

# B-factory Programme Advisory Committee

## Full Report of

### Autumn Review Meeting

19–20 November 2020 Remote Meeting

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## Executive summary

The autumn review meeting of the Belle Programme Advisory Committee (BPAC) was held remotely on 19th and 20th of November 2020 focusing on the progress of the SuperKEKB and Belle II operation since the last BPAC review meeting in June 2020. This section summarises the most important findings and recommendations of the committee.

After the summer break, the Belle II experiment has been taking physics data since the end of October 2020 (Run 2020c). Compared to the June BPAC meeting report, overall data taking efficiency has improved from 84.2 % to 88.3 % and the committee congratulates the collaboration for this achievement.

Hardware status of the detector is very good. Although the Belle II collaboration has been coping extremely well with COVID restrictions, continuous attention must be paid to ensure the stable and sustainable operation of the detector for the rest of 2020 and 2021 data taking, where the number of detector specialists onsite will likely be still limited. The committee encourages the collaboration to sustain its efforts to further automate the detector operation, in order to reduce the workload of the shift crews and on-call detector specialists.

Successful completion of the computing hardware replacement at the KEK Computing Research Centre was reported. This work took place during the intensive data processing period. Although most of the core computing activities were migrated to the new system as planned, some disturbance in the Belle II distributed computing activities

was unavoidable. The committee understands that the timing and process for replacing the computing hardware are constrained externally and cannot be controlled by the experiment. However, the collaboration could plan and prepare for the transition to minimise the interruption due to the shutdown and startup procedure. The experience gained from this operation should be used to prepare for the future.

Although there are still features in the data that cannot be fully reproduced by the detector simulation, the understanding of the Belle II detector performance has reached a level sufficient for complex physics analyses, which has been demonstrated by several published results. The collaboration should, however, continue its effort to improve their understanding of the detector performance.

The committee commends the ongoing data analysis work for the coming winter conferences. In parallel with the effort striving toward collecting  $1 \text{ ab}^{-1}$  of data, the collaboration is encouraged to develop a strategy that exploits the advantages of the Belle II experiment over others. For this purpose, the committee recommends to continue and enhance the existing framework for the communication and collaboration with theoreticians, as well as experimentalists from other experiments, to explore a wider scope of physics programme.

The committee is pleased to hear that the construction of the pixel vertex detector (PXD) with the full two layers and associated beam pipe is proceeding well to be ready for the installation in summer 2022. It is recommended, however, to build up contingency whenever possible since the installation of the PXD will be a delicate operation with a significantly increased number of cables to be accommodated in very limited space. The installation procedure has to be carefully studied.

The accelerator group has been coping very well with COVID situations. While the committee noted that starting up of the accelerator complex has not been so smooth for Run 2020c affecting the commissioning and operation of the SuperKEKB, the group has been addressing the problem efficiently. Stable operation of the linac injector is crucial for the success of the Belle II experiment and sufficient care must be taken. Whereas the understanding of the machine induced background for the experiment is making steady progress, the committee was alerted by the damage in the collimator jaws and a quench of one of the superconducting final focusing magnets. For the experiment running at high luminosities with a small diameter beam pipe at the interaction point, this type of accident is an intrinsic risk. The Belle II collaboration and machine group are strongly encouraged to investigate how to further improve the protection system for the machine and experiment.

Lastly, the committee is pleased to learn that the KEK management was able to allocate resources for an additional month of data taking during the 2020 Japanese Fiscal Year and looking forward to hearing more details of the long term plan with necessary upgrade to achieve  $50 \text{ ab}^{-1}$  in 10 years during the coming BPAC meetings.

# 1 Machine and background status

## 1.1 Status

The machine performance has become more stable with fewer beam aborts. However, the start up this autumn was slower than expected and it took about two weeks of attempts to finally get the HER  $\beta_y^*$  value back to 1 mm. Injection emittance has improved but still needs further reduction. The dynamic vacuum pressure in the LER has improved indicating that beam pipe “scrubbing” is working. The background simulation code has been further improved and it now models all backgrounds with differences that are now within a factor of ten compared to the data collected during dedicated background studies. The background model now includes neutron sources in the nearby tunnels and this has greatly improved the prediction of the KLM background. In addition, a major source of neutrons appears to be coming from the points at which the gamma from radiative Bhabha scatterings hits the beam pipe. This important finding should allow the team to reduce the rate through local shielding. Further improvements to the model are also being considered. Improvement in the background simulation has allowed the background team to produce optimised collimator settings that maximise the stored beam lifetime while minimising the detector backgrounds. The primary concern is now the TOP backgrounds. Thoughts of tailoring the collimator optimisation to minimise the TOP background exclusively are being considered. A careful study of the effect of adding more shielding around the bellow sections inside the inboard end of the cryostats has been made and a significant reduction of the background rate is seen in nearly all of the outer detectors in the simulation. This includes the CDC and the TOP. The committee congratulates the background team for the accomplishment of these impressive steps and the plan going forward.

## 1.2 Concerns

- The injection emittance and efficiency still limit the settings of the collimators in the rings.
- There are still unexplained differences between the simulation and the measured background rates.
- A collimator head was damaged during the last run.

## 1.3 Recommendations

- The committee highly encourages continued studies for improving the injection efficiency and the injection emittance. These issues affect many things including background levels in the detector as well as beam lifetimes in the rings. As the luminosity and beam currents increase, the beam lifetimes will decrease and injection efficiency will become even more important. Therefore, providing more resources to upgrade and repair ageing components in the linac should be considered.

- The committee encourages studies and possible implementations to further improve the abort system. Unstable beam conditions usually need several revolutions before the condition becomes dangerous and if the unstable condition can be detected early enough one might be able to abort the beam before damage occurs.
- The committee encourages the study suggested by the background team to optimise the collimator settings for the TOP backgrounds explicitly.
- Adding shielding to the bellow sections located between the cryostats looks very promising and it should reduce Touschek as well as luminosity backgrounds in the detector. The committee recommends a thorough study of the space constraints in this greatly congested region.
- The validity of the IR upgrade proposal should be carefully verified as the backgrounds become more manageable. The proposed upgrade may be worth doing if the resulting gain in the luminosity can overcompensate the loss of integrated luminosity during the required long shutdown.

## 2 Belle II detector hardware and operation

### 2.1 Status

The collaboration presented the status of the detector hardware and operation for the Run 2020c (started in October). The committee congratulates the Belle II collaboration for recording  $\sim 74 \text{ fb}^{-1}$  of integrated luminosity by the end of the summer,  $\sim 9 \text{ fb}^{-1}$  of which off-resonance. The collaboration has also achieved a world record peak luminosity of  $2.4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . The overall data taking efficiency has improved from 84.2% (as presented during last June BPAC meeting) to 88.3%, and the committee congratulates the collaboration for this achievement. Further efforts are going on to improve the efficiency of the detector operation, e.g. making a new optimisation of the injection veto. Luminosity is being restricted by the TOP background limit (1.2 MHz/PMT), which is the most critical issue and cannot be relaxed in run 2020c. Improved automation of the operation and monitoring and traceability of the failures, all show very positive impact. Like the previous 2020a and 2020b runs, 2020c takes place under the very difficult conditions created by the COVID-19 pandemic. Building on the outstanding dedication and professionalism of its collaborators, Belle II has managed to cope exceptionally well. Both the people on site, as well as the new scheme, started for 2020c, with two remote shifters supplementing the control-room shifter have contributed to this success.

The collaboration is committed to increasing the data-taking efficiency further to better than 90%. Thanks to the tools to analyse downtimes, specific areas for improvement have already been identified and implementation has started. It was noted that the HLT processing capacity will be further increased and expected to reach an input trigger rate of 12 kHz.

Major efforts were invested into the improvement of the stability of the KLM system before the 2020c run. The committee is pleased with the success of these measures.

## 2.2 Concerns

- Single Event Upset (SEU) of the electronics and neutron background will remain a challenge for the data taking.
- The situation with CDC remains worrisome. Although persistent dark currents have no longer been observed recently, careful online monitoring of sporadic current behaviour in the CDC chamber is mandatory.
- The upgrade of the readout-system has been postponed. It is now planned to start with TOP and KLM in February 2021. While it is a very necessary and well prepared operation, there remains operational risk.

## 2.3 Recommendations

- The SEU and neutron background must continue to be closely observed, in particular for the TOP that has been identified by the collaboration as the most susceptible system.
- Achieving a data-taking efficiency better than 90% is a challenge, but not impossible to reach. Success will depend on many individual optimisations and automation. It is recommended to study in detail the reasons for events causing long ( $> 30$  min) dead time, in order to prevent them as much as possible in the future.
- The new (PCIe40-based) readout should be tested as extensively as possible during the winter-break.

# 3 Belle II detector performance

## 3.1 Tracking

### 3.1.1 Status

The efficiency of the tracking detectors has been high and stable during the 2020 operation. The SVD and CDC tracking efficiencies are determined per run in Bhabha events, using standalone tracking in the other detector as a reference. They are typically above 99%. Several PXD modules show a minor degradation in the later part of the 2020ab run, when some sensors were operated with reduced depletion voltages due to current limitation of the HV power supplies. Nevertheless, the PXD shows an overall hit efficiency of 99%, after correcting for the 2.5% known dead channels. For di-muon events, the achieved resolutions are about  $14 \mu\text{m}$  and  $20 \mu\text{m}$ , respectively for the transverse impact parameter,  $d_0$ , and the longitudinal position along the beam,  $z_0$ . The transverse momentum resolution is about 45 MeV.

Higher background levels can be challenging for CDC based tracking, especially for the tracks not coming directly from the interaction point. A new multivariate based CDC track quality indicator has been implemented, aiming to reduce the number of fake tracks

and providing a better  $V^0$  reconstruction, which is most sensitive to the level of beam backgrounds. Further improvements are being planned: a better parameterisation of the CDC time-position calibration for long drift times and the introduction of SVD timing in the simulation, as well as new tracking algorithms and quality indicators.

A strong emphasis is being placed on the comparison of the tracking performance in data versus simulation. Different physics processes have been studied to cover various momentum ranges. It has to be noted that in some regions of phase space, performance in data is significantly different than in simulation; e.g. the efficiency ratio  $\varepsilon_{\text{Data}}/\varepsilon_{\text{MC}}$  is about 1.2 for slow pions ( $p_T < 200$  MeV/c). The momentum scale correction, derived from  $D^0 \rightarrow K^-\pi^+$  and  $\Upsilon(1S) \rightarrow \mu^+\mu^-$  decays, ranges from  $10^{-4}$  at low momenta to  $10^{-3}$  for muons from  $\Upsilon(1S)$  decays. Smaller corrections are expected for the next reprocessing of the data after an update of the magnetic field map. Good agreement is also observed in  $V^0$  reconstruction, where Belle II performance is now comparable to that of Belle.

Of particular interests are the newly developed methods using di-muon events to monitor the beam spot position and size, and the boost angles. These are designed to reduce the sensitivity of the estimated values for the beam parameters to the detector resolution. The accuracy is now at a level to provide valuable feedback to the machine group. For example, changes of the beam spot size between  $10\ \mu\text{m}$  and  $14\ \mu\text{m}$  in horizontal plane, due to modifications in the beam optics, can be followed with micron-level resolution. The resolution on the determination of the beam crossing angles has been improved by a factor of ten, making it possible to monitor their variation and pointing to a discrepancy of about 2 mrad with respect to the expected value in the horizontal plane.

Due to the compressed schedule of this review, it was not possible to go through the enormous amount of referenced material during the meeting. The committee expresses its appreciation for the number of analyses performed by Belle II members dedicated to tracking and trigger performance studies. In particular, the addition of the combined CDC and KLM triggers to the current CDC and ECL based triggers, as well as the usage of short tracks to improve the efficiency in the end-caps, are among the recent highlights.

The committee notices, with pleasure, how the work on detector performance also leads to publications. In particular, a tracking paper on algorithms and simulation studies for performance has been already published in 2020. The collaboration aims for two further papers in 2021, on tracking and on the measurements of interaction region.

The committee acknowledges the on-going work on the calibrations, including the alignment and the studies on the magnetic field, and commends the collaboration for the work done so far.

### 3.1.2 Concerns

- While it has been stated that the studies of the interaction regions may provide useful information to the machine group, it is not clear how this information will be shared with the machine group and how it can be used to improve the machine

operation.

- Future increases in backgrounds are expected to impact the tracking efficiencies, number of fake tracks and resolutions. This is a matter of concern, not only for the  $V^0$  reconstruction, but also for the overall tracking performance. There is a possible hint of a slight degradation in the  $V^0$  reconstruction efficiency at the end of the 2020b run, which requires more studies with the 2020c data.

### 3.1.3 Recommendations

- The committee recommends that the tracking community should continue the steady flow of improvements to the calibration, the simulation and the reconstruction which were briefly addressed during this review. For the future, it is recommended to develop a prioritised plan for the implementation of novel features and algorithms.
- In some cases, significant discrepancies between data and simulation have been shown and scale factors computed, like, for example, for the low- $p_t$  pion reconstruction and long-lived  $\Lambda$ s. The reason for these discrepancies needs to be understood and either corrected or accounted for in the simulation.
- It would be beneficial to understand to which extent the actual performance of the sub-detectors for tracking and trigger are already adequate to the ultimate Belle II physics goals. The committee also encourages Belle II to study potential improvement in the impact parameter resolution in the  $\phi$ -sectors where the two PXD hits are currently available.
- It will be the most useful to find methods that improve the performance of track reconstruction and to understand the impact of these improvements to the physics performance of the detector, with the installation of PXD2022 or with future upgrades.

## 3.2 Particle identification and neutrals

### 3.2.1 Status

#### 3.2.1.1 Overall PID performance

The stated goal of the physics performance team to optimise the workflow for particle identification (PID) and coordinate the work of subdetector groups is highly appreciated. First results on hadron and lepton identification are based on  $37 \text{ fb}^{-1}$  of data, analysed with Release 4 software and compared to MC13a simulation data. The information from each subdetector is analysed independently to determine a likelihood for each particle hypothesis ( $e$ ,  $\mu$ ,  $\pi$ ,  $K$ ,  $p$ ). These likelihoods are used to extract binary likelihood ratios. They are typically developed and validated by subdetector experts on the basis of control samples and simulations. In some cases, boosted decision tree (BDT) methods are considered for individual detector systems to be used in more global combinations.

The present study of  $K$  meson identification uses a control sample of  $D^{*+}$  decaying into  $D^0\pi^+$  followed by  $D^0$  decaying into  $K^-\pi^+$  final state, where the  $K^-$  is tagged by the  $\pi^+$  from the  $D^{*+}$  decay. The simulated shapes of the momentum and polar angle distributions for kaons and pions agree well with data. The agreement between the resulting  $K$  PID efficiency and  $\pi$  misidentification rate (mis-ID) for the data and simulation is best in the central section of the detector, i.e. the  $\cos\theta$  range of  $-0.5$  to  $+0.2$ , at the level of  $\sim 90\%$  for the  $K$  efficiency and  $\sim 5\%$  for the  $\pi$  mis-ID. Elsewhere the data indicate significantly smaller  $K$  efficiencies and larger mis-ID.

For lepton identification, several control samples are being used for the signal leptons and for the charged pion and kaon to derive PID performance based on the binary, global ID and BDT methods. These analyses rely on the charged particle tracks reconstructed in the SVD and CDC and extrapolated to the ECL and KLM. In addition,  $dE/dx$  information, as well as  $E/p$  for electrons and matching with a track found in the KLM for muons are used. The analyses are restricted to the barrel region. Above 0.5 GeV, the electron efficiency is close to 98% and independent of momentum. The  $\pi$  mis-ID is 2-3% and well reproduced by the simulation. There is an indication that the efficiencies and misidentification rates are impacted by nearby tracks. Above 1.0 GeV, the muon efficiency is about 90%. Below 1 GeV, the  $\mu$  efficiency drops fast and the mis-ID increases to greater than 10%.

### 3.2.1.2 PID performance of subdetectors

The smooth operation of the SVD continues to stand out with its excellent hit efficiency of 99.5%. Recently, modelling of the probability density function (PDF) for the energy loss in the SVD sensors was developed for charged hadron ( $\pi, K, p$ ) identification with  $dE/dx$  calibrations based on  $D^*$  and  $\Lambda$  control samples. At low momenta ( $\sim 0.5$  GeV), the pion efficiency is very high ( $\sim 95\%$ ) and agrees well with simulations, while kaon mis-ID performance is quite poor below 0.2 GeV. Studies of electron and muon identification using SVD information are being prepared for Release 5 software.

The operation of the CDC has further improved and so have the simulations for studies of lepton and hadron identification. Energy loss of the CDC depends on many factors, such as the environment under operation. Radiative Bhabha events are used to monitor the resulting effects which are taken into account in the analysis. It also depends on the configuration of electrostatic field in the drift volume introducing geometrical effect which are under investigation. For hadrons, non-linearities of the ADCs and gas gain saturation effects are taken into account in the data processing. CDC results for data and simulation agree best for momenta below 1.2 GeV and above 3.0 GeV where the  $K$  identification efficiency is about 80% and the  $\pi$  mis-ID (20%) for data and simulation. Elsewhere, the data-simulation differences are at a level of  $\sim 10\%$ .

The TOP continues to operate smoothly under current machine conditions. The analytic PDF simulation is based on performance studies of tracks extrapolated from the CDC and the generation and propagation of the photons through the quartz bars, including quartz surface and mirror reflection, as well as PMT response. A recent study



of  $\delta$ -rays increased the number of photons by 10-20%. Each additional underlying track is estimated to reduce the  $\pi$  efficiency by 1.5%, and increase the  $K$  mis-ID by 3.9%. The impact of these detector conditions and also the uncertainty in the time  $t_0$  have been assessed in separate studies, and appear to be within tolerances. Further studies are planned to model the quartz bar imperfections, to implement a more realistic digitisation, and to study the impact of backgrounds. These kinds of improvements may require extremely detailed simulations, and data driven PDFs will be tried to avoid large increments in computing needs. For the TOP, the data-simulation agreement is best between 0.5 GeV and 2 GeV for the  $K$  efficiency ( $\sim 90\%$ ) and  $\pi$  mis-ID ( $\sim 5\%$ ). At higher momenta the  $K$  efficiency is as low as  $\sim 70\%$ , and the  $\pi$  mis-ID exceeds 20%, with the data-simulation differences close to 10%.

The operation of the ARICH has been stable for some time. The alignment of the aerogel tiles relative to the photosensors has been performed, though some ununderstood residual effects still exist. The current focus is on PDF modelling, including uncertainties in the track extrapolation, the scattering of low momentum pions and kaons in the upstream material, as well as the aerogel photon path length and position resolution. Furthermore, effects of Cherenkov radiation in air and also Rayleigh scattering are taken into account. Current ARICH based results are largely independent of the momenta and polar angles and show very good agreement with the simulation results within 5%. The  $K$  efficiency exceeds 95% and the  $\pi$  mis-ID average is  $\sim 10\%$ .

### 3.2.1.3 Photon, $\pi^0$ and $K_L^0$

With stable operation of the ECL in 2020, very significant improvements to the performance have been made. Crystal level calibrations on a sample  $e^+e^- \rightarrow \gamma\gamma$  events resulted in a systematic uncertainty of 0.3% per crystal. Light loss due to damage is estimated to be less than 1%. At the cluster level, leakage corrections were assessed as a function of energy and angles, and indicated a bias in the data of less than 1%, a factor of two larger than required for analyses. Samples of  $e^+e^- \rightarrow \mu^+\mu^-\gamma$  events are being studied to determine photon detection efficiency as well as the energy and position resolution. For the photon efficiency, there is excellent data-simulation agreement, greater than 90% above 2 GeV. It decreases below 2 GeV, due to multiple initial state radiation. From those measurements, covariance matrix for the resolutions for the energy and position will be constructed. This will be important for future analyses, for instance searches for axion-like particles. Measurements of  $\pi^0$  efficiency for a variety of  $D$  meson and  $\tau$  lepton decays are in progress, both for low and higher  $\pi^0$  momenta. Further studies of pulse shape discrimination, low energy photon detection, and energy resolution are planned.

To enhance the use of  $E_{extra}$ , the sum of the unassociated clusters in the ECL, a method needs to be developed to distinguish photons that are not associated with physics processes. Recent timing calibrations of ECL photons may favour cuts to reject out-of-time photons, where their impact still needs to be assessed. It has been shown that interactions of  $K_L^0$  in the ECL can be identified by matching the angles of clusters in the KLM and ECL. Furthermore, a very detailed study has indicated that particle

dependent scintillation in the ECL can be used to identify not only  $K_L^0$  interactions but also differentiate photons from other hadrons.

The KLM has in the past suffered from a number of problems. Inefficiencies have been taken into account in simulations and PDF models have been added. The present  $J/\psi \rightarrow \mu^+ \mu^-$  control sample is statistically limited.

### 3.2.2 Concerns

- The current hadronic PID results indicate large kinematic areas where the simulation overestimates the efficiency by 10% and indicates lower mis-ID, even though the agreement in the momentum and polar angle distributions of the control samples between the data and simulation is good.
- The assessment of systematic uncertainties of the PID results will be very challenging and will depend on the processes that are being analysed. It is not obvious that the observed differences among different control samples can be used as a measure of the systematic uncertainties, since the same subdetector is used for the control sample.
- To reduce the current energy bias of the ECL of 1%, leakage corrections must be derived after geometric alignments and other calibrations are finalised. There is concern that the time available to complete these complex tasks may be too short, given the current overall schedule for the processing of the 2020 data.

### 3.2.3 Recommendations

- It is extremely important to establish an overall plan for the particle identification work to address technical issues and potential sources of the current disagreements between data and simulations.
- The committee recommend to establish a dedicated task force made up of experts from the subdetector groups for each of tasks identified in the work plan. Equally, documentation and sign-off of each task should be required.
- The impact of timing cuts depends strongly on the backgrounds. Selection criteria that directly or indirectly depend on timing should be used with caution until the backgrounds are better understood, and the data and simulation show better agreement.

## 4 Computing and data processing

### 4.1 Status

The successful completion of the computing hardware replacement at the KEK Computing Research Centre was reported. This work took place during the intensive data processing period. Although most of the core computing activities were migrated to the

new system as planned, some disturbance in the Belle II distributed computing activities was unavoidable.

In 2020, the usage of the computing resources was still dominated by the production of simulated data (MC). It was reported that  $5 \text{ ab}^{-1}$  of MC was produced in the MC13 campaign. The MC14 production is planned to start in late 2020 and will include run-dependent MC production once random trigger data is available.

The prompt processing of the 2020a/b datasets has been completed. This combined with the previous data will form the basis for analyses for the winter conferences. Automated calibration is in operation at BNL which will serve as the calibration and processing centre for the 2020c data. The recalibration is planned to be done at DESY. Prompt staging and processing after the calibration was aided by the good communications with the distributed computing group. Support for distributed computing and analysis remains a priority for this period.

At the time of the meeting the testing of the new Rucio data management system was nearly complete and the transition to operations had been scheduled for January 2021. The basic functionality has been confirmed and the LFC migration test has been completed. Testing of user analysis is underway. The transition was postponed to avoid interference with data taking (Run 2020c), however, some of the planned functionality such as Rucio-based monitoring is already in use.

## 4.2 Concerns

- The complete replacement of the KEKCC hardware on a fixed four year cycle base is a potential risk to cause a significant disruption to the operations of the experiment.

## 4.3 Recommendations

- The committee understands that the timing and process for replacing the computing hardware are constrained externally and cannot be controlled by the experiment. The experience gained from recent replacement of the KEK Computing Centre should be documented and used to prepare for the future upgrades to the system.
- The Rucio transition should be implemented as planned in early 2021, which will enable the collaboration to take advantage of the more advanced features of this now well established Distributed Data Management System.

# 5 Physics analysis and tools

## 5.1 Status

The committee congratulates the Belle II collaboration for recording  $\sim 74 \text{ fb}^{-1}$  of integrated luminosity by the end of the summer,  $\sim 9 \text{ fb}^{-1}$  of which is off-resonance. The collaboration has good prospects for 6.5 month operation in JFY2020, and hopes to

accumulate  $\sim 240 \text{ fb}^{-1}$  by 2021a, and reach the Belle integrated luminosity by 2021b. The target for the fall run peak luminosity will be  $4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . The target luminosity before the 2022 long shutdown will be  $> 1 \text{ ab}^{-1}$ . Before the shutdown, the collaboration also plans to collect (10 to 30)  $\text{fb}^{-1}$  data beyond the  $\Upsilon(4S)$ . More on the long term, the collaboration hopes to collect  $\sim 50 \text{ ab}^{-1}$  in 2030s, with a peak luminosity of  $\sim 6 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ .

The collaboration presented an impressive set of physics results at the ICHEP conference this summer. Nine new conference papers were uploaded to the arXiv this summer and three during the spring. These contained new physics analyses, as well as performance and analysis tool studies.

In particular, after the last June BPAC meeting, several B-physics studies were completed, together with a new  $\tau$  lepton mass measurement. These were based on up to  $\sim 35 \text{ fb}^{-1}$  data. The collaboration has rediscovered several  $B$  meson decays such as  $B \rightarrow \pi^- \ell^+ \nu$  and  $B \rightarrow \phi K^{(*)}$ . First measurements for the branching ratios  $B \rightarrow$  charmless and  $B \rightarrow D^{(*)-} \ell^+ \nu$  were also performed. Finally, the measurement of the hadronic mass moments of  $B \rightarrow X_c \ell \nu$  has been performed using the hadronic Full Event Interpretation (FEI).

A new iteration of performance studies has been made for the hadronic tag-side FEI algorithm and calibration factors were determined to account for the difference in performance of the tool on real and simulated data. Improvements on the performance of the hadronic FEI on the ICHEP data set were reported with more work needed to meet the target needed for the most precision-challenging measurements. Work on the semileptonic FEI algorithm has also proceeded with encouraging first performance studies in progress.

Good progress was reported for the flavour tagging performance based on the multivariate algorithm with a total effective efficiency of  $(33.8 \pm 3.9)\%$ ; this is lower but consistent with simulation predictions and comparable with the best value obtained by Belle. The uncertainty due to wrong modelling and peaking background is expected to be reduced by using the full dataset. Evaluation of the performance of a Deep Learning Neural Network (DNN) Flavour Tagger is in progress with initial results shown to be comparable to the default tagger.

Beam energies and their spreads provide limitation in many physics studies and their stability is being closely monitored fitting the  $M_{bc}$  distribution from  $B^- \rightarrow D^0 \pi^-$ . While beam energy spreads are stable, a drift of  $\sim 2 \text{ MeV}$  in the beam energies had been observed in the 2020 data taking. It also provides a non-negligible contribution to the systematic error in  $B\bar{B}$  counting, while the dominant contribution is offline luminosity determination. The evaluation of the final  $N_{B\bar{B}}$  for the sample to be used in the analysis for the Moriond conference was in progress at the time of the review.

Although there are still features in the data which cannot be fully reproduced by the detector simulation, the understanding for the Belle II detector performance has reached a level sufficient for complex physics analyses, which has been demonstrated by the several completed analyses.

The second Belle II physics paper has been published in PRL. This paper discusses the search for axion-like particles (ALP) with a mass above the pion mass, decaying into

two photons. This search was performed with Phase 2 data and has led to the world's most stringent bound on the ALP parameter space for masses at around 300 MeV. This is particularly impressive, especially keeping into account the relatively small amount of luminosity used for this analysis ( $445 \text{ pb}^{-1}$ ).

Several conference papers and journal publications are in progress. This includes the measurement of  $|V_{cb}|$  from the  $q^2$  distribution in  $B \rightarrow X_c \ell \nu$  decays, the time-dependent CP violation in  $B \rightarrow J/\psi K_S^0$  (this was done by Babar and Belle using only part of the collected data set), and the branching ratios and CP violating asymmetries in various charmless exclusive B decays. A publication on the untagged  $B^+ \rightarrow K^+ \nu \nu$  decay is also upcoming, where the collaboration expects to obtain a similar sensitivity as the Babar and Belle tagged analyses. This decay will have a very broad and complementary impact, as a major SM benchmark, as a cross-check of the flavour anomalies in B decays in the charged lepton  $l^+ l^-$  channels, and as a powerful probe of ALP couplings through  $B \rightarrow K a$  with  $a$  decaying outside the detector. Additionally, several other dark sector searches are in progress. This includes the search for the dark Higgsstrahlung and the search for inelastic dark matter.

In view of the 2021 Moriond conference, the next set of conference papers and publications will probably be based on the luminosity collected by summer 2020 ( $\sim 74 \text{ fb}^{-1}$ ). By then the collaboration expects to finalise the first performance studies of the semileptonic FEI, as well as lepton flavour violating  $\tau$  decay searches.

## 5.2 Concerns

None

## 5.3 Recommendations

- The committee recommends to continue and enhance the existing framework for the communication and collaboration among the several working groups.
- The collaboration is encouraged to develop a strategy that exploits the physics advantages of the Belle II experiment over others. For this purpose, the committee encourages the collaboration to intensify the communication and collaboration with theorists and explore new ideas for measurements and searches. The discussion with experimentalists working on other flavour physics and dark sector experiments could be also fruitful.
- The committee encourages further development of low multiplicity dark sector and  $\tau$  analyses in parallel to the core flavour physics program, also in view of the larger data set that will be collected in the coming years.
- The committee is pleased to learn that the KEK management was able to allocate resources for the extra one month of data taking during the 2020 JFY. The committee encourages KEK and the collaboration to find the resources for longer data taking also in 2021, to collect at least a  $1 \text{ ab}^{-1}$  data set usable for physics analyses, before the long 2022 shutdown.

## 5.4 Status of upgrade PXD2022

The work to replace the current PXD with a new detector, PXD2, with a full complement of ladders, is making steady progress. Two batches of 12 wafers each are in production for the sensors. Half of the wafers of the first batch, PXD9-20, have been completed with good yield. The remaining half is in the last step of processing and is expected to be finished by the end of February, 2021. The processing of the wafers in the second batch, PXD9-21, is waiting for the last phase (phase 3) of processing. This run is expected to be finished by the end of March, 2021.

As discussed already at the previous review, several problems with the flip-chip process were discovered during module production. These include particulate and interconnect issues. The interconnect problems were traced to a failure of the vacuum pump of the furnace. The vacuum pump on the furnace has been replaced and the process has been re-qualified, but a few tests remain to be done. To address the long-term effect of the interconnect problems and verify the reliability and performance of the modules, a temperature stress test was run with 50 cycles from  $-30\text{ }^{\circ}\text{C}$  to  $70\text{ }^{\circ}\text{C}$ . The results of the tests are fully satisfactory. To mitigate any further risks, one grade C module will be included in any long-term tests and one module will be submitted to a large number of power cycles.

The PXD2 detector calls for 12 ladders, plus six spares, for the outer layer (L2), and eight ladders, plus four spares, for the inner layer (L1). For L2, there are currently 12 ladders in hand, but no spares. Of those, one is not operational yet and is being repaired. For L1, five ladders are available from the 2018 production run, and five more ladders from the PXD9-20 run. The goal is to have one more ladder from the PXD9-20 run. Any additional ladders will have to come from the sensors of the PXD9-21 batch. It was noted that enough ladders are currently in hand to start the population of the first half-shell. The yield of the PXD9-21 batch so far looks good. However, during the wafer level measurements, nine modules were damaged. The reason is not understood and further testing has been halted.

At previous reviews, it was mentioned that enough ASICs were available to build the new pixel detector. Although this seems to hold for the PXD2 and spares, there are currently not enough Switcher ASICs available to populate all available sensors.

The PXD team has abandoned the aggressive scenario and has adopted the so-called conservative scenario for the production and installation of the PXD2. In this scenario, all module production will be completed by the end of April 2021 and all ladder assembly finished by May 2021. The current schedule has allocated ten weeks for half-shell testing at DESY. This schedule has not seen any slip compared to the previous review. It was not clear from the presentation if the PXD2 will include modules that were exposed to the flip-chip problem in the final detector. The schedule for the PXD2 detector does have adequate contingency at the moment. The production of the new beam pipe is on schedule. No detailed update was given about the cabling effort.

The committee commends the sustained efforts of the PXD team to operate the current detector and build its replacement and remains impressed by the dedication of the team. The path to a full PXD2 detector is in focus and achievable albeit with

persistent risks.

The PXD2 installation sequence was briefly discussed. Many details still need to be worked out and the committee is looking forward to a more detailed description during the BPAC in 2021.

#### 5.4.1 Concerns

- The sensor damage of the wafer level testing of the PXD9-21 run is worrisome. Although the end goal is near, the project remains vulnerable to technical risks and is exposed to the situation of not being able to have the full complement of required ladders and spares available for the PXD2. It was originally thought that the project did not have to rely on the sensors from the PXD9-21 batch, but that proposition is no longer tenable. The complexity of the project is such that the risk will be ever present until the detector is installed.
- The cable routing of the current PXD was non-trivial with space at a premium. Since the new PXD detector will have many more signal cables, assembly and installation of the full vertex detector system and its interface with the SVD, CDC and QCS, must be studied well in advance, preferentially with a complete mock-up of the various interfaces. This was not discussed during the current review given the time constraints. It was mentioned, however, that a mockup study of the cabling is not feasible. Given the difficulties experienced to date, simply relying on best estimates and good faith is quite concerning.
- Sustaining the expertise, knowledge and manpower for the detector, the beam pipe, QCS and related elements that affect the PXD detector is another major concern that was voiced previously. The PXD detector is a unique and highly sophisticated device and maintaining the technical knowledge will be required to operate the detector over its lifetime in a complex region of the detector with a delicate interface with the machine.

#### 5.4.2 Recommendations

- Identify the root cause of the sensor damage during wafer level testing of the PXD9-21 run before proceeding.
- Make a complete inventory of all the parts and determine how many modules can be built in the most ideal case. Every efforts should be made to produce as many ladders as possible to cope with possible production glitches.
- Although it was mentioned that a full mockup study of the cable routing is not feasible, the project is strongly recommended to devise intermediate solutions, such as studies with a partial mockup. In-depth reviews with all the groups involved, including the relevant machine experts, should be held to learn about possible configuration changes and to get the most up-to-date information on the various systems to mitigate any risk.

- The team is encouraged to remain as vigilant as ever in their final stretch to complete the detector.
- Enlarging the group with young physicists, who will become expert in the operation of the PXD and the interface with the accelerator, is strongly encouraged.
- Develop the installation schedule of the PXD2, including assessment of all resources and type of resources needed for the installation and related activities, as soon as possible.