B-factory Programme Advisory Committee
Full report for the 13th Focused Meeting
Review on Readiness toward Phase 3

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1 Short summary

The Belle Programme Advisory Committee (BPAC) is very impressed by the rapid progress made by the SuperKEKB collider for the Phase 2 run, rapidly achieving luminosities well above 10^{33} cm^{-2}s^{-1}. Similarly, commissioning of the Belle II detector is also advancing fast, demonstrating full capability to reconstruct B mesons.

The goal for the Phase 2 run was set to achieve a luminosity of $\sim 10^{34}$ cm^{-2}s^{-1} with machine background under control. While the luminosity achievement is good, understanding of the background requires quite some more work. The background level is much higher than anticipated from the simulation studies. Some of the background sources are not yet identified. In this situation, it is very difficult to extrapolate reliably the level of background at the design luminosity. Systematic studies of background require the machine to be operated in a stable condition. Given that the machine luminosity is already quite high, the committee thinks that some dedicated time should be given to the background studies between attempts to further increase the luminosity. Continuous injection must be thoroughly tested during the Phase 2 run so that it can be routinely applied without affecting the detector operation during Phase 3. Although there is still much work to be done, the committee is confident that SuperKEKB can be ready for Phase 3 operation after the long shutdown that will start in July of this year. Adding the proposed additional collimators in the Low Energy Ring is strongly endorsed.

The general detector operational status indicates that there is no show stopper for the transition to the Phase 3 run, provided that a mechanism for safe running of the detector is validated. Sequences of operations can bring the detector to a dangerous state, particularly with high voltage. The safety of the detectors should be protected by a robust control system, which is backed up by hardware interlocks. It should be noted that even the best operational procedures can never prevent human error. Operation of the vertex detector must be particularly well protected. The beam-abort system, based on very robust detectors such as diamond sensors, is essential and should be installed with sufficient redundancy. All the background information should be shared with the SuperKEKB control room.

The committee is very pleased to learn that the ladder assembly of the Silicon Vertex Detector (SVD) has been completed and that the ladder mounting of the second half shell is expected to be complete in early July. It is on track to be ready for installation during the summer shut down for the Phase 3 run. It is also very pleasing to see how well the SVD and PXD wedge has been integrated into the Belle II data taking and is making valuable contributions to the background studies.

On the other hand, production of the Pixel Detector (PXD) has experienced considerable delay and only the first layer can be fully equipped where one of the ladders comes with a poor quality sensor and no spare ladder is available. The second layer can be equipped with only two ladders. The committee considers that the PXD group should complete the detector with this configuration and the system should be sent to KEK for the preparation to be installed together with the SVD. Although the system is incomplete, it will provide indispensable operational experience and be useful for physics. One of the two half shells for the first layer has already been mounted with well functioning ladders. However, the PXD group is planning to make some intervention by dismounting ladders in order to rework the electrical insulation. Although practiced with dummies using the second half shell, this operation involves a risk without guarantee for success. Therefore, the committee recommends that the PXD group first makes a careful risk assessment and validation of the effectiveness of the rework from the second half shell. In parallel, the PXD group should make an effort to produce one more Layer-1 ladder after re-examining the production process and failed ladders. If successful, it would become a valuable spare in case of an accident in the repair process, or eventually a replacement for the ladder with poor sensor quality. The current plan presented is to replace the present PXD with a fully equipped PXD during the next long shutdown considered for summer 2020. Given the long construction time, the preparation work has to start now. The committee stresses that enough sensors should be fabricated in order to make sure that the new system will be equipped with first grade sensors and be ready for installation by summer 2020.

The committee recommends that the Belle II management closely follows the development of the PXD project and has experts external to the PXD group analyse the ladder production procedure.

2 Belle II physics prospect with Phase 2 data

The main goal of Phase 2 run is the commissioning of the SuperKEKB and Belle II detector. By the time of the BPAC meeting, 370 pb^{-1} of data have been taken at different levels of readiness and stability of the detectors and triggers. The Collaboration has successfully used the steadily improving performance to observe light mesons and baryons, charm and charmonium, and several B decay modes. Despite the modest integrated luminosity in Phase 2, the search for dark sectors remains the expected highlight of Phase 2 physics, since achieving the best limits on some scenarios remains feasible. A key for this is the single photon trigger in the first level.

The collaboration has also started planning its first publications. The Belle II Physics Book is in Collaboration review, and will be published soon. In preparation for Phase 3, a data challenge with $1\,\mathrm{ab}^{-1}$ generic $\Upsilon(4S)$ simulation sample with undisclosed new physics signals added is progressing well.

2.1 Machine interface and background

2.2 Status

Commissioning of the accelerator has made a good start and it is hoped to make further progress before the summer shutdown on July 17. The machine has achieved up to 4.2×10^{33} cm^{-2}s^{-1} peak luminosity and been able to deliver colliding beams to the detector. It is still operated with a relaxed β^* lattice and this should give the stored beam more room in the final focus magnets and central beam pipe.

2.3 Concerns

- The accelerator is suffering from a large number of final focus magnet quenches primarily due to beam losses in or near the cryostats.
- Levels of background from both single and colliding beams are higher than expected. Although the radiation levels in the diamond sensors are not too far from expected, the radiation levels in the PXD part of the BEAST Phase 2 detector are about 10-100 times higher than expected. Since the diamond sensors are relatively insensitive to Synchrotron Radiation (SR) backgrounds, it looks like that the PXD is getting a higher SR background than expected. The source of the extra SR has not been found and efforts are being made to try to track down this unexpected source.

2.4 Recommendations

- The committee strongly suggests making dedicated collimator studies for both rings. Many of the collimators are more open than the design settings and this may be a main reason for the high backgrounds in the detector. The design settings of the collimators may not be fully optimal for the relaxed lattice design currently in use. It is possible that the beam pipes in the cryostats and in the central region are the smallest physical aperture in the entire ring if the collimators are open. The collimator study may also result in reducing the QCS quench frequency. The collimator tightening may also have an impact on the injection backgrounds and efficiency and additional injection studies may also be necessary.

- Ongoing efforts to try tracking down possible extra sources of SR background is strongly encouraged. The addition of extra shielding for SR should be carefully considered and installed.

3 VXD, CDC, TOP, ECAL and KLM status

3.1 VXD

3.1.1 Status

The production of the Phase 3 beam pipe has been completed and the committee wishes to congratulate the collaboration on this significant achievement. The twist of the Phase 3 beam pipe has been reduced significantly with respect to the Phase 2 beam pipe and the new pipe meets all specifications. Although the backgrounds during Phase 2 are high, the collaboration has decided not to add a tantalum foil on the titanium part of the beam pipe in order not to cause any possible interference with the PXD. The mechanics and infrastructure are all ready for the VXD integration. The tools for cabling and installation of the piping are also complete, with the only remaining item being the forward patch panel cable cage. The VXD group plans on installing additional diamond sensors for background monitoring.

3.1.2 Concerns

- Due to the delay in the PXD production, only the first pixel layer of the VXD will be equipped with sensors for the initial Phase 3 physics run.

3.1.3 Recommendations

- The committee strongly endorses the installation of additional diamond sensors interlocked with the beam abort system for background monitoring.

3.2 VXD-PXD

3.2.1 Status

The PXD has been smoothly integrated into the Belle II Phase 2 data taking and is operating with excellent pedestal and noise distributions. The automation is at the level where a permanent presence of a PXD shifter is no longer required. The detector is stable at the micron level, in spite of the modules being freely mounted, that is, modules rather than ladders were installed. There is just one failed link out of 4×4, although the reasons are not yet understood. The main missing elements still to be demonstrated are the region-of-Interest selection and high level trigger event filtering, the firmware development for overlapping triggers, which currently prevents 30 kHz operation, and the gated mode operation.

The PXD group is making very detailed studies of backgrounds and has identified high occupancies at injection, bursts of high occupancy events, and a low energy photon peak, the source of which is currently not understood. The total ionising dose, inferred from the measured threshold voltage shift of the installed Phase 2 modules, gives an estimate of a total received dose of around 2-5 kGy, which is a factor 50-100 larger than estimated from the rates monitored in the diamond detectors. This could be due to the different positions and angle of mounting, the possible large contribution from the low energy photons that have an unconfirmed source, or the phi-position of the PXD sensors. We note that in this running period the luminosity related dose is currently about two orders of magnitude less than expected for the final detector running. However, the PXD is designed to withstand about 20 kGy per year based on MC simulations, with the dose completely dominated by 2-photon QED background not including any additional dose accumulated during injection. Although it is expected that the detector can tolerate a dose higher than 200 kGy, a better control of the backgrounds, in particular during injection, is mandatory, and is indeed expected when the collimators are optimised.

The status of the PXD detector for Phase 3 is sobering. It has become clear over the course of the last months that installation of a full vertex detector at the start of the Phase 3 run is no longer possible and PXD construction continues to face considerable challenges. The status at the time of the review was the following. Four grade A L1 ladders were installed on the first half shell and were being tested at DESY. The tests revealed higher and distorted noise distributions when voltages are switched on and cross-talk between modules. It is thought that damaged parylene coating on the support cooling block causes a high Ohmic contact with the sensor and results in the performance degradation. A full short was discovered during the mounting of ladders on the second half shell, which is attributed to the same cause. It is proposed to add a 20 μm thin mylar foil between the sensor and cooling block. The effect of the additional mylar on the thermal management was verified in simulation to give a 4-5 degree worsening of the thermal performance, which is deemed acceptable. It does introduce complexity in the construction. Moreover, retrofitting the populated first half shell implies transport from DESY to MPP and back and dismounting and remounting the ladders.

A second problem was observed during the ladder assembly, apparently involving damage caused by small particles pressing into the pixel matrices during the gluing process. This affected modules during the construction of ladders for the second half shell and is also believed to have affected a module in the first half shell. The origin and nature of the particles is not fully understood. It is speculated that they are associated with the 3D-printed transport boxes. Furthermore, it is not fully established that the particles are the true cause of the damage. During ladder gluing the modules are considered to be mechanically protected by introducing a 50×50 μm^2 nylon mesh during the gluing to trap the particulates. The modified gluing procedure is still under study, however, since a recent build of a Layer-1 ladder still resulted in a damaged ladder, the cause of which may or may not be due to particulates.

The current situation for L1 is that 8 ladders are available, albeit one with slightly reduced quality. Re-work is being attempted on one additional ladder. Two backward and one forward module are potentially available to assemble one more ladder. Building a new ladder is deemed too risky while the gluing problems are not fully solved. For Layer-2, the ladder assembly is currently halted, even though one ladder was successfully glued with the nylon mesh. Two L2 ladders are currently available and there are enough modules to make 15 more. The PXD group proposes to concentrate on the assembly and commissioning of the L1 halves with the available ladders, and to install the PXD with a fully populated Layer-1, albeit with one ladder of slightly reduced quality, and only two out of 12 Layer-2 ladders, with the Layer-2 ladders shadowing the Layer-1 ladder of reduced quality. The PXD group has started the production of a new set of wafers that would yield modules for another set of eight Layer-1 ladders.

3.2.2 Concerns

These last few months of the completion of the pixel detector before installation in the detector will be very demanding. The committee is unclear who now in the PXD group carries the ultimate responsibility and sign-offs on the proposed course of action. For example, while various hypotheses regarding the source of the electrical performance are still considered, it was unclear to the committee who in the end makes the decision and assumes responsibility for final sign-off. Similarly, it was unclear who and what process will be followed to stop or resume mounting or gluing ladders, or re-evaluate procedures. The committee unfortunately assesses the probability for an incomplete Layer-1 to be non-negligible and urges the PXD group and collaboration to proceed with utmost diligence.

3.2.3 Recommendations

- The committee notes that the integrated dose of the currently installed ladders is quite high related to the detector lifetime and strongly encourages effort be directed towards understanding the various background sources to ensure that the detector can be protected for Phase 3 running.

- It is recommended that the matrix of the interference tests between modules of the first half shell be completed as quickly as possible and correlated to the optical observations of the parylene damage.

- The committee recommends to verify the electrical performance of the second half shell and to confirm that the addition of the mylar has the intended effect before proceeding with dismounting the ladders on the first half shell and adding the mylar foils.

- The committee supports the decision of the PXD group to suspend the gluing activities until the ladder building problems have been understood, both for L2 and the remaining L1 modules. The committee recommends that an external expert be engaged immediately to help evaluate the ladder production procedure and help with the investigation of the cause of the failures.

- The suspension of the ladder production to understand the gluing issues has the consequence of installing the PXD with L1 and just two L2 ladders for Phase 3 running, which is expected to extend up to at least 2020. The committee notes that, after the PXD installation, this will result in the PXD group running three parallel activities: the commissioning of the Phase 3 PXD and the analysis of the data, the investigation of the electrical performance of the half shells, and the launch of the next PXD production round. The collaboration is strongly encouraged to explore strengthening the manpower resources of the PXD group to meet these challenges and ensure the success of the installation of a complete PXD detector around 2020. A clear organisational structure is recommended so that the personnel responsible for each task is clearly identified.

- The committee encourages detailed simulation of the VXD with the latest beam pipe design, backgrounds at various levels and full performance evaluation of the VXD with zero, one and two PXD layers.

- The committee recommends that a very clear and strict protocol for the decision taking process be established during these last months to validate and support as much as possible the reason(s) for each decision.

- Collaboration management is strongly urged to closely follow the development of the PXD project and to request an analysis of the ladder production procedure by experts external to the PXD group.

- Now that the beam pipe has been finalised, it is recommended that care be taken to make sure that it is properly modelled in the simulation and that all layers including the new 2 μm Titanium layer and the final thicknesses are properly implemented, especially if new studies are about to be launched concerning the performance with different numbers of PXD layers.

3.3 VXD-SVD

3.3.1 Status

The SVD group completed the ladder production in May and at the time of the meeting a full half-shell was already assembled. There are no show-stoppers for the completion of the second half-shell by July 2018. Since the last BPAC only minor problems have been encountered and managed efficiently. The committee commends the collaboration for this achievement and is looking forward to the commissioning of the detector in the B4 cleanroom. The preparation for the test stand has been completed and reviewed by the SVD QC group. It will allow a complete readout of the detector with the final readout system, CO_2 cooling, interlocks and the full power supply system. System tests of the SVD, including cosmic runs, can continue during PXD assembly and will last until the SVD-PXD integration will start.

Operation during Phase 2 is providing important information for the background measurement and evaluating the machine safety. Based on the observed hit rate, an increase in the background level is observed that is approximately one order of magnitude greater than expected for the LER and two orders of magnitude (even though the total rate is smaller) for the HER. It is expected that such background levels will be reduced by optimisation of the collimator settings and could be further reduced with the installation of additional collimators before Phase 3. Even at the current level, background should not be critical for the detector operation. The detector has a high S/N ratio, and is already aligned to 20 μm resolution. It shows a time resolution better than the 16 ns bunch crossing spacing and therefore timing information may be integrated in the track reconstruction. The diamond detectors, which are part of the SVD, are now providing a beam abort signal with 100 kHz integration time, which is effectively protecting the QCS from quenching. It also provides an instantaneous dose measurement.

3.3.2 Concerns

No particular concerns were identified for the SVD.

3.3.3 Recommendations

The committee makes the following recommendations:

- Continue towards the installation of the detector according to the schedule presented at the meeting and complete the beam radiation monitor for Phase 3, verifying an adequate redundancy of the beam abort system.

3.4 CDC

3.4.1 Status

The CDC was carefully calibrated and aligned in Phase 2, enabling rapid observation of excellent multihadronic D and B decay candidates in Phase 2 data. For example, robust signals of the D decay modes, $D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, and $D^0 \to K^-\pi^+\pi^+\pi^-$ were observed with peaks in both D^0 mass and the mass difference between the D^{*+} and D^0 candidates. Typical measured resolutions are already within about 10% to 15% of those estimated in Monte Carlo simulations. B meson candidates were reconstructed in a variety of multihadronic modes. The beam constrained mass distribution of these candidates already shows a clear signal peak above background. dE/dx bands for electrons, pions, kaons, and protons are already being exploited successfully for particle identification (PID).

3.4.2 Concerns

- During Phase 2 several problems were identified in a total of 26 CDC front end boards (FEBs). This is a substantial increase above the 3 FEBs with HV problems identified in Phase 1. Understanding these problems and implementing mitigation strategies is the major challenge for CDC readiness for Phase 3.

3.4.3 Recommendations

- The CDC group must be very well prepared to address successfully the CDC FEB issues in the 2 weeks allocated for this effort in the shutdown schedule.

3.5 TOP

3.5.1 Status

During the meeting, impressive progress was reported by the TOP group in the following areas: performance of the production firmware, in particular with Phase 2 experience; high-rate tests; Phase 3 preparation and data quality; masked channels; and the TOP trigger status.

In March 2018, the production firmware was rolled out using feature extraction for the first time. The firmware was running mostly in stable conditions during luminosity runs with trigger rates below 1 kHz. Occasionally, various issues occurred, some of which required a power cycling, resulting in an O(1 h) restart time. High-rate tests at higher occupancy, important for Phase 3 preparation, are showing issues at 10 kHz or higher which are understood to be linked to latency and can be solved. Primary issues with the production firmware data quality (carrier offsets, short waveforms, and channel level inefficiencies) are understood and expected to be fixed soon. The main outstanding firmware issues are at this point: truncated waveforms that are planned to be fixed by the end of Phase 2; improvement of the robustness and recovery time of the firmware before the start of Phase 3; stable operation also at higher rates and occupancies, where, e.g. the feature extraction is crucial to lower the gain from the current 5×10^5 (due to high backgrounds) down to the target gain of 2.5×10^5. Lowering the gain is important for the lifetime of the conventional MCP-PMTs until their replacement, foreseen in 2020. About 1.7 % of all readout channels are currently masked, either due to PMT issues, to be investigated after Phase 2, or due to carrier or ASIC issues, which are (partially) recoverable by firmware modifications or parameter adjustments. The TOP timing signal works well for cosmic ray runs but is not yet usable for collision data due to the high background rate. PID performance (efficiencies and fake rates) with Phase 2 data has been presented already, but the results are not yet at the anticipated level.

An additional list of issues to be addressed for Phase 3 preparation was presented to the committee:

- Validation of PID performance through a sufficient number of di-muon events for alignment, common T0 determination, determination of hit number, and its dependence on $\cos\theta$.
- Improved calibration through new calibration data (local T0 from laser data, time base constants).
- Clarifying the effect of the MCP-PMT rotation.
- Implementing a feature extraction with the template fitting technique in order to reduce the gain to the target gain, by Phase 3.
- Resolving the issue of waveform truncation during Phase 2.

- Check of the ultimate PID performance based on improved calibration and alignment.
- Recovery of the masked channels.

3.5.2 Concerns

- While it is hoped that backgrounds in Phase 3 can be reduced below those in Phase 2, the target gain for Phase 3 running is a very important goal to ensure that the lifetime of the conventional MCP-PMTs is sufficient for operation until at least 2020.
- Readiness for operation at high rate and occupancy is another important goal.
- Full demonstration of the PID performance is also a high-priority goal.

3.5.3 Recommendations

- The TOP group has a clear picture of the topics to be addressed for Phase 3 preparation and should prioritize the work ahead based on the available manpower.

3.6 ARICH

3.6.1 Status

The ARICH collaboration also reported impressive progress in dedicated presentations on the detector operation experience gained during Phase 2, with emphasis on the firmware issues and the plan to install additional cooling after Phase 2, which was presented in the BPAC meeting in February 2018.

During Phase 2 operation, the full ARICH can not be operated over a long time due to insufficient cooling of the front-end boards and merger boards (MBs). Therefore, most of the time the ARICH was operated with only 2/3 of the FEBs and MBs switched on. To prepare for Phase 3 operation, it is planned to open the endcap during the shutdown and separate the ARICH and ECL endcap to install copper pipes for additional water cooling. It is possible to install this cooling without a MB re-design using an additional aluminium cooling body mounted on the back of the MB. An additional pipe for each sector will be attached to the ARICH aluminium holding structure to provide additional cooling for the FEBs. In addition, it is planned to add an additional cooling plate with a thermal pad on the FPGA chip of the FEB. Modifications to the structure seem to be minor. The time schedule for tests, production, and installation was presented with the first cooling mockup test foreseen in July 2018 and the first full test by end of September or beginning of October 2018. According to the schedule, full installation should be finished by the middle of November 2018, giving some contingency before start of Phase 3.

Phase 2 detector running has revealed that nine of the merger boards show problems and therefore are currently excluded. Since a complete system test after installation and before Phase 2 operation was not possible, these problems were not detected earlier. Studies of these nine MBs will be done in the remaining time of Phase 2. It is planned to fix these problems or replace these MBs during the shutdown. The MB problems could be due to connector or cable problems, since connector issues were already reported in the February 2018 meeting.

Important progress was made with the ARICH firmware. At the beginning of Phase 2 the ARICH firmware was not fully functioning, but the ARICH detector is now being fully operated inside the global DAQ system at high rates, which is a major achievement. Based on reconstructed tracks from beam collisions, Cherenkov rings can be reconstructed. The functionality to control the ARICH via the GUI is implemented. However, there is still a list of issues to be addressed in connection with the firmware and currently these are addressed only in part by fixing the firmware. The ARICH also observes (global) DAQ problems, which in part are also observed in other subsystems (e.g. "ttlost" and "clocklost"). The ARICH slow control, due to the very large number of parameter values to be stored in the EPICS archiver, experiences problems. Therefore, currently this information is only stored locally. The analysis software (histograms/graphs) is still under development.

A list of issues to be addressed for Phase 3 preparation was presented to the committee:

- Implementation of SEU detection in FEB firmware (to monitor radiation damage).
- Investigation of problematic mergers in Belle2Link during accelerator studies.
- More preparation of Slow Control and logging.
- Investigation of the problematic HAPDs reported on at the February 2018 BPAC meeting (to be replaced after Phase 2).
- Study of the alignment.
- Study of PID performance, which requires more preparation on the treatment of unused channels (dead, masked, etc.).

3.6.2 Concerns

- Although the modifications to the ARICH design from the additional cooling do not seem to be critical, it is not completely excluded that undesirable effects on the ARICH will be introduced. The same holds for integration effects on other sub-detectors.
- If the DAQ problems with these nine MBs are induced by connector/cable problems, they might be easily fixed but could also point to a possible weakness in the connector design.
- Manpower might be a concern to fix the open (firmware) issues for Phase 3 readiness.

3.6.3 Recommendations

- The ARICH team should plan carefully how to put sufficient manpower on firmware, DAQ, slow control and study of the alignment and PID performance during the remaining part of Phase 2 and in the preparation time for Phase 3 operation.
- The problems with the nine merger boards should be carefully studied to ensure that no problem exists in that part of the electronics.
- The first cooling mock-up test should include, if possible, not only thermal testing, but also readout tests to make sure that the ARICH readout is not unexpectedly influenced by the modifications.
- The ARICH team should carefully plan, in close collaboration with the technical coordinator, the additional cooling measures and their installation, taking into account not only the requirements of the ARICH but also of the adjacent subdetectors, effects on the overall detector performance, and possible damages to the ARICH and other subdetectors by the installation procedure.
- The ARICH team should prioritise the work to be done for Phase 3.

3.7 ECL

3.7.1 Status

The performance of the ECL during Phase 2 has been excellent. All counters are working and the ECL DAQ works well. The energies and times of hits are reconstructed correctly and the ECL also provides online luminosity measurements. Robust π^0 and η signals are clearly evident above combinatorial backgrounds. Between Phases 2 and 3, a number of routine maintenance efforts will be underway, along with firmware and DAQ upgrades. With these improvements and calibration refinements, the ECL should be ready for Phase 3.

3.8 KLM

3.8.1 Status

The KLM is now taking data from all modules including the scintillators as well as the RPCs and provides muon identification. Run control and HV slow control are operating stably and HV interlock to KEKB is integrated in the master.

In order to take data from the scintillators, a simplified version of firmware without utilising waveform information was developed. The simplified firmware can send trigger primitives and timestamps which are more or less equivalent to the information sent by the RPCs. However, the efficiencies and DAQ rates are still low for scintillators, and further tuning is required. A hardware interlock was implemented to turn off high voltage to protect readout electronics when the low voltage power supply for the electronics fails.

The RPC part of the electronics is in good shape. It can function with the DAQ at a 30 kHz trigger rate, although a firmware upgrade is required to accept two triggers within 200 ns.

During the Phase 2 run, three sectors out of 16 are off due to a power issue of three VME crates. Since the VME crates for the BKLM are more than 20 years old, a plan is to replace those VME crates.

Basic capability for the muon identification is in place although it requires some improvements. The KML trigger had a latency issue and is being addressed.

3.8.2 Concerns

- There are still a number of issues in the firmware, such as missing waveform information from the scintillators, high rate operation of scintillator readout, accepting short trigger separation capability, and trigger latencies.

3.8.3 Recommendations

- The KLM group should be well organised with priorities set to address the remaining firmware issues in preparation for Phase 3.

4 Trigger, DAQ, detector control and interlock

4.1 Trigger

4.1.1 Status

Trigger work is making steady progress. Trigger rate of about 230 Hz at a luminosity of $\sim 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, is well below the designed capability of the Belle II trigger and DAQ systems. Physics triggers are based on 2D tracks and calorimeter information. Timing information is provided only by the calorimeter for this run. Physics trigger rate accounts for 65 Hz. In addition, data are taken for calibration and background events that will be used in the Monte Carlo simulation as overlay events. Without 3D-track reconstruction, background rejection is found to be difficult. Various triggers have efficiencies of around 90%, acceptable for the moment, and are operating stably. The CDC trigger suffered initially for a significant amount of the time from a bug in the implementation of the Belle2Link in the Track Segment Finders. It still needs some hardware work to reduce noise and to implement 3D-track trigger. Excessive rate generated by the TOP trigger has still to be understood.

4.1.2 Concerns

- 3D-track trigger with the CDC is not yet implemented. As results, background cannot be controlled and its classification is difficult.

- Only the ECL trigger is fully integrated in the slow control. The overall trigger control is not integrated in the run control.

4.1.3 Recommendations

- Hardware issues such as lost link, noise etc. should be fixed as much as possible during the shutdown period
- At least one of the two 3D-track trigger systems should be brought online.
- All trigger subsystems should be integrated in the slow control, even if they are not working perfectly, to gain vital operational experience and to enable the capabilities for automatic recovery. Integration of the trigger in the run control should be a priority.

4.2 DAQ

4.2.1 Status

The data acquisition system has been working well in Phase 2. A detailed analysis of the causes for DAQ downtime has been presented, which demonstrates that the DAQ team has a very good understanding of the weak parts of the system. The DAQ team presented a new circle of experts-in-the-making, who will be able to assist the core team.

4.2.2 Concerns

- The file handling and copying to the offline seems not well developed. There is a danger for generating errors and, in the worst case, data loss.
- Causes for the failures of the COPPER CPUs are not understood. Since the operating system monitoring gives no indication of any problem prior to the freezes or crashes, there is a reason to fear a - transient - hardware issue, such as, for example, a weak supply voltage.
- There are still occasional problems with the Belle2Link, even though these seem to originate in the sub-detector firmwares.
- Although the system works globally well in Phase 2, the rates are still much lower than what Belle II is aiming for. The committee had the impression that several subsystems are already at the limit of the rate they can tolerate.
- The core team is still very small and the addition of outside experts is only just starting.

4.2.3 Recommendations

- The training of additional experts must be followed up vigorously. These experts could also help with writing documentation to help newcomers.
- The limitations in the sub-detector DAQ systems in terms of rate and stability must be catalogued and monitored constantly. Whenever possible, the root cause should

be followed up to avoid that problems remain because of unclear responsibility between the central and subdetector DAQ groups.

- The file handling should be made robust by a small team with at least one expert from DAQ/online and one from offline.

4.3 Slow control

4.3.1 Status

Efforts of the extremely small, devoted expert crew cannot be commended enough. The slow control, which includes the run control has made significant progress. Operation by a small shift crew is now possible, when there are no significant problems. The capabilities of the run control and slow control panels are continuously extended.

4.3.2 Concerns

- Despite of the increase in the number of members, the central DAQ and slow control teams is still uncomfortably small
- The system was affected on several occasions by computer hardware or operating system issues, which had to be fixed by the central team.

4.3.3 Recommendations

- The Belle II management is encouraged to help the slow control and data acquisition team not only by requesting more collaboration members to join the group, but also by finding technical support for computer hardware and operating system management. The Belle II online computing infrastructure is already quite significant and it will certainly grow. With the help of a dedicated system management support and more junior experts, the small core team will have more time to develop robust and lasting solutions for the open issues and be relieved from routine technical duties such as disk changes, backups, testing of security patches and maintenance of the operating system.
- The scalability of hardware and software for the growing needs of the experiment should be analysed such that hardware upgrades and software changes can be planned in advance, in order to avoid interfering with the physics run. Some funding for hardware might well be necessary, e.g. for redundant server and storage infrastructure.
- In some cases, ease of operation can be acquired by using commercial solutions. An example is a commercial file management system with automated backups, snapshots, etc. Such systems come with built-in redundancy, allow for easy upgrade without downtime and guarantee well tested security updates.

4.4 Interlocks

4.4.1 Status

A brief overview of the interlock box was presented. However the VXD was not included in the global system and an overview of the integrated concept showing all components including elements such as IBBELLE was not shown. The role of the hardware interlocks as a last line of defence is crucial for the experiment and functionality such as injection inhibits in the case of peak voltage on the PXD or non safe CDC conditions are very important.

4.4.2 Concerns

- The committee noted with some concern that due to a human error in configuring the slow control, the detector was potentially put at risk.
- The interlock system seems to consist of multiple parallel systems and not to be well monitored by the slow control.

4.4.3 Recommendations

- Detector safety should be ensured by automated failsafe hardware systems, such as for example Programmable Logic Controllers, wherever possible. These systems are the last resort and normally equivalent protection mechanisms in the slow control would be expected to alert the operators or take automated actions before. But complex software systems can hardly be made completely error-free and human operators will often make mistakes. Improved instructions and procedures for the operators are a necessary part of continuous improvement of the operation of the experiment but not sufficient.
- The interlock system should be coherently implemented such that all systems pass through the same path. Coherent monitoring of interlock sources and actions with time-stamping should be put in place. The scenario of directly connecting the output of the VLHI to the central interlock should be considered. This could add hardware functionality for an injection inhibit in case of unsafe voltage conditions on the PXD. Similar scenarios could be imagined for the CDC.

5 Software and computing

5.1 Status

The committee was extremely pleased to learn that the Belle II offline software has been ready and successfully used for the full Phase 2. It has been running in a very stable manner in the High Level Trigger (HLT) and for the production of mDST; furthermore it has allowed members of the collaboration to produce nice results from first collisions very shortly after the data was collected. The HLT has been running in flagging mode without selecting events, and adding the trigger decisions to the output. This has been exploited to select events for the event display and to produce skims offline. Monitoring of event processing via DQM plots has been improved during the run. The tracking software including alignment and particle identification has run very nicely and testing of more advanced algorithms is progressing well.

A dress rehearsal for Phase 3 software is being carried out to test the capability to register and process RAW data with the distributed computing system and identify potential issues/bottlenecks.

The migration of computing services from PNNL to BNL was almost completed successfully at the time of the BPAC meeting. The committee acknowledges that this very smooth transition has been achieved thanks to the efforts of the Belle computing and software groups in collaboration with PNNL and BNL teams. The only visible negative impact has been the delay in the development of some essential computing end-user tools in the area of distributed data management.

5.2 Concerns

- Copying the raw data from the online system to offline and later to the Grid has just about worked for Phase 2 with some small hiccups. Converting it to ROOT files is an operation that takes time and resources. It would need to be optimised, probably, by parallelising it in order to scale to the amount of data expected in Phase 3.

- The committee understood that many data management operations are done in a manual manner mainly due to delays in the provision and development of the data management tools. This has not been a problem for Phase 2 but it could become an issue in Phase 3 when the number of data files increases with the increasing luminosity and longer running periods.

- User analysis jobs on the Grid are not yet taking off. Only a small fraction of the available CPU resources are used for user jobs. When the amount of data will increase from Phase 3 onward, the necessity of running user analysis on Grid resources will certainly increase; the various computing and software elements that are slowing down the adaption, such as the automatic data distribution, the availability of more software versions, the usability of the gbasf2 tool, etc., will need to be improved.

- The software versions and conditions DB global tags are strongly tied with procedures and workflows in place for software development and the “default” tags provided within the software itself. As more and more users will develop analysis software, other compatible combinations may need to be tried out and a way to do so safely should be provided.

5.3 Recommendations

- The committee recommends analysing and eventually streamlining all the needed data operations from the online system to the user analysis on the Grid. In particular, avoiding unneeded copies of files, minimising manual actions, ensuring robust protocols between the different subsystems to guarantee that no data is lost, and automated procedures, etc. are recommended.
- The committee supports the plan by the software group to introduce a monitoring system for raw data distribution with shifters to alert the experts in case of problems.
- The committee also recommends that instead of developing Belle II specific tools for distributed data management the collaboration seriously evaluates existing solutions used by the experiments at LHC. Tools such as Rucio, originally developed by ATLAS and will be provided as a service to the experiments hosted by the BNL, or the LHCbDirac Data Management that LHCb developed for DIRAC, are in use or being evaluated by several other experiments and would most probably fulfil all the requirements with less demanding development effort.