gas equipment when the circulation flow rate is increased without changing the number of gas ports. More checks and optimisation studies are necessary.
- A slow drift of the gas gain represents one of the major concerns for the CDC long-term operation. If confirmed that it is caused by the onset of anode ageing effects, the initial degradation (5%-10%) should not be linearly extrapolated as a function of the total accumulated charge, but it can be more rapid and adverse in reality.
- Shortage of the personnel in the CDC group (both for online operations and for the development of mitigation strategies) remains critical.
- The progress with a laboratory ageing test setup has been slower than originally hoped.
- Poor injection conditions of beams in the 2022b run provide a preview of post-LS1 CDC operating conditions, with the background situation being significantly more challenging than anticipated at the design stage.

3.4.3 Recommendations

- Continuation of systematic studies with already existing data is important. To better understand the slow drift of gas gain, a correlation plot of gain drop vs total accumulated charge should be made (where each individual layer would contribute one point) since the early stages of the experiment with the past cosmic data taken without beam. Study of dE/dx versus accumulated charge can also improve understanding of the gain loss.
- The CDC gas system should be consolidated and modified during LS1 to improve gas tubing and filters, to understand better the flow dynamics inside the chamber, and to increase safely the CDC gas flow rate.

- Trials to reproduce the gain drop with the laboratory test chamber ageing setup should be pursued without further delay, with dedicated personnel. This will facilitate the developing and testing of different remediation strategies for gain recovery.

3.5 Detector slow control and monitoring

3.5.1 Status

Excellent performance of the Belle II detector will be critical for achieving the ambitious – and in many ways unique – current and future physics goals of the experiment. This can only be achieved by high levels of stability and detailed monitoring, controls, and calibrations, online and offline, and interfaces to databases, to machine and detector systems, and online computing.

Up to recently, the slow control and alarm systems were the sole responsibility of the different sub-detector groups, using the infrastructure provided by the DAQ group. They were developed mostly independently, and the type and details of information varied and were not officially documented or reviewed. Online monitoring of the environment and basic performance data like the RPC gas flow were limited and, in some cases, not reported. Some sub-detectors have an independent alarm system, not connected to a central interface!

A Detector Control System (DCS) group was recently formed to address some of these issues and establish a system that will be capable of controlling and monitoring the whole Belle II detector. The plan is to review the current sub-detector systems and develop global control systems for detector monitoring (HV, LV, power supplies, interlocks), environmental conditions (humidity, temperatures, gas flows, etc.), limiting operational parameters (HV thresholds, masking, etc.) and interfaces to databases. The DCS group will establish liaisons to each of the sub-detectors, including the trigger and machine-detector interface groups.

Given the limited time during LS1 the DCS team has decided to prioritise their work on a few detector-control and alarm systems, starting with the HV systems. These decisions will require approval by the Technical Board or Run Coordination.

For Online Data Quality monitoring infrastructure is in place to collect histograms from the High Level Trigger (HLT) application and express reconstruction (ERECO) of a subset of the events to provide the shift crew with some webpages with reference plots to identify data quality problems. The online DQM can also transmit observables and status to EPICS for monitoring and in some cases trigger alarms.

During each run raw data are recorded and archived and after the end of the run can be processed offline to check for problems; for instance, slowly developing deficiencies from accumulated data quality plots for many runs. A large number of histograms is available and overlays with reference plots are being analysed by shifters who report anomalies to experts. Mirabelle is used as a common monitoring tool for all sub-detectors based on observables extracted at the end of each run from DQM plots. Set up by a core software developer, this system indicated the gradual efficiency losses of the CDC, PXD, and KLM.

While the current DQM system is complex and serves its purpose, there is an opportunity to introduce improvements. The tools are available to provide the automation and alarms, and once the observables with appropriate sensitivities have been selected for each detector system the DQM web interface should provide the shifters with the required plots, EPICS reports, and also their interpretations. There are plans to upgrade the data storage to ZeroMQ and use ERECO, especially for vertex detector and physics features.

3.5.2 Concerns

- It has been realised that the detector control and monitoring systems of the Belle II detector require substantial revisions and upgrades, with additional monitoring sensors and criteria to further improve the data quality.
- Currently the DCS group does not have "independent" developers, who can devote their time on the choice and implementation of common hardware and software for the extended and more efficient future systems.
- Performing a full assessment of the status of existing systems, documenting them, and establishing a future plan, will be very difficult to complete during LS1. Nevertheless, this should be pursued because it will be important for all future data taking.

3.5.3 Recommendations

- Upgrades of the detector control and monitory system should be given high priority to guarantee high quality data.
- In the interest of speedy progress, general decisions for implementation should be reached by the DCS team, under a mandate from Technical Coordination and Run Coordination.
- The development of common components for the control and alarm handling would benefit from engaging dedicated experts.
- More software engineering efforts and integration will be needed for online and offline DQM. In addition, strong coordination will be needed to choose the appropriate granularity of monitoring and bringing all sub-detectors to the same level and decide on the importance for online versus offline monitoring.
- Close contacts between the DCS group and the liaison assigned to each subsystem (including the trigger and machine and interface groups) is advised, given their experience in such control and monitoring systems.
- The establishment of a dedicated development and test setup with replay possibilities (especially during the long shutdown) and for regression testing would be beneficial.

- Documentation and consolidation of DCS components should continue beyond LS1. Major system revisions and upgrades can be installed during future shutdowns after the successful test.

4 Detector performance

4.1 Status

During the final months of running before the LS1 in early 2022 the SuperKEKB luminosity exceeded $4 \times 10^{34}\,\mathrm{cm^{-2}s^{-1}}$. Beam currents were ramped up and some collimators were lost, resulting in relatively high beam background conditions. It is essential that the impact on the detector performance and physics analyses is fully characterised. Among the various sources of background, one of the most important and difficult tasks for the machine is to maintain stable injection background conditions. Newly injected bunches are perturbed and appear to oscillate in the horizontal plane around the stored beam, causing high background rates for many milliseconds after injection. Dedicated trigger vetos avoid saturation of the readout. The most recent data processing includes the event time after LER/HER bunch injection, and will be used to characterise the performance of the detector systems as a function of this time difference.

High and stable PXD and SVD efficiencies were observed during the latest running period. The PXD efficiency of around 95% was well reproduced by run-dependent simulation. The average CDC gain was initially stable and then steadily decreased up to about 15%. The impact on tracking performance has been studied in dimuon events, with the lower gains leading to a decrease in the number of CDC hits. The momentum resolution for high momentum tracks deteriorates, while the vertex spatial resolution is stable, because to first order it depends on the VXD performance and not the CDC.

The dE/dx mean and resolution versus time after bunch injection have been studied using radiative electrons. Below about 20 ms there is a clear shift and degradation in resolution, becoming worse at higher luminosity. The dE/dx group has plans for changes to the calibration to recover the performance in future prompt and re-processed data. $\mathrm{K^0_S}$ reconstruction has been studied in $\mathrm{D^{*+}} \to (\mathrm{D^0} \to \mathrm{K^0_S}\pi^+\pi^-)\pi^+$ events, observing a lower $\mathrm{K^0_S}$ yield for higher backgrounds. The more displaced a vertex, the more it depends on CDC tracking, leading to lower reconstruction efficiency. The data/MC agreement is better for large event times after LER injection. It is planned to assess the efficiency corrections and systematic uncertainties in bins of the event time after the injection.

The injection background causes loss of ECL signals for low energies and therefore higher pedestals lead to lower amplitudes, and more hits below the 1 MeV threshold are discarded. The recent data show a noticeable decrease of occupancy soon (about 10 ms) after LER injection. Effects are clearly observed in the π^0 mass peaks (shifting by a few MeV) and resolution (worsening from 6 to 8 MeV), particularly for the most recent period at higher backgrounds. Electron ID likelihoods have been studied with two-photon events. The CDC likelihood is severely affected by the variations of background conditions, and similar effects are also seen for the ECL likelihood. Muon ID is much more stable under increasing beam backgrounds and the event time since injection. A similar study has been made for hadron ID, using $K^0_S \to \pi^+\pi^-$ events, and also here the CDC is heavily affected by the background conditions. Below (above) the crossing point of the dE/dx curves, particles are more pion- (kaon)-like due to the shift to lower values of dE/dx at times close to injection. Effects on the TOP performance are much smaller and visible only for very high background conditions. Hadron ID performance is also being studied in a low-multiplicity environment using tau events, and up to 6.5% efficiency drops are observed for periods of higher beam backgrounds, when tight criteria on the pion ID are applied.

The yields of fully reconstructed $B^\pm$ decays do not appear to be affected strongly by the high beam background, although low-multiplicity decays still remain to be checked. There is an increase in background yields, coming mostly from the $D^0 \to K\pi\pi^0$ mode, likely due to degradation in π^0 performance. Studies are ongoing, and it is planned to retune π^0 reconstruction criteria for higher background conditions. The philosophy being followed is to correct the data for the observed effects, rather than reject events with high background soon after injection.

The committee was impressed by the detailed studies that have been presented, and looks forward to a more comprehensive report of the findings at the next BPAC.

4.2 Concerns

- A clear degradation of performance is seen in some of the sub-detectors during the period of up to 20 ms following LER injection. The beam injection background may be expected to get worse as the currents are further increased to achieve higher luminosity.

- The CDC in particular is losing performance as its gain reduces, apparently due both to background-related effects and in addition a gradual reduction with time. The future running at higher luminosity, and concomitant expected increase in backgrounds, may magnify this loss of performance, which will be significant for the momentum measurements and dE/dx resolution of charged tracks.

4.3 Recommendations

- Continue the detailed studies of the influence of the backgrounds on all of the sub-detectors, and prepare a strategy for corrections of the effects of higher background. Belle II detector experts are encouraged to participate in the detailed study of the beam injection with the machine group, to help identify injected bunches that do or do not significantly reduce the performance of the experiment, and thereby help to tune the injection parameters.

- The evolution of the CDC performance should be monitored carefully, and ageing effects be studied with high priority, as well as considering possible interventions to recover the performance when it becomes critical.

5 Data processing

5.1 Status

Data processing of the full data set with software release-06 has steadily proceeded toward completion over the summer, in line with the schedule presented to the committee in June. Production of analysis skims for the prompt sample collected in 2022 and the whole reprocessed samples collected up to 2021 (*proc13*) were 50% completed at the time of the BPAC meeting. The reprocessing time per fb^{-1} in *proc13* has significantly improved from the previous *proc12*. Nevertheless a delay of 3 months in reprocessing with respect to the original schedule of October 2021 was reported. The delay was due to taking longer than expected for staging of the data and for re-calibration, the latter still being a large fraction of the reprocessing time. Concurrent calibration of the prompt samples, which had a higher priority, was also a contributing factor in the delay. Long-term strategies to further reduce the re-calibration time, while ensuring prompt calibrations to be of the highest quality, consist of allowing to reduce the re-calibrations to only those greatly improving the quality of the samples and deploying a second calibration centre. Reprocessing occurs in a very uneven manner in time with evident bursts. In addition to the unavoidable delay in starting a production due to waiting for the re-calibration to finish, a few percent of the productions suffer from long tails preventing a campaign to be announced as completed. A variety of problems have been identified as the cause of the latter, mostly related to file replication or the production system (within single sites, networking between sites, etc.) and requiring manual interventions and investigation by experts. The data processing and computing teams are considering mid- and long-term solutions to improve the interface between the Dirac production and Rucio file management systems. Monitoring and debugging tools within the production system to help in prompt deployment of solutions are also under consideration.

The production of run-independent Monte Carlo (MC), *MC15ri*, was completed for both generic and signal samples and the production of the analysis skims for the generic samples was well under way to 60% completion. The production of run-dependent Monte Carlo *MC15rd* generic samples was expected to be completed at the end of November, with analysis skims to start soon after. For the first time, the production of run-dependent MC signal samples has also been launched. The committee was pleased to hear that *MC15rd* for generic samples was proceeding smoothly. The delay of four months was mostly due to a late start since the Physics Performance Working Groups required more time that anticipated to perform all checks needed for the validation process. This was compounded by the need to wait for completion of (re-)calibration for the corresponding data samples. The Data Processing team presented their first experience with the newly deployed production of run depended signal MC. While the number of signal events per production is small, many different configurations need to be modelled. The impact of the resulting many short production runs and how to optimise the access to the many small files produced has to be understood. The experience gained with the production of analysis skims in *MC14* and *proc12* led to a reduction of the number of combined skims by a factor of three, easing both production and use of the skims. Nevertheless, as each set needs to run independently for each MC physics process and each data taking period, the production of skims is still limited by the number of sustainable concurrent productions in Dirac.

So called *collections* of samples have eased running on large data sets and Belle II collaborators are more and more exploiting the Grid for analysis. The availability of the process samples coupled with the large number of short jobs[1] has led to a large number of analysis jobs waiting to be processed on the Grid. The Data Processing team has identified short-term solutions to make data production sustainable for analysis jobs, e.g. by providing separate data sets for long and short runs allowing to analyse them separately. Merging of small files will be provided as a mid-term solution.

Release 7 for the next processing campaign, *proc14* and *MC16*, was frozen in the summer and is under test. More time has been allocated to understand in depth improvements in performance. Before the official start of the production campaign, data sets will be produced for extensive tests: an order of 100 fb^{-1} of run-independent MC and ~ 30 fb^{-1} of data. The pledged Grid resources made free by this choice are being made available for special requests. The main lines of development in Data Processing for LS1 were identified in a dedicated workshop and will be described in a report. They address how to make the access to data easier, as well as the production task less onerous, and describe calibration strategies for the future processing of real and simulation data, and for data quality assurance. Extensive work plans for software and computing are also being refined.

5.2 Concern

- Data and MC production as well as analysis are suffering from short runs that magnifies the number of different jobs to be submitted and limits the number of concurrent production that can be processed.

5.3 Recommendations

- Problems at production sites or mis-configuration of sites are unavoidable from time to time. The committee recommends the computing and data processing groups to investigate long-term solutions to make the system more robust against those incidents.

- The committee recommends to carefully prioritise the work plan for LS1. In particular, advantage should be taken of this time to better harmonise Rucio and Dirac.

[1] Each input file requires a separate job and there is one file per production.

6 Physics

6.1 Status

The committee congratulates the Collaboration for the impressive set of new analyses finalised since the last BPAC review, producing new and unique physics results. These include the most precise lepton-flavor-universality (LFU) test in semi-leptonic B decays with electrons and muons. This is a crucial step toward the exploration of the tau channel. Important measurements toward the understanding of the nature of the $\Upsilon(10753)$ were also pursued. Advancements in the analysis technique in for other measurements are also impressive: e.g., the 92% increase in statistics for charm tagging in view of the exploration of mixing and CP violation in D meson decays, and other advances. In total, 16 new preprints/publications have been completed, based on ~ 189 fb^{-1} of integrated luminosity. Six of these papers have been submitted and/or accepted for publication in refereed journals.

Furthermore, SuperKEKB set a new world record for peak luminosity, reaching 4.7×10^{34} cm^{-2}s^{-1} with the Belle II detector taking data. Another factor of 12 is needed to achieve the design luminosity. The total recorded luminosity before the Long Shutdown 1 (LS1) is now 424 fb^{-1}.

Belle II completed new analyses on leptonic and semi-leptonic B decays, electroweak and radiative penguins, time-dependent CP-violating rate asymmetries, charmless B decays, charm, rare tau decays, and dark sectors.

Several milestones have been reached. In particular, Belle II performed the most precise LFU test in semi-leptonic B decay via the measurement of $R(X_{e/\mu}) = \frac{\text{BR}(B\to Xe\nu)}{\text{BR}(B\to X\mu\nu)}$. The measurement of the B^0 mixing phase confirmed good time resolution and flavor tagging. Belle II also set the world-leading bound on a dark Z' decaying invisibly and produced in association with two muons, probing a large part of the parameter space that can address the $(g-2)_\mu$ anomaly.

Furthermore, ~ 10 fb^{-1} data at $\sqrt{s}$ =10.75 GeV were recorded. This data sample was used to search for $\gamma X_b,\ X_b \to \omega\Upsilon(1S)$. No significant X_b signal was observed.

6.2 Concern

- Most of the recent data recorded at higher beam currents might be impacted by large beam injection backgrounds, which will need to be studied for all subdetectors and included in the run-dependent MC simulations.

6.3 Recommendations

- The committee encourages the Collaboration to keep their plans focused as much as possible on measurements that have scientific importance and for which Belle II will have a unique reach in the future, focusing on studies of $B \to K\nu\nu$ and $R(D^{(*)})$, rare tau decays, the exotic spectroscopy recently discovered, as well as the exploration of the dark sectors, such as dark photons, Z' and ALPs.

- During LS1, it will be essential to keep producing new physics results based on the collected luminosity. In addition, it might be important to improve some of the analyses (for instance, $e^+e^- \to \gamma,\ a \to \gamma\gamma$) that were done in the past with a very limited luminosity, using the full $\sim$430 fb^{-1} data set.

- The committee agrees with the Collaboration that there will be a need for a balance between quick physics results and the exploitation of the fundamental capabilities of the experiment, remaining creative at the same time.

- It is important to improve the supervisor-student contacts, which appear to be somewhat weak. The committee supports the stated intention to continue improving the WG procedures and work towards a consolidated set of tools for the different working groups.