1 Executive Summary

The 11th Annual Meeting of the Belle Programme Advisory Committee (BPAC) took place from 12 to 14 February 2017 at KEK and reviewed the status of the Belle physics analysis and construction of the Belle II experiment. This is an executive summary followed by sections of the full comprehensive report.

The committee is very pleased to see continuous exploitation of Belle data resulting in a steady flow of high quality physics publications since the end of data taking in 2010. This effort should be sustained and supported till the Belle II experiment will accumulate enough data to start producing physics results.

The committee is pleased with the steady progress of the Belle II detector construction where commissioning work has already started in some areas. In addition to following the progress of individual subsystem construction, it is becoming important to pay attention to the integration and operation of the full system.

The Belle II detector structure with its superconducting solenoid is now filled with the Central Drift Chamber (CDC), the barrel particle identification system based on the Time of Propagation detector (TOP), the barrel Electromagnetic Calorimeter (ECL) and the barrel K-Long and Muon detector (KLM). Commissioning work for those detectors is well advanced.

The commissioning and calibration work of the CDC system is at an advanced stage. The committee stresses the particular importance of this point, since a well calibrated CDC could be used as a reference detector by the other subsystems for global commissioning and calibration.
For the TOP system, mechanical stress on the photon detectors due to the detector magnetic field, reported during the last Focused Review meeting in October 2016, remains as worry. Although measures have already been taken to prevent photon detector movement, it is not yet completely clear whether the situation has stabilised. Simulation studies show that separation at the optical interface between the quartz bar and the photon detector has little influence on the particle identification performance. However, mechanical stress on the pins could result in breaking the vacuum of the photon detector. The TOP group is testing a method to further improve the mechanical stability by fixing the positions of the individual photon detectors. If this is successful, the collaboration should seriously consider applying this to all of the photon detectors. Although good progress has been made in electronics, still more work is needed to be ready for the global cosmic ray test. The TOP group must make sure that the necessary firmware effort is made available. Given the serious concern over the ageing of the photon detectors in the region where high machine background is anticipated, the collaboration should prepare for the purchase of photon detectors with improved radiation resistance.

The end-cap particle identification system, the ARICH system, is also affected by the detector’s magnetic field. Although the magnetic force is not expected to be enough to unplug the photon detectors, the committee suggests that the ARICH group implements mitigation measures while they are still mounting the photon detectors.

The committee is informed that two scintillator modules in the end-cap KLM must be replaced. However, this does not appear to be a major concern. The committee is happy to see that the production of missing electronics for the Resistive Plate Chambers of the barrel KLM is advancing well in Italy, which is an example of an efficient collaborative effort.

Due to the delay in the production of ASICs for the Pixel Vertex Detector (PXD) and of the ladders for the Layer 6 of the Silicon Strip Vertex Detector (SVD), the installation plan for the Vertex Detector System (VXD) has no contingency for the timely start of the physics run. The committee thinks that it is too late to set-up another Layer 6 ladder production line and it would be better to inject additional technical personnel into the current production line at IPMU, where human resources are very stretched. The committee is somewhat concerned by the schedule delay for implementing the latest modifications to the readout card (FADC) of the SVD before the start of mass production. Given the tightness of the VXD schedule, components must be tested as early as possible so that further delay can be avoided. In this context, full system tests of the SVD with the final components before being combined with the PXD is very important. Thus, modifications to the card should be restricted to the absolutely minimum and all options must be explored for timely delivery of the final version of the FADC for full VXD system tests. The committee recommends that the VXD team fully exploits the DESY beam test and Permanent Setup at DESY (PERSY) to validate the integration and operation of the VXD including the readout system for smooth installation and commissioning for the physics run.

Progress in more global aspects of the experiment, such as the trigger, data acquisition, detector control, signal transmission and grounding is also satisfactory. With more subsystems being integrated, the roles of the central teams on those subjects become
increasingly important and the Belle II management must ensure that they are equipped with the necessary authority to ensure safe and coherent operation of the experiment as a whole. The global cosmic ray run planned for Summer 2017 is a crucial step.

The committee acknowledges the large progress made in the software and computing area since the last focused review in June 2016 on this subject, including the enhanced coordination between different activities. Further development in this direction is encouraged. The committee is looking forward to the results of the scheduled full dress rehearsal and the lessons that the collaboration will learn from them.

The committee is pleased to hear the success of the Beast Phase 1 run demonstrating that different machine background sources can be identified separately. The committee is looking forward to receiving a full comprehensive analysis of the Phase 1 data. The committee understands that a dedicated vertex detector system with several different types of sensors will be installed instead of the Belle II VXD for the Beast Phase 2. For the timely start of the physics run, the committee recommends that the Belle II collaboration sets up a clear commissioning plan, where the highest priority must be the commissioning of the Belle II detector and understanding of the SuperKEKB background.

2 Belle Status and Physics Achievements

2.1 Overview

The Belle collaboration has sustained a continuous growth over the past years, impressively demonstrating the attractiveness of the Belle/Belle II scientific program. In comparison to the previous year (numbers in parentheses), Belle now comprises 542 (495) scientists from 89 (87) institutions in 20 (19) countries. About 49% of its members are students and postdocs.

The analysis of Belle data, recorded until 2010, continues to provide very competitive physics results. In 2016 the collaboration published 24 papers (23 in 2015). The Belle publications are expected to appear at this level until Belle II analyses will take over. In the future, joint studies of Belle and Belle II data could be envisaged, taking advantage of the newly developed Belle II analysis framework B2BII.

The collaboration has been applying an opt-in authorship confirmation procedure: each eligible author must positively confirm his/her authorship for each publication. A similar procedure is also foreseen in Belle II.

Belle sustains a high visibility with presentations at conferences. Together with LHCb, Belle is co-leading the Heavy Flavour Averaging Group (HFAG). The formation of a Panel on Hadronic Amplitudes (PHASE) has been proposed to seek a deeper understanding of strong interaction dynamics in a joint effort of experimentalists and theorists.
2.2 Hadronic $B(\phi)$ Decays and $CP$ Violation

A time-dependent Dalitz-plot analysis of $B \to D^{(*)0} h^0, D^{(*)0} \to K_S \pi^+ \pi^-$, has been used to determine the CKM angle $\phi_1 = (11.7 \pm 7.8 \pm 0.08)\degree$. This measurement resolves the two-fold ambiguity in $\phi_1$ from the well-known result for $\sin 2\phi_1$. Branching ratio and $CP$ asymmetry for the decay $B^\pm \to K^\pm K^- \pi^\pm$ were obtained as $B = (5.68 \pm 0.38 \pm 0.25) \times 10^{-6}$ and $A_{CP} = -0.177 \pm 0.067 \pm 0.006$. The process $B^0 \to \pi^0 \pi^0$ is of interest both for the theory of hadronic $B$ decays and as an essential component for determining $\phi_2$ through an isospin analysis. An update to the full Belle data sample has been performed and a publication is in the stage of authorship confirmation. The decays $B^\pm \to K^\pm K^- \pi^\pm$ are, and will remain, important ingredients of the flavour physics program.

2.3 Semileptonic, Leptonic and Electroweak $B$ Decays

Numerous studies have been performed on (semi-)leptonic and rare electroweak $B$ decays. Some observables, related to $B \to D^{(*)} \tau \nu$ and $B \to K^* l^+ l^-$, are of particular current interest, because of tensions with the standard model expectation.

Two new measurements with the full data set have been performed on $B \to D^* \tau \nu$, one using a semileptonic tag, the other using a hadronic tag and hadronic tau decay modes, $\tau^- \to \pi^- \nu$, $\tau^- \to \rho^- \nu$. These analyses are statistically independent from each other. The two-body tau decay modes used make the hadronic analysis are statistically independent from previous studies with hadronic tags and leptonic tau decay, and enable the first measurement of tau polarisation in $B \to D^* \tau \nu$. The latter was measured to be consistent with the standard model within still sizeable uncertainties. Defining $R(D^{(*)}) \equiv B(B \to D^{(*)} \tau \nu)/B(B \to D^{(*)} l \nu)$, the combined Belle results for $R(D)$ and $R(D^*)$ show a 2.5$\sigma$ deviation from the standard model, in comparison to 3.9$\sigma$ for the world average.

The angular analysis of $B \to K^* l^+ l^-$ with the full data set shows a deviation from the standard model in the quantity $P_S$ similar to LHCb. For electron and muon modes combined, the deviation amounts to 2.5$\sigma$. The analysis has been updated for a separate measurement of muon and electron modes, showing a deviation of 2.6$\sigma$ and 1.1$\sigma$, respectively, a first test of lepton flavour universality in this context.

Among the many further interesting results are a new measurement of $B(B \to X_S \gamma)$ with an inclusive method, a search for $B \to h\nu\bar{\nu}$ with a semileptonic tag, and the best current limit on the branching ratio of $B^0 \to \phi \gamma$ ($< 1.0 \times 10^{-7}$ at 90% C.L.). All these analyses have used the full data set.

There are several ongoing analyses ($D^*$ polarisation in $B \to D^* \tau \nu$, $B \to l \nu$, radiative $B$ decays, and others), some of them (e.g. $B \to l \nu \gamma$) within the B2BII framework.

2.4 Charm and Hadron Physics

The search for $CP$ violation in charm hadron decays and in $D^0 - \bar{D}^0$ mixing, better measurements of the mixing parameters, searches for flavour-changing neutral-current charm decays are, and will remain, important ingredients of the flavour physics program.
A sensitive search for the flavour-changing neutral-current decay $B(D^0 \to \gamma \gamma) < 8.5 \times 10^{-7}$ (90% CL) has been published, establishing a bound which is several times better than the previous best limits. Invisible $D$ decays, such as $D \to \nu \bar{\nu}$ are extremely suppressed in the standard model. With the full Belle data set, the world’s best bound, $B(D \to \text{invisible}) < 9.4 \times 10^{-5}$, was obtained.

Sensitive searches for $CP$ violation in $D^0 \to V\gamma$ decays were performed, yielding some of the world’s best constraints on $A_{CP}(D^0 \to \phi \gamma)$, $A_{CP}(D^0 \to K^{*0} \gamma)$, and $A_{CP}(D^0 \to \rho^0 \gamma)$, including the first observation of $D^0 \to \rho^0 \gamma$ decay. While $CP$ violation searches in these channels were particularly well motivated by hints for $CP$ violation in $D \to K^+K^-$ and $\pi^+\pi^-$ decays a few years ago, they remain sensitive probes of interesting new physics models. The new bound $A_{CP}(D^0 \to K_S K_S) = -(0.02 \pm 1.54)\%$, which is about three times stronger than an LHCb limit, is also interesting.

Motivated by the $c\bar{c}$ spectroscopy discovered in the last decade and the recent LHCb discovery of a $c\bar{c}uuud$ pentaquark-like resonance in $\Lambda_b$ decay, the charm group has searched for the analogous $\Lambda_c \to P_s^+(ssuuud)\pi^0$ decay. Several $\Lambda_c$ branching ratios were refined, and no resonance was observed.

Heavy quark symmetry makes some model-independent predictions for the spectroscopy and decays of heavy baryons. With the full Belle data set, the masses and widths of several excited $\Xi_c$ baryons were measured, in some cases improving the precision by an order of magnitude. Numerous excited $\Xi_c$ decays were also measured, including first observations of $\Xi_c(2815)^+ \to \Xi^{0}_c \pi^+$ and $\Xi_c(2980)^+ \to \Xi^{0}_c \pi^+$. The strong interaction dynamics is probed by measuring how these baryons decay to a (charmed baryon + light meson) and (light baryon + charmed meson). Belle made the first observation of the $\Xi_c(3055)^+ \to \Lambda D^+$, $\Xi_c(3080)^+ \to \Lambda D^+$, and $\Xi_c(3055)^0 \to \Lambda D^0$ decays.

Belle also made the first observation of transverse $\Lambda$ polarisation in $e^+e^-$ collisions, and studied its energy and $p_T$ dependence, which are interesting for the dynamics of fragmentation.

2.5 Tau and Two-photon Physics

The physics of the tau lepton is another fruitful field for research with Belle data. An ongoing project aims at the determination of tau-lepton Michel parameters $\rho$, $\eta$, $\xi$, $\xi \delta$ from $\tau^- \to l^-\nu \bar{\nu}$ to better than 1% accuracy, substantially improving on previous measurements. The precise trigger efficiency is still under investigation. Additional Michel parameters ($\eta$, $\xi \kappa$) are accessible in $\tau^- \to l^-\nu \bar{\nu}$. Those have been measured for muon decay, but not yet for tau. The branching ratios of the radiative modes $\tau^- \to l^-\nu \bar{\nu} \gamma$ and $\tau^- \to l^-l^+l^-\nu \bar{\nu}$ are studied. Investigations continue on the hadronic modes $\tau^- \to h^- h^+ h^- \nu$. A search is being performed for the lepton-flavour violating mode $\tau^- \to l^- X$, where $X$ is an invisible particle not decaying inside the detector.

Interesting physics can further be studied in two-photon reactions. Recent examples are the measurement of the cross section for $\gamma \gamma \to J/\psi \gamma$, leading to a precise determination of the $\gamma \gamma$ decay width of charmonium state $\chi_{c2}(1P)$, and the extraction of transition form factors (TFF) for resonances in $\gamma^+\gamma \to K_S K_S$. The TFF for $f_2^+(1525)$ ($J^P = 2^+$) is measured for the first time.
2.6 Dark Sector, $\Upsilon(5S/1S/2S)$

Using data taken at the $\Upsilon(5S)$ resonance, decays of the $B_s$ meson become accessible. The final states $\eta\eta'$, $\pi\eta'$, $K_S\eta'$, $K_S\pi$ and $\phi\pi$ are being studied. The observation of $B_s \to K^0\bar{K}^0$ has been published recently. The published results also include the observation of the resonances $Z_b^\pm(10610)$ and $Z_b^\pm(10650)$ decaying to $B$ mesons.

The first searches for a $0^{--}$ glueball in $\Upsilon(1S)$ and $\Upsilon(2S)$ decays, and for $XYZ$ charmonium-like resonances in decays of $\Upsilon(1S)$, have been published in the past year. Numerous further studies are under consideration in this area.

The search for light dark-sector particles up to a few GeV in mass is ongoing. Studies look for short-lived or long-lived dark photons $A'$, coupling to ordinary matter through kinetic mixing with the photon, in decay channels such as $A' \to e^+e^-$, $A' \to \mu^+\mu^-$. A search for dark vector gauge bosons decaying to $\pi^+\pi^-$ using $\eta \to \pi^+\pi^-\gamma$ has been published in 2016. Dark Higgs and dark matter can be searched for in $\Upsilon(1S)$ decays.

2.7 Concerns and Recommendations

The committee encourages the analysis of Belle data with the B2BII framework.

3 Belle II Physics Programme

Belle II aims at nearly two orders of magnitude increase of the existing $e^+e^-B$ factory data sets. The measurements will complement both the LHC searches for new heavy particles, as well as the LHCb flavour physics studies and those at other facilities.

3.1 Physics of Phase 2

The primary goal of the Phase 2 is to understand the machine backgrounds and tune the operating parameters with no vertex detector system installed in the Belle II detector. The initial collisions for machine commissioning will be at the $\Upsilon(4S)$ energy. An important progress since last year is that the collaboration identified running on the $\Upsilon(6S)$ at 11.020 GeV as a target to match both the accelerator goals and to enable collecting a unique data set giving some high impact physics results. The relatively small amount of past data collected at the $\Upsilon(6S)$ would allow Phase 2 to provide an order of magnitude increase in statistics. Should accelerator priorities dictate running at a lower energy, another option is to collect data at 10.75 GeV, which is between the $\Upsilon(4S)$ and $\Upsilon(5S)$ states, another interesting and poorly explored region.

The suite of interesting physics results that can be obtained from Phase 2 include studying the $\Upsilon(6S)$ cross section, measuring $R_b$ in a region where the current uncertainties are large, numerous studies of bottomonium-like $Z_b^\pm(10610)$ and $Z_b^\pm(10650)$ states, etc. Probably the greatest improvement in Phase 2 for the sensitivity to new physics will take place in searches for possible dark photons and axion-like dark sector particles. These require a new single photon trigger, which is under development (it was not available in Belle), which will also remain important for Phase 3 physics.
3.2 Physics of Belle II

The excellent opportunities to improve the sensitivity to new physics and for precision flavour physics are well documented. Many important processes have been identified as benchmark modes, some favouring the $e^+e^-$ environment, e.g., inclusive decays, large missing energy final states, modes with neutral particles. The benchmark modes include time-dependent $CP$ asymmetries in $B \to \phi K_S$, $B \to K_S\pi^0\gamma$ and related modes, precise determinations of $\phi_3$, the rare decays $B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$, and decays with large missing energy, such as $B \to \tau\nu$, $B \to \mu\nu$, $B \to K(\ast)\nu\bar{\nu}$. There are many important charm and tau physics measurements that may discover new phenomena, and a rich quarkonium physics program is also of great interest.

It has become increasingly clear recently that there will be as much competition as complementarity between Belle II and LHCb, as LHCb has made impacts on areas previously viewed as rather difficult in a hadron collider environment (e.g., $B \to D^*\tau\nu$, $|V_{ub}|$ from $\Lambda_b \to p\mu\nu$, etc.). Thus, the competition between Belle II and LHCb in the 2020s promises to be intense and exciting. This amplifies the importance for Belle II to achieve or surpass its luminosity goals.

The Belle II Collaboration initiated in 2014 the “Belle II Theory Interface Platform” (B2TiP), a series of joint experiment-theory workshops, to study the impact of the Belle II program, the complementarity with LHCb, and to jump-start the collaboration to be ready for the many interesting analyses to be carried out. The last two B2TiP workshops took place in 2016 in Pittsburgh in May, and an editorial meeting in Munich in November. The current goal is to finalise the B2TiP Report, “The Belle II Physics Book”, by April 2017. It will summarise benchmark measurements and golden mode predictions for three integrated luminosities: 1 ab$^{-1}$, 5 ab$^{-1}$, and 50 ab$^{-1}$. This effort has been synergistic with getting ready for the Belle II physics analysis activities, which are organised in nine physics working groups, and the development of analysis software tools. The B2BII framework allows concurrent analysis of Belle data and Belle II simulation data. Continuation of the B2TiP activities are envisioned to maintain the dialogue with theory community.

3.3 Concerns and Recommendations

While the collaboration has been counting on nine months of data taking per year, it is reported that only six months is acknowledged by the KEK management. The Belle II experiment needs to surpass the 1 ab$^{-1}$ Belle data to start making very significant progress in its core physics program. While the LHCb experiment continues to collect data, the detector upgrade for aiming at ten times more integrated luminosity is in progress. It is therefore crucial that the Belle II experiment will be able to collect data with high rates and long running periods. The committee urges the KEK management to make all efforts to maximise the Belle II running time.
4 Belle II Interaction Region, Beam Pipe, Machine Related Issues and Beast

4.1 Status

The committee is gratified to learn that the major components of SuperKEKB are coming together for the Phase 2 run: QCSL was already installed and QCSR arrived during the review and installation commenced. Attention is now fully focused on getting ready for Phase 2 operation, which will be the first SuperKEKB operation with QCS magnets, focused beams, and collisions.

The presentation on beam backgrounds is very impressive. A great deal of effort has gone into using the information learned from the Beast Phase 1 experience to update the background simulation programs. Improvements in the simulation of the detector magnetic field and final focus quads (both field and materials) have led to a much better match between the results of SAD and GEANT4 simulations. This has encouraged the team to use the GEANT4 simulator on the KEK computing centre farm of > 1000 CPUs and the 15th Campaign results provided them a more thorough study of collimator optimisation settings for the upcoming Phase 2 and 3 runs. They have now found new collimator settings that improve the predictions made in the previous background study (14th Campaign). In addition, updates to the detector, final focus, and beam pipe models have been made where “as built” modifications are now being included in the model. The result is that some of the assumed shielding has become thinner in places, e.g. in the QCSs. The effects of these modifications are being closely monitored.

A summary presentation on the ongoing analysis of the Beast Phase 1 data shows that the HER data looks fairly consistent with expectations but presently the LER losses do not agree with expectations. The LER beam losses are 3-4 times higher than expected, but the LER background rates at the IP are 5 times lower than expected. Work is ongoing to see if these discrepancies can be resolved.

4.2 Concerns

- From the schedule, the committee notes that the integration of the VXD and final beam pipe will start already during or right after the Phase 2 run. Hence, the background team will have little time to conclude whether the background condition is acceptable for the VXD operation. Any needed changes to the hardware will become increasingly more difficult to implement as time goes by.

4.3 Recommendations

- The background team needs to stay focused on the essential issue of determining – as soon as possible during the Phase 2 run – whether the Phase 2 backgrounds are acceptable for the VXD.

- The current close collaboration between the background team and machine team should be continued and even strengthened. They need to work out the Phase 2
programme to match the accelerator start-up plan with a rapid understanding of the background.

- The background team should put together a detailed step-by-step plan for Phase 2, with a priority on getting information about background levels in the VXD region as soon as possible. This may include asking the accelerator team to place emphasis on one of the beams first (either LER or HER). It may also mean asking for particular machine configurations (e.g. fewer bunches but full bunch current).

- The committee is also very pleased to hear that the background team is checking for possible modifications to the hardware during construction and are updating the interaction region model to reflect these changes. The committee strongly encourages the continuation of this effort as it will unquestionably improve the comparison of simulations to the actual machine.

5 Belle II Vertex Detector

5.1 Pixel Detector (PXD)

5.1.1 Status of Sensors and ASICs

The committee is pleased to see the great progress that is being made on the pixel detector. Production of the DEPFET sensors is close to being completed. The yield has been excellent and almost twice the number of required prime grade sensors are available. Small changes in the layout of the sensors, such as increased line width of the clear signals, have improved the gated-mode performance.

The final versions of all ASICs are now in hand. An unfortunate “glitch” with the layout submission of the Data Handling Processor (DHP) chip caused a near five month delay, but chips are now in hand and are being tested. Test results so far indicate that the chips are exceeding specifications. A persistent issue has been the placing of the bump bonds on the Switcher chip, with poor under-bump metallisation on a single die basis. Wafer-level bump placement has been tested at IZM with good results and production bump-bonding is now proceeding at IZM. First devices are expected back at the end of February. A new vendor for the Kapton flex circuits has been selected and all cables are expected to be delivered at the end of February.

The module pilot production revealed problems with the bonding of the switcher chips. Even though the bonds were placed successfully on the chips, the bonding of the switchers to the DEPFET balconies posed problems. Apparently the reflow temperature was not reached in the middle of the module during the bonding process. Early results from a preproduction batch indicate that the bonding problems have now been resolved. None of the modules for PERSY have the final version of the ASICs. Dummy ladders are in production and assembly is progressing well. The already tight schedule has become even tighter with the bump-bonding problems and lack of available final version of the ASICs. The current schedule has an explicit contingency of only four weeks, and a
half-shell commissioning period at DESY of three month, with a delivery of the PXD at KEK in early February 2018.

Testing of the assemblies and system integration has been well developed. Full functionality tests are being carried out at the level of the individual components, that is, ASICs, sensors, modules and ladders. A final functionality test of the completed half-shell is foreseen with the PERSY system at DESY before shipment to KEK.

5.1.2 Concerns

The PXD schedule has little to no contingency left. Furthermore, the whole readout chain with final components remains to be exercised. Although the DESY test beam has proven to be invaluable, and further tests will continue to provide vital details on the performance of the system, they are no substitute for a true functionality test with final components in the final configuration. The schedule of the Belle II detector is, without reservation, vulnerable to any further delay in the PXD schedule, with no hedge.

5.1.3 Recommendations

Despite significant progress, no solution could be identified to address the vulnerability to the schedule. Given these conditions, the committee would like to iterate its previous observation that, with the upcoming DESY test beam, the pressures on the PXD group will not relent, where there is a massive set of tasks to be completed with limited manpower. The committee recommends that key priority tasks be identified and adequately staffed.

5.2 Strip Detector (SVD)

5.2.1 Status

The committee is pleased to learn that the SVD group is now producing ladders at full speed after numerous issues were resolved. The delamination of the Origami Kapton flex, reported at the last full BPAC, is now addressed by manual soldering of the passive components after verifying that only water is absorbed in the flex. Since the February 2016 BPAC, SVD ladder production encountered the following issues:

- Micro-cracks in the APV25 chips were found due to a poor thinning process. The issue causing the cracks was resolved by switching to another thinning company; the origami production was completed with 20% spares by the end of 2016.

- Discoloration of HPK sensors was found, which halted the ladder assembly for a month. The vendor attributes this to oxide thickness variations and no major ill effect is expected. After verifying that there is no effect on the AC capacitor tolerance, ladder assembly was resumed.

- The pitch adapter came off from forward (FW) sensors presumably due to insufficient glue strength in several assembled ladders. All FW sensors and assembled
ladders were reinforced by adding glue, which halted the ladder assembly for a month and a half. Development of a repair procedure for those ladders that have peeled-off pitch adapters are on-going. One Layer 4 ladder and three Layer 6 ladders are to be fixed. These ladders are not counted as installation-grade ladders.

Despite the above issues, Melbourne completed production of Layer 3 ladders, that is, 11 ladders built for 7+2 ladders needed. TIFR produced 5 good Layer 4 ladders for 10+2 ladders needed. HEPHY produced 7 good Layer 5 ladders for 12+3 ladders needed. IPMU produced 3 good Layer 6 ladders for 16+4 ladders needed. In order to accelerate the ladder assembly at IPMU, a 7-day work plan is developed with a reinforcement of human resources. Assuming 3 weeks per ladder, 16 ladders are expected to be ready by the end of 2017 if no major issue occurs during these 10 months. This schedule is barely on time for ladder mounting, which starts in the middle of January 2018 for the second half.

The ladder mounting procedures have been developed and tested, including proper strain relief implementation and the rotation mechanism. The cooling pipe attachment procedures have been developed and tested, which revealed a difficulty in the Layer 4 pipe routing. A solution for the cooling pipe routing has been found and is being designed. Plans for electrical verification after a half-shell is completed were developed. End-to-end verification of the ladder mounting procedures are planned one month before the start of the actual ladder mounting.

The SVD group identified a possible grounding issue for the FADC readout card. In addition, the current FADC card has an issue with the Gigabit-Ethernet system for the slow control. Since 100Base-T seems to work fine, it is presumably due to a firmware issue. However, this is not certain and needs to be verified. Because of those issues, the SVD group plans to redesign the FADC readout card. As a result, the full SVD cannot be tested before May 2018 due to the delay of the FADC readout card. If the SVD group gives up the detailed test of the redesigned system, they may be able to operate the full SVD in March 2018 before the integration with the PXD.

The thermal mockup test performed at DESY in the summer of 2016 revealed that the cooling of the APV chips on the Layer 3 ladder is not sufficient. The large temperature drop on the stainless steel forward end-ring finger is found to be the cause of the issue. Adding copper inserts on the Layer 3 fingers reduces the temperature drop by 29 degrees.

5.2.2 Concerns

- The schedule of the Layer 6 ladder assembly has no contingency, which means any issue with the Layer 6 ladder assembly during the 10-month production period could delay the completion of the SVD production. The SVD group presented a plan to implement a second assembly line in case the assembly schedule falls behind. However, the committee is concerned that the preparation of a second assembly line takes valuable time from the Layer 6 assembly crews and does not support setting up a new assembly line.

- The committee is somewhat concerned by the schedule delay due to modifications
to the FADC readout card before the start of mass production. Given the tight VXD integration schedule, components must be tested as early as possible so that further delays can be avoided. In this context, full system tests of the SVD with the final components before being combined with the PXD is very important.

5.2.3 Recommendations

- The committee suggests to reinforce the human resources for the Layer 6 assembly so that the production schedule can be accelerated further. Every effort should be made to develop the repair procedures for the Layer 6 ladder with the peel-off issue and implement them very carefully. The repair procedures should be verified with dummy modules so that no Layer 6 ladder will be lost due to mishandling of the repair. The SVD group should consider using the Layer 6 ladders with the peel-off issue in the final detector in case the ladder production cannot meet the schedule, since the peel-off issue only affects a small portion of the ladder.

- Modifications to the FADC readout card should be restricted to the absolute minimum and all options must be explored for timely delivery of the final version of the FADC for full SVD system tests.

5.3 General Issues

5.3.1 Cooling

5.3.1.1 Status

The VXD has very demanding cooling requirements, with the need to remove 700 W from the SVD and 360 W from the PXD within a confined space, while maintaining the temperature of the CDC inner wall constant. In total 12 independent cooling circuits with a total capacity of 2-3 kW remove heat from the system. The thermal mockup has provided essential input to the cooling design, in particular by pinning down the role of the nitrogen temperature and flow in the system, and also by providing invaluable experience on the mechanical interfaces, such as the pipe brazing on the end-rings. The mockup has been continuously upgraded to incorporate additional elements, and in particular the SVD shells have now been added. Results were reported on the SVD temperatures and interface to the PXD, on the dew points, and on the interface to the CDC. A major finding was the large temperature gradient over the stainless steel bridges which connect the L3 ladders to the end rings, discovered in the thermal mockup and confirmed by simulation. This has particular impact on the N-side APVs, which can be 80°C above the cooled end-ring base temperature. A solution has been proposed to add a copper insert to the assembly, which should improve the performance by about 29°C and will be acceptable for operation. The temperature in the sensor part of the ladder is dominated by the PXD and can be well controlled with a reasonable flow of injected N₂. The dew point in the warm dry volume, which is very crowded with cables has also been studied, and it has been shown that a N₂ injection rate of greater than 20 L/min is necessary to avoid condensation on the unprotected CO₂ lines. The temperature on
the CDC inner cylinder is asymmetric top to bottom and slightly asymmetric forward to backward, and has been shown to be stably maintained. The pressure drop in the cooling circuits has been characterised with a range of power loads and found to be well within the capability of the cooling system.

The team is to be congratulated on the very successful construction, transport and commissioning of the IBBelle cooling unit. All the elements were assembled at MPI before shipping and the cabinets were installed during October, checked for basic functionality, and connected to the transfer lines and junction box. The system was fully connected by January, including heaters and NTCs in the dock boxes, to allow warm and cold CO₂ circulation and varying power loads. The flexlines were produced at DESY, with all orbital welding visually inspected prior to pressure testing of full lines. There is a clear plan in place to implement the last remaining details, including the regulation during sudden changes of heat load, a new vacuum pump for the flex lines, and the transition of the control software from WinCC OA to EPICS. In addition, heater and temperature monitors will be installed in the dock boxes.

5.3.1.2 Concerns and Recommendations
The committee has neither specific concerns nor recommendations with regard to the thermal management. Great progress is being made and the collaboration is encouraged to keep up its excellent work and progress.

5.3.2 Grounding/EMC

5.3.2.1 Status
The committee is pleased to learn that all inner detectors have safety, shielding and grounding policies in place and have carried out EMC tests and susceptibility tests. Information from those tests helped subsystems to improve the emission and susceptibilities. In order to take full advantage of those test results, the group is planning to check compatibilities between subsystems.

5.3.2.2 Concerns
Although safety, shielding and grounding policies are in place, it appears that there is no comprehensive review of the shielding and grounding scheme for each subsystem planned in order to make sure that the policies are completely implemented in the schematics and the real system.

5.3.2.3 Recommendations
The committee recommends that the Grounding/EMC group should conduct in-depth reviews of the schematics to verify that the shielding and grounding policies are correctly implemented.

5.3.3 Slow Control and Software

5.3.3.1 Status
Even if no specific report on VXD slow control and software was presented, the progress has been reported in several presentations. The PERSY system in DESY is used as a test bench for the integration of the Slow Control, based on EPICS and CSS for the control and GUI. This system implements all the functionalities needed for operation of the DESY test beam and it is almost identical to the infrastructure needed for Phase 2 operation. Also, remote access to the Slow Control systems (PERSY from Japan and IBBelle from Germany) has been tested. There is an active effort in the definition of the VXD interlock signals and their integration with the central systems.

Version 2 of the VXD track finder (VXDTF) is being implemented and it will also be tested at the DESY test beam.

5.3.3.2 Concerns

• No specific concerns are raised on the Slow Control and on the interlock system, except for not having a complete definition of the latter. The steady work to move the software from PERSY to Beast Phase 2 and its extension for the integration tests and full detector operation should be continued to meet the schedule.

• It was reported that VXDTF version 2 does not provide yet the performance of version 1, and it may not be available for the start of the physics run.

5.3.3.3 Recommendations

• The VXD interlock system should be defined and implemented in order to be tested during Phase 2 run.

• An effort should be made to complete the implementation and deployment of VXDTF version 2. If possible, it could be used for the processing of Phase 2 data, where also the alignment of a VXD slice and its stability can be checked.

5.3.4 Ladder mounting and integration

5.3.4.1 Status
An overview of the procedure and planning for PXD and SVD ladder mounting on half-shells and their integration with the beam pipe was presented, which is becoming increasingly more detailed and precise. The committee is very pleased to see the strengthened coordination between the PXD and SVD groups, where the teams now work as a single unit for the installation. Two VXD installations are being prepared for Phase 2 run and Phase 3 physics run, respectively. The Phase 2 VXD assembly has to be completed by June 2017. A detailed workflow for each phase has been worked out as well as a detailed task schedule. Installation clearances, connections are all being rigorously checked and the details of the installation in the dock area are being developed in detail. The design of the cold and warm dry volume is also being developed.

SVD ladder mounting for the Phase 3 run will start at KEK in July 2017 and will be completed by March 2018. PXD ladder mounting is foreseen at MPI in July-September
2017, followed by three months commissioning at DESY. Integration of the beam pipe with VXD and SVD half-shells will happen at KEK in April-June 2018. To support this integration a clean room in Tsukuba Hall will be installed in the space now used by the ARICH.

The tools for PXD ladder assembly are in an advanced design stage. Mounting ladders are picked by vacuum tweezers and loaded on top of a rotation stage. First tests will start in early summer.

A detailed planning of the SVD ladder mounting procedure has been developed. Layers will be mounted in sequence, with cooling pipe attachment and cold tests to check thermal contact of the front-end chips with the cooling pipe attached at the end of each layer mounting. The ladder assembly sequence, consisting of pick-up, placement, cable connection, insertion of optical fibre, and survey, has been exercised. This exercise has identified issues with the Layer 4 cooling pipe routing and the need of a tool for 180° rotation of the SVD $-$x half-shell for transportation towards the VXD integration clean room. They are now being addressed and a full dress rehearsal is foreseen in June, before the starting of Layer 3 ladder mounting.

The VXD mechanics integration has been laid out and is almost entirely verified. It is using a procedure very similar to the one used for Phase 2 run, in which a slice of the VXD will be integrated with other background monitoring detectors. In this way, Phase 2 will be a rehearsal for the Phase 3 installation. Almost all components have been delivered, with the notable exception of the Phase 3 run beam pipe, which showed an Au-layer delamination. It is still under investigation, but it seems connected to the order of parylene coating and the Au sputtering steps. A new beam pipe is currently being produced, with a nine months expected delivery time.

Installation of external services is progressing. A test installation of the VXD was performed in November 2016. It permitted the verification of the temporary supports for the detector slide-in, the connection to the CDC supporting structure and the accessibility to the services and bellows pipe after insertion of the VXD. A critical item is the routing of services in the narrow gap between the QCS and the VXD, and then between the QCS and the CDC.

5.3.4.2 Concerns

- As it stands, the detector integration time will need to absorb any further delay in the assembly of PXD and SVD ladders. The current schedule provides for some commissioning and testing time and cosmic ray data-taking, that can be partly used as contingency. In addition, there is no contingency between the end of SVD ladder mounting and the start of VXD integration. It is important to be sure not to overestimate the effective time available for contingency.

- A prototype of the tooling for PXD ladder mounting is not available yet, and therefore testing of the mounting procedure has not been performed. If modifications or redesign of the tooling will be required, it may have a significant impact on the schedule.
• While impressive progress has been made on the SVD ladder mounting procedure, some tools are not yet available and a full rehearsal is scheduled just before the start of the assembly. The mounting procedure is defined but, in case a fault is detected during the mounting, a dismounting procedure is needed. This is especially relevant if the cooling pipe needs to be removed.

• The reproduction of the inner section of the beam pipe, after the discovery of Au-delamination, is barely compatible with the schedule, therefore any further issues will impact the beginning of the physics run.

5.3.4.3 Recommendations

• Fabrication of all tooling and a full rehearsal of the assembly procedures should be completed as soon as possible, to reduce the impact on the schedule of any tuning of the procedures that might be needed. Training of critical personnel should occur to gain valuable experience with the installation procedures.

• The SVD group should prepare a well defined set of procedures in case of repairs needed during the ladder mounting. In particular the scenario needs to be studied if part of a half-shell needs to be dismounted to access a damaged or non-functioning ladder.

• The committee encourages the collaboration to pursue the understanding of the Au-delamination, in order to intervene in the reproduction process if required.

6 Belle II Drift Chamber (CDC)

6.1 Status

The Central Drift Chamber group has made remarkable progress since the focused DAQ review last October. The committee is gratified to see the results of this effort demonstrated by displays of a variety of tracks in cosmic ray events. In these events, the hit efficiency appeared to be high for showers as well as single tracks. The CDC group deserves congratulations for reaching this stage of development so quickly after installation of the CDC into Belle II.

Cabling and piping of the whole chamber was completed and the CDC was integrated into the global DAQ. A problem with cooling the FPGAs in the Front End Boards was discovered, i.e. the temperatures of many FPGAs were close to 80 °C. In about a month, a cooling upgrade was designed, fabricated, and installed. This reduced the maximum temperatures observed to about 45 °C, considered to be acceptable.

Since the cooling upgrade, the CDC is fully operational, and performance statistics were accumulated for the whole chamber at once. The data are taken in cosmic ray runs (without magnetic field) with events triggered by a scintillation counter located near the centre of the chamber. Overall, the performance of the CDC is high and uniform. For example, the mean of the pedestal sigmas is 0.49 ADC counts, with the values of nearly
all channels lying between 0.44 and 0.60 ADC counts. The azimuthal angle distributions of hits in all layers are quite uniform and reasonable. The TDC distributions of the hits in all layers exhibit the behaviour expected as the cell size increases from the inner to outer layers and the ADC distributions for the hits are also reasonable. There are only 11 dead channels (out of 14336) and eight of them can probably be recovered in September during installation of the forward end-cap and Beast Phase 2 detector.

Progress continues in understanding the cosmic ray data taken before installation of the CDC. By the time of the focused DAQ review, calibration of the time-to-distance relationship was already well advanced. Comparison of the two portions of a track above and below the centre of the chamber had identified some possible alignment discrepancies. These discrepancies were studied further by comparing the portions of tracks in the main part of the CDC with the portions of those tracks found in the inner (conical plus small-cell) part of the chamber. Observed discrepancies are extrapolated in $z$ to the ends of the chambers. Then possible translations in $x$ and $y$ and a rotation in $\phi$ of the inner part relative to the main part are studied by examining the $\phi$ dependence of the residuals between the inner and outer tracks. The results are encouraging.

During DAQ high-rate tests, the CDC performance was unstable at rates $\gtrsim 5$ kHz. This behaviour appears to be due to voltage drops in the COPPER power supplies. There are plans to augment the COPPER power supplies to alleviate this problem.

### 6.2 Concerns

- Running with the 1.5 T magnetic field will present new challenges for the CDC software. Belle experience will be invaluable, but readiness of the necessary software will remain somewhat of a concern until development is reasonably complete and the software is functioning well during global cosmic ray runs. Completion of efficient and reliable software for extrapolation of CDC tracks into the outer detectors, particularly the TOP, will be crucial for the success of the global cosmic ray and Phase 2 runs.

- The high-rate performance of the CDC DAQ remains a concern until improvements in the COPPER power supplies are shown to be effective.

### 6.3 Recommendations

- Continued software effort aimed at providing accurate time-to-distance relationships and reliable tracks in a magnetic field and their extrapolation to the outer detectors should be a high priority of the CDC group.

- The CDC should be tested with augmented COPPER power supplies to verify that CDC performance will be stable at high rates with this upgrade to the DAQ system.
7 Belle II Particle Identification

7.1 Barrel Particle Identification (TOP)

7.1.1 Status

The TOP group made excellent overall progress in the year since the last BPAC, with a complete complement of high-quality TOP modules now installed and running basic module-level calibrations. The committee joins the TOP group and the Belle II collaboration in celebrating this outstanding achievement, and notes that the TOP management leadership has been updated to reflect the shift towards commissioning and data taking.

The TOP group’s emphasis has now shifted from fabrication and installation to commissioning, especially for the electronics and DAQ, which must reach some appropriate level of maturity in order to begin to take reliable data and understand the overall system performance. The initial status of this work was discussed at the focused review in October, 2016, and has continued apace in the intervening months. The recommendations and comments from that review are being addressed, but a number of issues remain open. Progress has been steady, but not all required features of the electronics/DAQ are yet fully functional, and the time scale for attaining a reasonably stable version remains somewhat unclear. A number of the problems are subtle and can take considerable time to solve, while new problems can emerge as old ones are overcome. The region of interest (ROI) and feature extraction (FE) firmware have been debugged and are running on the installed modules. However, better internal data management is required, data taking must be stable at a 30 kHz L1 trigger rate, and TOP data taking must be able to join into the overall DAQ system to allow participation in the Global Cosmic Ray Trigger (GCRT) run scheduled for April 2017. Channel-by-channel time alignment has been successfully implemented. However, not all features of the laser data are understood yet with time shift differences being observed between MC and data. Detailed test bench studies are underway to help understand these.

In parallel with the FE/DAQ work, the calibration and alignment software needs to be fully implemented and debugged in order to be able to study data from the Global Cosmic run. Runtime software (such as a Data Quality Monitor, a local run control panel, etc.) still needs development. The committee was shown an impressive list of people committed to these many tasks, backed up by students and staff, but clear milestones for task completion remain uncertain.

The 224 conventional MCP-PMTs in 7 modules out of 16 modules have inadequate quantum efficiency (QE) lifetimes and will need replacement quite early in Belle II’s operating period. To maximise PMT lifetime, it is essential to keep signal amplitudes from the PMTs as small as possible, but this leads to timing resolution degradation. To partially alleviate this problem, a template fitter has been developed that will be implemented in the FPGA, allowing lower tube gain to be used. Even with this mitigation, the projected machine luminosity profile leads to a requirement that these tubes be replaced in the 2020 shutdown. At a projected tube production rate of 10 tubes per month, this will require a startup for further tube production in the summer of 2018. The plans are in place to continue a low production rate from now until the actual back-
grounds are understood from Phase 2 run, and then alter the plan accordingly to meet the installation needs in 2020.

The committee learned in October 2016 that the MCP-PMTs experienced substantial forces in the 1.5 T field, which led to rotation of modules and PMTs. The obvious bubble formation (due to module rotation) on the silicone cookie-optical oil coupling has been prevented in situ by shimming. Once a PMT peels off, it is less simple to repair. However, simulation work shows that the performance degradation due to a small air gap is modest. It is difficult to identify formation of an air gap in situ with the CCD camera and only a few percent of the PMTs is thought to be impacted. The other potential concern is mechanical stability of the tube and its vacuum under this constant rotational force.

An active R&D program on this magnetic-field problem has been underway since October 2016 to understand and attempt to address all concerns. Further R&D is underway to decide on the best overall mitigation program, which should be completed by June 2017. These tests include mechanical tests to verify PMT safety, tests in a magnetic field, long-term mechanical testing with forces similar to those induced by the field simulated by hanging appropriate weights, and further studies to determine the best shimming methodologies.

7.1.2 Concerns

- Performance degradation due to air gap introduced by the PMT movement has been studied only for a limited number of physics cases.

- The electronics/DAQ work will continue to require substantial investment from the expert crew from the central DAQ team until the system is fully integrated into the Belle II DAQ system.

7.1.3 Recommendations

- As indicated at the last review, the committee believes that the planned GCRT running is of great importance to gain further experience with DAQ and online, as well as to exercise all the software and begin to understand TOP performance over the full tracking phase space. The strongest possible effort should be maintained to ensure that this occurs, and that results can be reported in June 2017.

- The R&D program to understand and prototype a robust methodology for dealing with the MCP-PMT rotations should be completed by June 2017 so that a repair plan can be developed for implementation after the Phase 2 run. Simulation work should be continued to understand the degradation of physics performance.

- Radiation damage of the PMT should be carefully monitored so that the replacement tubes will be available when needed.
7.2 Endcap Particle Identification (ARICH)

7.2.1 Status

The status of ARICH detector construction and installation was reported. The committee congratulates the ARICH team for their constant progress in many areas.

At the time of this report, all aerogel tiles were integrated into the support assembly and are ready to be connected to the sensors (HAPDs). The aerogel database was updated with the latest measurements.

For 92 of the HAPDs, “getter reactivation” was done in order to cure the problem of large output pulses when being operated in a magnetic field, leading to dead times of order 0.1 s per pulse. After “getter reactivation”, dead times for these photosensors was found to be well below 1 % (except in one case), both immediately and when tested again four months later. It is therefore concluded that “getter reactivation” cured the relevant HAPDs for the long term. As a result, the 420 high-quality HAPDs required for the detector plus about 25 spares are available.

The torque on MCP-PMTs due to the solenoid B-field, which is also present in the TOP detector, is a potential problem for the aerogel HAPDs, since their rings are made from Kovar, containing ferromagnetic cobalt. The magnetic field is not expected to cause a mechanical stress that leads to short-term performance losses. However, it is not completely excluded that an HAPD can be pulled out from the socket after a long time due to small vibrations and/or thermal cycles. Hence, the ARICH team plans to perform a test together with Hamamatsu to see whether a 1 kg weight producing an equivalent torque is able to pull out the HAPD from the socket pins in the presence of vibrations. During the meeting, solutions that bind the HAPDs to the socket boards more tightly were discussed. As an example, the ARICH team has proposed gluing the HAPD’s unused pins to the socket to mitigate the problem. An alternative solution could be to bind each HAPD to its socket board using a thin string, which would decrease the photon detection efficiency only by a very small amount, but would still allow an HAPD to be easily removed, if an intervention were needed.

While the high-voltage (HV) cables and their connectors have been ordered and are expected to arrive by March 2017, the HV power supplies still need to be ordered. For the HV power supplies, bidding is close to being finalised. Once the decision is taken, the first power supplies will be delivered by the end of June 2017 for a full test of a complete sector. Full installation of the ARICH detector is expected by the end of September 2017, with the last sectors completely tested by November 2017 when the last HV power supplies are expected to be delivered. For the CAEN power supply, however, first tests together with the cables can be performed as early as March, since the ARICH team has a CAEN power supply for testing purposes in hand. Overall, there is a three-months schedule delay compared to the one presented at the BPAC meeting in October 2016. According to the updated schedule, the ARICH detector could still be briefly tested together with the other subsystems near the end of the GCRT, provided no further delays occur.

DAQ tests with cosmic muons continue using the pocket DAQ system. The number of merger boards in these tests was increased to four, with 23 FEBs, one COPER
board, and 16 HV lines. The DAQ system was able to run for more than 20 hours in this configuration. Occasional DAQ errors still occur and are being investigated. An extension to two COPPER boards is the next envisaged step. A second pocket DAQ system is in use to test the behaviour with random trigger at a rate of up to 30 kHz. Errors occur above about 3 kHz and are under investigation. (In the last October BPAC meeting, it was reported that problems started already at 10 kHz. This information was corrected in this meeting: in fact errors had already appeared at 1 kHz.)

Significant progress was reported in the area of slow control. The control software is updated resulting in simplification of operations. The HV control speed for CAEN was tested, demonstrating that the set-up of all channels was possible within 1 s. The low-voltage (LV) slow control (WIENER) is being integrated, while monitoring and recording of relevant condition data (temperature, LV, HV, ...) for the FE boards is now available.

The main components of the reconstruction software are ready and constantly being updated; e.g., the particle identification was improved by taking into account the mean emission point inside the aerogel which is slightly shifted from the entrance point of the aerogel in the transverse direction due to the curvature of the particle trajectory in the magnetic field. The reconstruction software now accesses the database instead of xml files and is used in reconstructing data from the ongoing cosmic-ray runs.

The LED monitor system was successfully tested with long multi-segment optical fibres allowing the LED module to be moved to the electronics hut. Polyethylene-based radiation shielding for the HAPD is now in hand. It will be slightly modified and then installed soon. The design of the cooling pipes is being prepared by the company in charge. The LV power supplies are available; the LV connectors and short cables are available and partially assembled; and the long LV cables are currently being tested.

7.2.2 Concerns

Overall, the ARICH subsystem is making good progress, with the following areas of concern:

- It is not likely that torque on the photodetectors due to the magnetic field poses a serious problem. Nonetheless, it is not completely excluded that there is a long-term risk that an HAPD could be pulled out from a socket board undergoing continuous vibrations and/or many thermal cycles despite the fact that about each HAPD is held by about 100 pins in the socket via friction.

- The HV cables and power supplies are on or close to the critical path.

- While it is quite plausible that the present DAQ problems can be resolved in time, it is important to get the system running without errors as soon as possible to make sure that no deeper-level underlying problems remain hidden that would have to be solved under high time pressure.

- ARICH integration into the Belle II detector has shifted by three months compared to the schedule presented in October 2016, due mainly to the late delivery of the power supplies, which will not start before June 2017. Only after integration of the
ARICH with the ECL end-cap can both sub-detectors be installed into Belle II. Little time is left for integrating the ARICH and the ECL end-cap in time to participate in a short GCRT run.

7.2.3 Recommendations

- During the few months remaining before installation, the committee recommends that the ARICH team fully develops a solution to firmly attach the HAPDs onto the socket board to mitigate the problem induced by the magnetic field. This solution should take into account that a possible future intervention might require removing of an HAPD from the socket board. In order to decide whether to implement the solution, the team should in parallel study the forces needed to pull an HAPD from the socket board and test whether a torque of the expected size is able to pull an HAPD out from its socket in the presence of long term vibrations or temperature cycles.

- The ARICH team should ensure that sufficient manpower is available to adequately test the DAQ well before full detector integration so as to be confident that the complete detector system will work at high data rates.

- The ARICH team should closely monitor the progress in production, delivery, and assembly in order to avoid further delay in the schedule. If possible, missing components, like HV power supplies, should be delivered to KEK as soon as each unit becomes available rather than waiting for a complete batch, so that they can be tested and deployed avoiding any problems discovered at the last moment.

8 Belle II Electromagnetic Calorimeter (ECL)

8.1 Status

Installation of the backward end-cap counters and the readout electronics were completed and initial tests performed. The results show that all the counters are alive and connected. The noise of the each counter is at a reasonable level. Further tests and calibrations will be continued and the backward end-cap ECL will be included in the regular calibration procedure together with the barrel ECL. The forward end-cap ECL will be installed in September 2017 and further tests and calibrations will follow.

In November 2016 and in February 2017, cosmic-ray data were taken by the ECL trigger and the ECL data were readout. By comparing the two recorded energies, one on the trigger and the other on the readout path, a reasonable correlation between the two has been obtained. The firmware for the ShaperDSP module should be finalised to implement all the required functionalities as well as to fix the instability found in the latest version. The other firmware for the FADC Analysis Module (FAM) has an instability problem in the Belle2link to the global trigger module and it also needs to be fixed.
The environmental monitors of the ECL system are running continuously. The ECL provides the online luminosity information and all the monitoring modules for this purpose were produced and installed. The firmware of the online luminosity monitor is under development.

8.2 Concerns

• Installation of the forward end-cap ECL is planned in September 2017. This is very tight for the Phase 2 run, which starts in February 2018, since the system must be properly commissioned.

• The firmware development for both electronics modules, ShaperDSP and FAM, has not been completed yet and instabilities are found.

8.3 Recommendations

• The firmware of ShaperDSP and FAM should be finalised and verified as soon as possible for the calibration runs, cosmic-ray runs, high-rate tests. The observed instabilities of the Belle2Link should be understood and fixed.

9 Belle II K-Long Muon Detector (KLM)

9.1 Status

The last items to be produced and installed in the KLM system are the readout boards of the Resistive-Plate Chambers (RPC) in the Barrel KLM (BKLM). The committee was happy to learn that fifteen pre-production boards were produced and tested in Italy, and are at KEK for final testing before full production. The production and testing of the BKLM RPC readout boards will be completed by the end of June 2017 in Italy and installed at KEK soon afterward. The committee is pleased with the efficiency of this collaboration that brings the long-delayed production of the RPC readout boards within sight.

Two half-octant sectors of the BKLM, one in the top and the other in the bottom part of the barrel, were outfitted with RPC readout boards and data were readout by the Pocket DAQ: one sector with boards produced by the Indiana group and the other with the INFN produced boards. Cosmic-rays were triggered by the top sector using two layers of the scintillator strips and tracks were observed in both the top and bottom sectors.

Condition of the RPCs has been monitored since January 2017. The integration of the KLM DAQ system with the Belle II global DAQ is planned in early March. The slow control system, especially the high-voltage power supply control software, needs to be completed in the framework of the new user interface CSS (Control System Studio).

The committee notes that two scintillator modules in the backward end-cap KLM must be replaced, but understands that this is not a major concern.
9.2 Concerns

- Only a part of the KLM system is able to participate in the initial phase of the global cosmic-ray run due to the late delivery of the RPC readout boards, even if the production, tests and installation go smoothly.

- The user interface and the related control software of the high-voltage system has not yet been completed.

- The integration of the KLM DAQ system with the global Belle II DAQ needs to be completed, although the full chain of trigger and readout has been validated with the Pocket DAQ.

9.3 Recommendations

- The user interface and related software of the high-voltage control system should be completed as quickly as possible and it should be used intensively during the global cosmic-ray run to improve the control system.

- The KLM DAQ system needs to be integrated with the global Belle II DAQ in a short time scale and stress tests with high rates and stability checks with long runs should be performed.

- The full procedure of the detector and DAQ commissioning needs to be established with the top and bottom BKLM sectors using the pre-production RPC readout boards. After the delivery of all of the production boards, the KLM group should apply the established procedures and quickly finalise the commissioning of the full KLM system.

10 Belle II Detector Control, Trigger and Data Acquisition

10.1 Detector Control & Interlocks

10.1.1 Status

The committee is pleased to note the progress in the run-control and slow-control. A fair amount of automation has already been achieved, allowing non-expert users to operate. The interlock installation is progressing well.

10.1.2 Concerns

None

10.1.3 Recommendations

Well written documentation, also of seemingly trivial “tricks” such as the right way to setup a remote connection, can help to avoid unnecessary frustrations among non-expert users.
10.2 Trigger

10.2.1 Status

The committee was pleased to note the progress made in the trigger system, in particular in the CDC, the largest system, which is almost completely installed, functionally validated to a good fraction and seems to be on good track to be fully operational by summer 2017.

10.2.2 Concerns

Progress in some subsystems in commissioning the trigger seems slower than desirable, although no serious delay has been reported so far.

10.2.3 Recommendations

A subsystem responsible person should be encouraged to validate the full trigger functionality as early as possible. This is important to uncover firmware and connectivity problems, which, if present, will delay global commissioning.

10.3 Data Acquisition

10.3.1 Status

A large amount of work has been achieved, where the full DAQ validation at 30 kHz of the ECL is one of the highlights. The observed limitation in the maximum readout rate of the CDC is reported to be understood. All subsystems are actively testing the full readout chain.

10.3.2 Concerns

There is no particular concern for the DAQ as such. As has been said repeatedly, the DAQ team is very small and will need vigorous cooperation of subsystem teams for successful commissioning.

10.3.3 Recommendations

Subsystem responsible person should be encouraged to educate commissioning coordinators who will be competent in their respective readouts electronics, DAQ and trigger. It is important that all system tests are done at the maximum random trigger rate and, as far as possible, with nominal and also pessimistic occupancies.
11 Belle II Software and Computing

11.1 Software

11.1.1 Status

The committee was presented with an incremental update of the offline software project organisation since the focused review on software and computing that took place from 27 to 28 of June 2016. The collaboration reported mainly on the state of the adoption and further clarifications of some of the concerns and recommendations. The first positive news is the smooth migration of the code repository from SVN to GIT. The committee has expressed a concern that changing the code depository might produce negative impact in the productivity of software developers. The tools are very different and require that the collaboration adapt their workflows to the new tool. However, the effect of the migration is not visible in the graph showing the steady increase of commits over time, and the collaboration was correct in proceeding with the implementation of these changes. The JIRA tool is now adopted by the software project to manage the release roadmap responding to the recommendation from the committee. The tasks are defined in terms of software features assigned to developers and grouped according to the fixed release dates. At any given moment, unfinished tasks for a given release are clearly visible.

The project also adopted the recommendation to organise a series of full dress-rehearsals in order to better integrate the online and offline subsystems, as well as to stress the computing system exercising all the steps. The committee is looking forward to the results of the scheduled rehearsals and the lessons that the collaboration will learn from them.

Execution time of the various modules for tracking, PID and clustering of neutrals are being monitored continuously to ensure that the execution time stays within the budget of the HLT system. Finally, the project took note of some of the recommendations such as support for multi-threading, some use of deprecated C++ containers, or better support for event data schema evolution. Those works will slow down progress and could be addressed later if needed. Delaying them, however, will increase the amount of effort needed. Good progress has been made in the conditions database with a production server with improved reliability and implemented with Dockers containers for easy scalability. It is being used regularly in the MC campaigns. Many of the concerns from the committee in update policy and organisation of IOVs (interval-of-validity) has been addressed.

Some progress has been made in software for the raw data encoding/decoding. A more thorough test is expected for the data production rehearsals.

Reconstruction software seems to be in a reasonably good shape. A few critical items identified last summer have been addressed. The relative low efficiency of the CDC track reconstruction at low $p_T$ reported last summer has been understood. Additional studies have shown that the apparent inefficiency is due to a problem in the matching of the reconstructed tracks to MC particles, in particular for “looping” tracks. Concerns in the performance, developments and maintenance of the VXD tracking software have been
alleviated by assigning additional manpower, in particular from KIT and Pisa. The ECL reconstruction has been completely rewritten to account for the larger backgrounds in comparison to those in the Belle experiment. The new algorithms contain handles to optimise for different background conditions. The development of calibration algorithms for the different sub-detectors is well advanced, with the exception of the KLM. Algorithms have been tested on simulated events, and, where possible, also on the Phase 1, cosmic and test beam data.

On the simulation software, progress has been made as well. For the maintenance and development of EvtGen, an agreement with LHCb collaborators was made for a common code repository. Digitisation (encoding) of the simulated detector responses is almost complete, which allows to run simulated events through the HLT. A central procedure for validating/monitoring simulation software is in place. Progress is made on the implementation of a realistic material budget, for instance, by comparing to material scans taken from test beam data. Strategies for validation of reconstruction efficiency and resolutions based on cosmic and Phase 2 data are in place as well.

11.1.2 Concerns

• The raw data must be stored in a format that can still be decoded many years from now. The committee is not entirely convinced that a ROOT format is suitable for this.

• It is unclear to the committee to which extent the simulation of the trigger is complete. The trigger reconstruction seems to develop independently of the offline reconstruction software.

• As mentioned last summer, the committee is concerned that track reconstruction software is not an institutional responsibility. Although new institutes have been assigned to contribute to VXD tracking, progress on the actual implementation has not yet been reported. The situation of maintenance and development of the track fitting code remains unclear as well.

• For the PXD, SVD and KLM detectors the persons responsible for developing calibration codes have not yet been identified.

11.1.3 Recommendations

• The committee recommends that calibration and alignment workflows be part of the scheduled full dress rehearsals, which should include the update and distribution of the conditions database. Exercising the complete system as close as possible to the physics run will allow the collaboration to discover many of the missing features and to identify the parts on the software and computing system that need to be improved.

• The progress in the development of VXD tracking software will need to be watched. An institute responsible for the track fitting code still needs to be identified.
• For all sub-detectors, persons responsible for the calibration should be identified. When appropriate, the algorithms should be tested on simulated data.

11.2 Computing

11.2.1 Status

The Belle II computing model is based on a distributed approach using grid and cloud technologies to access the computing resources hosted in centres of different sizes and types. A hierarchical structure, composed of four layers of data centres with different functionalities, has been designed: the Raw Data Centres with tape capabilities¹ and high network bandwidth where raw data are stored and processed, the Regional Data Centres where copies of the reconstructed data (mDST) are stored and Monte Carlo production as well as the physics analysis are performed, the MC Production Sites dedicated to the Monte Carlo production and physics analysis and the local sites where the last step of the user analysis is performed. The collaboration has presented the computing resource requirements for the activities scheduled in the years 2018-2021 and an update of the computing model whose design has much improved in the last year. The evaluation of these requirements and the comments on the model are reported in a dedicated BPAC document.

The orchestration of this heterogeneous system of computing resources is performed by the DIRAC framework acting as workload and data management system. In the last year, DIRAC has been frequently updated causing several interruptions of the computing activities. The committee is pleased to notice that the time needed for each upgrade has been drastically reduced, from about one month to two days, thanks to the experience acquired and to the use of a validation server in PNNL. This has greatly increased the Monte Carlo production efficiency.

One of the main recommendations expressed in the June focused review in 2016 was about the evaluation of the essential services for the Belle II operations in order to cope with the lack of human resources. The collaboration has given a priority list of the essential services and the Production System is considered as the basic infrastructure for production, data distribution and analysis. The usage of the system for the offline calibration is still under discussion. The system, built on top of DIRAC, consists of four modules: Production Management, Fabrication, Data Management and Monitoring. Many efforts have been spent by the collaboration for the upgrade of the Production System, as suggested in the June review where it was recommended to implement as soon as possible the missing components. The Fabrication System and Distributed Data Management have been already implemented for the MC6 campaign and a version with a new Production Management system, where many tasks are performed automatically, has been deployed in the Monte Carlo campaign MC7. In this campaign, from November 2016 to February 2017, 27 billion events have been produced with up to 25k concurrent jobs on the grid using the resources in all the centres of the collaboration corresponding to more than 200 kHS06. The Data Management system, fully synchronised

¹The PNNL centre will store the raw data on disks for the first three years.
with the Production system, has moved successfully many thousands of files per day, up to 85k, for a total of up to 300 TB transferred with an efficiency of about 99%. The Monitoring has been upgraded as well, providing many features useful for the shifters, such as the production status, the sites availability and the CPU and storage usage.

The Committee notices that the collaboration plans to increase the grid usage both for centrally managed and user analysis activities and is pleased that the first tutorial of the grid usage for user analysis has been organised. So far, only the Monte Carlo production has been checked in the last campaigns and, starting in the MC8 campaign, datasets will no longer be transferred to KEKCC and the analysis will be based on Gbasf2. The reconstruction on grid, a very challenging activity, is part of the full dress rehearsal while it is still to be confirmed the possibility of performing the mDST skimming on grid, so far based on basf2 on local CPUs.

The skimming procedure of the mDST datasets, a fundamental part of the analysis model, it is not yet defined. Two options are still under investigation: production of skimmed files in $\mu$DST format or index files, i.e. a collection of pointers to the selected events. The current baseline is the production of skimmed files copying $\mu$DST on the worker nodes and in parallel the collaboration is still investigating the possibility of having in the future a skimming model based on index files to replace the $\mu$DST. The choice of one of the two technologies will have a strong impact on the way users will perform analysis and on the number of mDST replicas.

Many computing activities have been scheduled in the next years before the start of data taking, but, as already stated, the emphasis is placed on the full dress rehearsals where also the computing system will be stressed testing the full chain workflow from raw data production and reconstruction to skimming. The results of these tests will be very useful to identify any remaining issues and to optimise the whole system.

11.2.2 Concerns

- The committee notices that the progresses on the skimming have not been fully reported and the procedure seems not to be as mature as the other parts of the computing system: possibility of running the centrally managed $\mu$DST on grid is not yet confirmed and the technology of the index files has not yet been fully investigated. Moreover, the concerns and recommendations made in the June focused review in 2016 have not been completely addressed.

- The collaboration has not reported about the implementation of an automatic data deletion system nor the lifetime model for the various data formats. The experience of the LHC experiments has shown that these are really necessary to cope with the fast saturation of storage space due, for example, to the release of new software versions and the related replication policies.

11.2.3 Recommendations

- The committee is aware of difficulties in using the grid computing resources, which take away many physicists from the analysis activity, and welcomes the software
and computing tutorials being organised. Continuing such tutorials is recommended, in order to train both newcomers and already experienced people along with the evolution of the system.

- The committee has positively noticed that the collaboration has adopted the recommendation of organising a series of full dress rehearsal in order to stress test the online and offline environments at the same time. However, it seems that the collaboration has not yet identified the sets of metrics necessary to evaluate the success of the tests. So, the committee recommends finding a set of convenient parameters for evaluating all the activities foreseen leveraging the experience of the other HEP experiments.

- The evaluation of the computing resource requirements is one of the main tasks of the committee. The usage of the resources has to be reported in full detail and the committee recommends showing plots where the CPU and storage usages are compared with the funded resources for every site or federation of sites in the future BPAC meetings.