B-factory Programme Advisory Committee
Full Report for
Focused Review Meeting on LS1

26-27 June 2023

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21 August 2023 (Revised on 27 August 2023)

1 Short summary

The B-factory Programme Advisory Committee met remotely on the 26th and 27th of June 2023 to assess the status of the Long Shutdown 1 (LS1) work and progress in physics analyses.

For the LS1 status, the questions asked by the director of the Institute for Particle and Nuclear Studies are:

- *Have all issues to be resolved during the LS1 been addressed appropriately?*
- *Is the schedule of each work arranged well?*

The status of the LS1 work was presented starting with an overview followed by status reports on the accelerator complex (injector chain and SuperKEKB), vertex detector system (VXD) consisting of pixel detector (PXD) and strip detector (SVD), central drift chamber (CDC), barrel particle identification system (TOP), K-long and muon detection system (KLM), data acquisition system (DAQ), changes of raw data formats, and monitoring and alarm handling.

The committee unanimously agrees with an enthusiastic "yes" to both questions. All the issues are being thoroughly addressed and the work plan developed is very solid and indicates that the LS1 is advancing well to achieve the goal to resume operation

in December 2023. The committee appreciates the effort made by the accelerator team and Belle II collaboration for this achievement.

While the committee is confident that the LS1 work will continue with full steam, it is important now to start developing strategies for the start-up and commissioning process of the accelerator complex and the Belle II detector, in close collaboration of the two teams. Since many systems have been changed, work plans have to be carefully thought through. Some ideas have already been presented at this meeting and the committee is looking forward to assessing the full picture during the focused review meeting in November.

Here are some more comments on the individual items. The committee is very impressed by the progress in consolidating and improving the injector system and SuperKEKB rings. For VXD, the committee would like to congratulate on the successful assembly of the system and notes that some delicate work still remains, such as the installation and testing, which should be handled with utmost care. The committee is pleased to hear that ageing tests with a CDC test setup will finally start in August and is looking forward to hearing the first results in November. CDC needs continuous attention and any sporadic current activity inside the chamber has to be carefully monitored as the amount of water in the gas decreases. High statistics comparison of performances among different sectors in Layer 0 should be made with the normal state gas mixture in terms of oxygen content. For TOP, the successful exchange of photon detectors is very much appreciated. The committee is eager to learn further progress in understanding the differences in quantum efficiency measurements observed between those taken on the bench and in situ and in the degradation of the quantum efficiency with temperature. The group is encouraged to continue its efforts to monitor and hopefully reduce the operating temperature of the detector. For KLM, the committee thinks that comprehensive and systematic studies of all the test RPC chambers will be needed to decide whether the inefficient layers of KLM should be treated with ammonia gas. Since the KLM gas system does not allow an isolated gas flow for those specific layers during the detector operation, and because it takes a long time for the gas volume of those treated chambers to become clean from ammonia, it should be absolutely certain that ammonia does not cause any damage to the chambers. The committee fears that deciding in August would be premature. Concerning the DAQ, the committee appreciates that the PCIe40 upgrade has been completed substantial progress has been made in speeding up error recovery. The committee looks forward to a report on trigger developments to improve the sensitivity to low multiplicity channels. The committee notes that work on data transfer from online to offline is well advanced with full system tests planned shortly after the BPAC meeting. While the work on monitoring and error handling by the central team is progressing well, the sub-detector teams should provide enough human resources to implement their systems.

For the progress in physics analyses, the questions posed are:

- *Is the progress toward summer conferences in good shape?*
- *Are efforts being put appropriately into analyses that should be focused on?*

After listening to three presentations on physics analyses, one summarising the overall situation and the other two focusing on dark sector physics and on hadronic B-meson decays, the committee again concludes "yes" to the two questions. The committee also applauds the successful effort to unify the analysis process for Belle and Belle II and produce combined results based on the two data sets, which is particularly important now for the core B physics program with the statistics of Belle and Belle II being comparable. Some of the physics results presented, especially when unblinding data sets, indicate that the sensitivity of the experiment has reached a level where in-depth understanding of the detector performance is required even for basic responses of sub-detectors. Being able to reproduce those responses with simulations will be crucial for the analysis. The committee is looking forward to learning about the progress in the understanding of the basic detector performance during the November meeting.

The committee learned about the ambitious goals of the experiment for 2024, i.e. to achieve a peak luminosity greater than $10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, a monthly integrated luminosity of 150 fb^{-1} and a total integrated luminosity exceeding 1 ab^{-1}. This will require very stable operation of the machine with high currents and low background, efficient data taking and sufficiently long running periods. The committee encourages the accelerator group, the Belle II collaboration, and the KEK management to strive towards this goal.

2 Injector chain and SuperKEKB rings

2.1 Status

A large number of improvements are being made to the linac subsystems and to the SuperKEKB rings in order to increase the delivered luminosity and to reduce the background levels.

This summer downtime is an especially active period for the linac. New pulse quadrupole magnets are being installed in the J-arc section and this will allow for separate optics solutions for the electron and positron bunches. In addition, new pulsed quadrupoles near the positron source will allow for a low beta lattice for the bunches for the High Energy Ring (HER) in this region. A fast kicker will be located at the end of the accelerating structure which will be used to correct the orbit of the second bunch with respect to the first bunch. New accelerating structures are gradually replacing the existing structures in the last three sectors of the linac. The current structures have been running in over the designed condition and are starting to break down. A new, larger vacuum chamber has been installed at the injection point for the HER and this should improve the HER injection efficiency. New beam diagnostics will be installed in the beam transport line and magnets are being realigned. The positron damping ring has received improved power supplies for the fast kickers that extract the beam bunch out of the damping ring. In addition, the vacuum in the damping ring has been improved which should make the stored beam more stable. All of these modifications are designed to improve the injected beam quality, intensity and efficiency for both the LER (low energy ring) and the HER.

In addition, there are several improvements in the rings and near the interaction

point. The vacuum leak in the final focus cryostat has been found, fixed and tested. The tungsten tips of the cryostats have been replaced with stainless steel units after a background study found the tungsten to be too thin to be an adequate shield and actually became a source of background. The shape of the cryostat front cone has been made thinner to accommodate the service needs of the VXD. Improved concrete shielding will be used around the detector. The non-linear collimator is being installed in the LER to reduce the limitation due to the transverse mode coupling instability observed on the positron beam, and several collimator heads that became damaged in the last run are being replaced.

2.2 Concern

- Many changes are occurring in the linac and in the main rings. At the time of restart of operation, the behaviour of new components and their impact on the SuperKEKB and Belle II performance need to be assessed. That may require a significant effort by the machine group.

2.3 Recommendation

- As mentioned in the short summary, the committee suggests that a plan for the startup of the linac and the SuperKEKB program be made, providing a balance between machine studies and delivered luminosity to Belle II.

3 Belle II detector

The status of the LS1 work on the Belle II detector was presented, including status reports on the vertex detector system (VXD) comprising pixel detector (PXD) and strip detector (SVD), the central drift chamber (CDC), the barrel particle identification system (TOP), the K-long and muon detection system (KLM), the data acquisition system (DAQ), and monitoring and alarm handling. These items are discussed in detail in the sections below. Overall the progress has been excellent, and the committee was happy to see that a detailed scheduling system has been implemented, including the availability of personnel. No particular concerns were raised for the other subsystems of the experiment.

3.1 Vertex detector (VXD)

3.1.1 Status

The VXD team is to be congratulated with the progress made to date during LS1. The PXD2 half-shells were safely transported to KEK in March and the mounting of the PXD on the beam pipe was completed on 5 April, 2023. Basic functionality checks then started with a full PXD2 cooling test during the period 17-20 April. Both the thermo-mechanical and electrical test results were satisfactory and the internal review committee gave the recommendation for the extraction of the current PXD and initiate

the installation of the new PXD on 21 April, 2023. The BPAC wishes to congratulate the team on this major achievement.

All 40 modules of the PXD2 are operational. Although the gliding mechanism has been studied intensely and improved (see reports of the October 2022 dedicated review and the last BPAC), three ladders exhibited a large deformation when operated at $-20\,^{\circ}\mathrm{C}$ and were fully powered. Two ladders on the negative x-side in the equatorial plane show a sagitta of about 500 μm; one ladder on the opposite side shows a sagitta of about 250 μm. The deformation largely disappears when the ladders are powered off. Even though the torque for these ladders has been lowered to 7.5 mNm, the origin of the deformation is not understood. The glue joint between the modules within a ladder has been extensively tested and it has been confirmed that a ladder can survive more than 50k thermal cycles even with larger deformations. The team is considering lowering the operating temperature of the PXD2 to $-25\,^{\circ}\mathrm{C}$ to mitigate the effect of the bowing of the ladders.

The VXD was safely extracted on 10 May, 2023 and the two SVD half-shells were safely dismounted on 16 and 17 May, respectively. Stand-alone verification of the SVD was completed on 2 June, indicating proper performance of the SVD. Just prior to this review the two SVD halves were mounted on the PXD2 and the VXD is currently being cabled with commissioning of the VXD planned to start in early July. A detailed day-by-day schedule has been developed for the installation of the VXD. The LS1 schedule is driven by the installation and commissioning of the VXD. The current schedule calls for the start of Run 2 on 11 December, 2023.

The original plan was for the PXD detector to be electrically isolated from the beam pipe. Just before the SVD attachment it was noticed that the PXD is electrically connected to the beam pipe. This situation is reminiscent of a situation during Phase-2 of the first run when the PXD was also electrically connected to the beam pipe with no adverse effects on its performance. The plan is to not try to fix the issue, since it would be too risky and there is no guarantee that it would improve the robustness of the detector.

3.1.2 Concerns

- The bowing of PXD ladders remains a concern. Continued studies to develop a full understanding of the origin of the bowing is suggested. One option to minimise the bowing is to lower the operating temperature of the detector. This may affect other systems and will require very careful study. For example, the glue joint may also be affected by temperature and its effect should be well understood before any permanent change is made.

- The grounding of the PXD2 to the beam pipe seems to have no adverse effect, but further checks of this are warranted.

- The LS1 schedule of Belle II is essentially driven by the installation and commissioning of the PXD2. There may be pressure on the team to complete their work as quickly as possible, at the risk of compromising the detector performance.

- The detector is entering its final stretch and we are looking forward to a successful conclusion. But it also means that some of the key scientists in the project will soon retire.

3.1.3 Recommendations

- Maintain the deliberate and targeted pace for the VXD installation and commissioning, and do not to compromise on the validation of the detector performance due to schedule constraints. The PXD team has come a very long way and the end goal of a fully populated two-layer pixel detector with great physics potential is within reach. That should remain the driving force for closing out LS1.
- Continue to study the ladder bowing, understand its origin and develop mitigation strategies.
- Appoint a small working group of experts of affected systems to assess the full impact of changing the operating temperature of the PXD.
- Document in full detail the construction and assembly of the as-built PXD2 detector. This reference document will help address any future issue that may arise during the many years of operation, when some of the current expert manpower will no longer available.
- Establish a safe storage location for the PXD1 to ensure it can be used as a fallback detector for the duration of the experiment.

3.2 Central drift chamber (CDC)

3.2.1 Status

Several major improvements to the CDC detector have been implemented during LS1, such as replacement of HV resistors to suppress gain drop at high rates, recovery of gain by decreasing water content using dry tubes, removal of oxygen with the help of oxygen filters after the large leak due to damaged tube in September 2022 and installation of additional gas outlet ports to increase circulation gas flow rate. In addition, improvements in monitoring and alarm systems, e.g. water/oxygen content, are foreseen to identify potential malfunctions in real-time. Significant progress has been achieved on all fronts, and the committee takes the opportunity to congratulate the CDC team on this progress.

The oxygen content has decreased to a level below 100 ppm, which is similar to the conditions of the 2018 physics run, when the oxygen monitor was properly working. Several medium size datasets with cosmic rays were taken after that. The onset of ageing effects has been studied by comparing gas gain between different sectors in Layer 0, where one of the HV sectors, sector-1, was switched off for an extended time. No difference in ADC spectra, where only hits on reconstructed tracks were compared, has been observed among different sectors within the statistical uncertainties. Higher statistics cosmic runs are foreseen in early August to achieve a finer comparison.

Over the last two months, the CDC water content decreased from 5000 ppm to 2500 ppm. During this period, silica gel tubes were replaced five times. Once tubes became saturated with water vapour, an increase in the water content was observed and they have to be replaced with new ones. This might indicate that water is still being released from the gas system and the CDC inner surfaces. Two new dry tubes are available and more can be purchased if necessary.

Last but not least, ageing studies using a laboratory test chamber are foreseen starting from August.

3.2.2 Concern

- Recent studies revealed that both water and oxygen monitors did not function properly.

3.2.3 Recommendations

- High statistics cosmic runs are necessary to compare CDC performance in 2023 with that of earlier data taking periods for quantities, such as angular and azimuthal distributions in different layers, as the gas quality is now close to optimal.
- Relative pressure measurements versus gas flow after installation of additional gas outlet ports should be used for determination of better operation point and safe margin.
- Systematic real-time monitoring of any sporadic activity inside CDC, such as HV trips and increase of leakage current, has to be foreseen while the water content level is decreasing.
- Considering the onset of persistent dark currents of unknown nature in 2018, it is recommended to keep the target water content at the level of at least 1500 ppm during the coming physics runs.
- Redundant real-time monitoring and alarm systems for water and oxygen content inside CDC have to be envisaged during the coming physics data taking.
- Ageing studies with a laboratory test setup have to be pursued to determine CDC chamber longevity. On a longer term, this might facilitate development and test of different remediation strategies for gain recovery, if anode/cathode ageing effects are observed.

3.3 Barrel particle identification system (TOP)

3.3.1 Status

In the period since the February 2023 review, the TOP group successfully performed the planned replacement program for the PMTs, and exchanged and repaired the front-end electronics, all within the scheduled time frame. The PMTs in the upper half

were replaced with new life-extended ALD PMTs. The PMTs for the lower half were selected and optimised for expected lifetime, while ensuring a flat quantum efficiency (QE) distribution within a given TOP module. For the most part, conventional PMTs were replaced by the best ALD PMTs from the upper side. Four PMT modules with the best conventional PMTs remain in slots 15 and 16. They will be carefully monitored and may need to be replaced in the next long shutdown. Thermocouples were also installed in four slots to monitor the PMT temperatures.

Dead board-stacks and front-end electronics were repaired, so that over 99.5% of the channels are active. Following the repair work, high rate DAQ tests were run for more than two weeks without any hardware issues.

The PMT QE measurement program at Nagoya was very active in characterising the PMTs from the detector during this entire programme. A clear correlation is observed between the bench measurements in Nagoya, and those measured by the detector monitoring. However, the slope is different from unity, and this is not yet understood.

Overall, this TOP intervention was a major success for the TOP team–made possible due to meticulous planning, preparation, and training, with support from the CDC cabling crew. The committee warmly congratulates the TOP group for their great effort and achievements.

3.3.2 Concerns

- As further PMT production is needed and, indeed, already underway, it would be helpful to present the production and testing plan at a future BPAC meeting.
- Although not a focus of this meeting, the overall performance of TOP still seems to be poorly understood.

3.3.3 Recommendations

- The differences in QE measurements between the bench and the detector monitoring need to be understood.
- Efforts to better understand the loss of PMT QE, and especially to understand and mitigate the effects of temperature on the PMT efficiencies, should continue.
- Increased contributions from the TOP group to characterise the physics performance at the detector level would be very helpful.

3.4 K-long muon detector (KLM)

3.4.1 Status

The low efficiency of RPC BB2 layers began in June 2021 when the gas circulation was interrupted. The continuous operation under water vapour contamination may have caused damage of the RPCs. It was confirmed that circulation of fresh gas with high rate did not cure the efficiency problem (during 2021-2022).

The degradation of the physics performance due to the low-efficiency of RPCs was determined. The muon identification efficiency in this particular region, BB2 and BF2 corresponding to 1/8 of the barrel system, is lower by 10% for low-momentum muons below 1.0 GeV/c, while there is no visible impact on the $K_{\rm L}$ identification. The effect has been taken into account for the run-dependent simulation samples and when physics analyses are performed.

Preparation for recovering the efficiency by flushing the chambers with a gas mixture containing ammonium is progressing. The first step is to learn the recovery procedure using test RPCs and then, if the tests are successful, apply the method to the damaged RPC layers. By operating the test RPCs with water vapour contamination, the efficiency drop was reproduced. First results on the recovery of efficiency of two RPCs by circulating ammonium mixed gas were reported. One chamber recovered the efficiency from 10% to 70%, and the other one demonstrated a modest recovery - from 5% to 20%, while the original efficiency was about 70%. Other results with RPC test chambers will be available soon.

The KLM group is reinforcing slow control monitoring and data monitoring to find similar problems in real time. The gas flow for each outlet line and the relief bubbler for each inlet will be monitored for a total of 832 channels.. The first electronics board for monitoring was tested in situ at KEK, and the second prototype board will be produced and tested in summer. In the most optimistic scenario, the whole system will be installed in October followed by the commissioning. In addition, a dew point monitor and additional mass flow meters will be installed, and inlet plastic tubes of BB2 are being replaced by copper tubes whenever accessible.

3.4.2 Concern

- The KLM gas system does not allow flushing specific layers with dedicated gas flow lines during the detector operation and it might take a long time to clean the chambers treated with ammonia. Therefore, it is premature to make a decision to treat inefficient RPCs with ammonia in August based on the currently reported results with the test RPCs.

3.4.3 Recommendations

- Comprehensive and systematic studies of all the test RPC chambers should be performed to draw a conclusion on whether the inefficient layers should be treated with ammonia gas.

- There is a possibility that gas flow monitoring and other condition monitors may take longer to commission than expected. It is recommended to start early tests in situ, since they will be important for stable and reliable operation after LS1.

3.5 Data acquisition system (DAQ)

3.5.1 Status

The DAQ team has used LS1 to complete the transition to the new PCIe40 based readout, while keeping the old COPPER system as a backup. The event-building software has been changed to now profit from the larger memory available on the hosting PC. This change improves performance significantly under congestion scenarios and has been successfully tested. Numerous performance improvements have been applied to whole event-building and distribution resulting in much larger headroom for future operation. Most systems have been intensively and successfully tested throughout LS1 and only minor issues have been observed, further discussed below.

The HLT has been strengthened and numerous improvements have been made to the HLT software. Directly creating ROOT files online can help to reduce offline resource requirements. This new scheme has been found to work well and, after some more tests, it is expected to become the new baseline.

The committee wishes to congratulate warmly the Belle II DAQ team and the subdetector readout experts for these significant improvements. The long list of very sophisticated and advanced improvements currently under investigation is a testimony to the achieved stability of the base-system and the ongoing commitment and creativity of the team.

3.5.2 Concern

- The FTSW connection via long (longer than 1 m) copper cables for trigger/clock distribution remains problematic. This seems to be induced by pick-up noise even on high-quality (Cat-7) cables.

3.5.3 Recommendation

- As the tests of replacing the problematic connections with optical connections were universally successful, this should be pursued as soon as budget and schedule allow.

3.6 Online data format

3.6.1 Status

The ongoing project of improving raw data transfer and workflow from Online (HLT) to Offline is progressing very well. It is expected to be completed by the end of LS1 to be ready for operation for the next data taking period. With the new system, the HLT units will produce files directly in ROOT format, avoiding the conversion of the old SROOT format to ROOT at KEKCC, therefore helping to sustain higher overall bandwidth because the files are smaller (compressed) and the conversion work is distributed to all HLT units. Small files created as a consequence of short runs will be merged on the DAQ servers before they are transferred, thus reducing unnecessary overhead for handling very small files. The new handshake protocol, using the Online database to communicate

between the DAQ and Offline the state of the run and files to be transferred, looks very reasonable, and the data transfer protocol based on XRootD seems to be a good solution.

3.6.2 Concern

- The design of the transfer and handshake protocol seems to be fine, nevertheless before putting the new system in production a thorough system testing needs to be performed. A variety of things can go wrong during data taking and the system should be resilient to many of these hiccups ensuring that raw data is never deleted before it is safely copied to offline.

3.6.3 Recommendations

- Testing the full system in a realistic manner, as far as possible, is essential. The committee recommends to devise tests to be run for longer periods of time to validate the sustainability and robustness of the overall workflow and to use a realistic mix of long and short runs, on which the merging processes will also be triggered. This will also allow the locking mechanism between data transfers and merging to be validated, that has been put in place to alleviate the contention in the disk I/O bandwidth.

- The committee recommends to prepare for data taking by systematically studying what could go wrong, by listing all possible problems and hiccups and evaluating how the system will react, the consequences and their impact. The most important asset to preserve is the data itself. Ideally, it would be nice to design specific tests to validate how the system reacts to the most common problems.

3.7 Slow-control, Monitoring and alarm handling

3.7.1 Status

The detector slow-control, monitoring and alarm handling are provided by the hardware oriented Detector Control System (DCS) and the performance oriented Data Quality Monitoring (DQM). Both provide monitoring and alarms (alerts) to the shift crews in the control room as well as remote. The DCS is also the principal system for experiment control. A review and consolidation process has started under the auspices of the technical coordination and run coordination. A prioritised plan for review, design, and implementation in 2023 has been established.

The main goals for the DCS are to satisfy new requirements, unify the behaviour of the processes across the sub-systems and to review and improve the monitoring system and alarm handling. Since the last review the following has been achieved.

Two reviews of the HV control, including the injection inhibit system, took place, summarising the current system and identifying the requirements of the new system.

This was documented and serves as the official document for future iterations and reference. The actual implementation has started and a first version is foreseen for end-August. For the alarm system, the Phoebus system, well integrated with CSS (Control System Studio), has been adapted. A demo version with basic functionality is ready. Concerning the detector environment monitoring, the assembly of a list of monitoring items from each sub-system and their alarm condition is in progress.

The main goal for the DQM is to reorganise the main control room DQM panels in order to provide the shifter with unambiguous information of when, and what kind of action is needed. Two main panels, one for monitoring the ongoing run and one for monitoring the longer-term (run-dependent) evolution, are foreseen. Since the last review, a revision of the DQM content has been done by all detector groups, at the same time making the approach more uniform across sub-detectors. The technical implementation by the central DQM group and all sub-detector groups is ongoing and a first version is foreseen end-summer. A test system with an HLT unit and DQM processing has been established. It is ready to be used by sub-detector developers using playback of existing raw data.

3.7.2 Concern

- A schedule for the review, implementation and test of the DCS has been established for 2023. In addition to the two main tasks of HV control and detector environment, interlocks and detector settings are to be completed in parallel. It is not clear whether sufficient human resource are available in the central and/or sub-detector teams, given the limited time for implementation and the need for thorough testing.

3.7.3 Recommendations

- There is considerable momentum in the consolidation effort. The upgrades of the detector control monitoring should continue to be given a high priority in order to achieve a well-tested new system in advance of the next data-taking period.

- A peer review process of the implementation would be beneficial, engaging people from sub-detector groups as well as central experts.

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

4 Physics

4.1 General status

4.1.1 Status

The overall progress and plan in physics analyses are very good. The analyses are competitive on many topics despite the limited data sample size. Many new results were announced at the Moriond 2023 conference. Most analyses were based on up to $\sim$190 fb^{-1} data. In particular, Belle II presented a new way to test light lepton flavour universality using angular asymmetries in $B \to D$ transitions, the world's best determinations of the τ mass and of the D_s^+ lifetime, and new results on hadronic B decays. The committee enthusiastically congratulates the collaboration for these scientific achievements. The collaboration also completed the first search for long-lived particles at Belle II, and it has progressed towards the exploration of the dark sector, with searches sensitive to new scalars, ALPs, Z's, and sterile neutrinos. Overall, 22 papers were accepted for publication in major journals in the last 16 months.

Several new results are in the pipeline for the summer conferences. This includes spectroscopy measurements, the measurement of $e^+e^- \to \pi^+\pi^-\pi^0$ to reduce the theoretical uncertainty in the determination of $(g-2)_\mu$, flavour violating tau decays, tests of flavour universality in the tau sector, and several hadronic and semi-leptonic B decays.

The collaboration finalised several efforts to streamline future data analyses. In particular, the collaboration finally successfully unified the analysis process for Belle and Belle II to produce combined results based on the two data sets. A detailed plan on how to handle joined analyses is now in place. This is particularly important now for the core B physics program with the statistics of Belle and Belle II being comparable. The collaboration decided that starting from Moriond 2024, no analysis based on run-independent Monte Carlo will be approved. This is very important to increase the quality, consistency, and precision of the published results. A new scheme for the theory-experiment interaction was established, whose structure is different from the highly successful B2TiP. It is more focused on the immediate needs of the experiment, which goes hand in hand with the fast pace of the data taking. Yearly focused meetings with theorists on particular topics of interest to the collaboration are envisioned. For example, this year's focus will be on $|V_{cb}|$ and related topics.

Lastly, the collaboration has been engaged with the US Snowmass 2021 and P5 processes.

4.1.2 Concerns

- After unblinding, the analysis teams sometimes met unexpected surprises that caused the delay of several high-profile analyses. This points to a less than adequate understanding of detector effects that are currently not modelled properly. It was shown that there were significant discrepancies between the simulation and the data in the modelling of the energy of electromagnetic clusters and reconstruction efficiencies of basic detector primitives. Not enough details were given during the

presentations for the committee to develop an informed suggestion. This indicates, however, that a more in-depth understanding of basic detector parameters than is currently available is required.

- While clearly useful for the experimentalists, the new theory-experiment interaction scheme is focused on the immediate needs of the Belle II collaboration. It is not clear that such a scheme will be also useful for the theorists in proposing new measurements, methods, and analyses that could be performed at the Belle II experiment.

4.1.3 Recommendations

- The committee strongly recommends to work towards a further in-depth understanding of the detector performance even for basic responses of sub-detectors. Being able to reproduce those responses with simulations will be crucial for the analyses. The committee is looking forward to learning about the progress in understanding the detector performance during the November BPAC meeting.

- The committee encourages the collaboration to complete the highly anticipated results from last February BPAC meeting, $R(X)$, $R(D^*)$ and $B \to K\nu\bar{\nu}$, soon, hopefully helped by the successful action indicated in the previous point, and the "staggered" procedure planned by the collaboration.

- The committee strongly encourages the collaboration to pursue and achieve the luminosity goals described during the meeting. This would make the experiment very competitive in most measurements and searches.

- The committee encourages further analyses based on the combination of Belle and Belle II data.

- Depending on the outcome of the first meetings of the new theory-experiment platform, it might be beneficial to broaden the effort.

4.2 Dark sector

4.2.1 Status

The collaboration completed one new dark sector search since the last BPAC meeting: the search for a long-lived new particle produced from B decays and decaying to two charged particles. In addition, two analyses got published: the tau decay to a lepton and an invisible particle and an invisible new gauge boson produced in association with two muons. The dark sector working group has already published several papers since the start of Belle II. Some of these analyses were based on smaller data sets, compared to the available data, in such a way to get timely publication. Nonetheless, the excluded parameter space for different dark sector models were often world-leading. The committee congratulates the collaboration on this progress.

Several dark sector searches are in the pipeline. This includes some searches close to completion: the search for a new particle decaying to taus and produced in association with muons, and the complementary search with the new particle decaying into muons. The collaboration has also started several other searches, particularly the search for an invisible dark photon, new axion-like-particle searches and the search for inelastic Dark Matter.

4.2.2 Concerns

- The impact of photon inefficiencies on the planned prospects for the invisible dark photon search is a concern which threatens the ultimate reach, as pointed out in the presentation.
- From the presentation, it was not fully transparent the difference in procedure when using the same data to search for different sectors of the dark arena (e.g., the parameter space for exotic scalars vs. that for ALPs decaying into taus), nor the hypothesis involved in the different analyses.

4.2.3 Recommendations

- The committee congratulates the collaboration in recruiting more man power working on dark sector/low multiplicity searches and encourages to keep the pace in producing new results on dark sector searches.
- The collaboration is leading an effort dedicated to discussing trigger strategies for the coming run. This work is encouraged by the committee, since triggers are a critical issue for searching for dark sectors at Belle II. Trigger strategies that allow dark sector searches should be continuously maintained.
- The committee encourages completing dark sector searches that are more involved, e.g. the invisible dark photon search, in a timely manner.

4.3 Hadronic B decays

4.3.1 Status

The collaboration performed several impressive analyses of hadronic B-decays, focusing on the ones with neutral mesons in the final state, where B-factories have considerable advantage over other B-physics experiments with prioritised topics following the roadmap for the key LS1 analyses.

Five new analyses were presented at the Moriond 2023 conference, resulting in four new papers. The topics include extraction of the CKM angles ϕ_1 (with $B \to K_S\pi^0$) and ϕ_3, as well as isospin analyses in $B \to hh'$ decays. The GLS/GLW studies of CP-violating angle ϕ_3 used both Belle and Belle II data sets. Notable results also include measurement of CP-violation in $B \to K_S\pi^0$ decays, and observation of $B \to DKK_S$ decays. The analyses underway include $B \to \rho\rho$ needed for the extraction of ϕ_2 (another flagship Belle/Belle II analysis), as well as $B \to Dh$.

4.3.2 Concern

No particular concern is found.

4.3.3 Recommendation

- The committee congratulates the collaboration on successfully completing the presented analyses and encourages to keep the pace in producing new results in hadronic decays of b and c-flavoured hadrons.