Proc. 13th International Beam Instrumentation Conference,Beijing JACoW Publishing
ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-THP16

STATUS AND PERFORMANCE OF LumiBelle2 IN THE 2024 BEAM OPERATION OF SuperKEKB

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Abstract

LumiBelle2 is a fast luminosity monitoring system designed to do fast luminosity feedback and machine tuning for SuperKEKB. It uses sCVD diamond detectors placed in both the electron and positron rings to measure the Bhabha scattering process at vanishing photon scattering angle. The system provides Train-Integrated-Luminosity signals at 1 kHz for dithering feedback and Bunch-Integrated-Luminosity signals at 1 Hz to monitor variations along the bunch trains. After a long shutdown, in order to ensure its proper functioning during the 2024ab run, LumiBelle2 underwent testing, calibration, and upgrades. This paper describes the updated status of LumiBelle2 and presents its performance during the 2024ab run of SuperKEKB.

INTRODUCTION

SuperKEKB uses the so-called nano-beam scheme to reach a very high instantaneous luminosity of up to, nominally 8×10^{35} cm^2 s^{-1} [1]. It consists of using a large crossing angle at the interaction point (IP) to enable colliding 2500 ultralow emittance bunches with very small beam sizes (design value $\sigma_y \sim 50$ nm). The luminosity is very sensitive to beam-beam offsets, which is caused by ground motion or other external source. To maintain the optimum beam collision condition, orbit feedback systems are essential at the IP. At SuperKEKB, the beam-beam deflection method is used for vertical orbit feedback [2], while in the horizontal plane, a dithering orbit feedback system using the luminosity as input, similar to that operated in the past at PEP-II [3], has been adopted [4].

For this purpose, a fast luminosity monitor based on sCVD diamond detectors, named LumiBelle2, was developed and successfully operated in 2019-2021 [5]. By measuring the rate of Bhabha events on each side of the IP at vanishing photon scattering angle, LumiBelle2 can provide both Train-Integrated-Luminosity (TIL) signals and Bunch-Integrated-luminosity (BIL) signals simultaneously, over a large range of luminosities. The TIL signals, as input to the dithering feedback system, with relative precision better than 1 % at 1 kHz, can be used to maintain optimum overlap between the colliding beams in the horizontal plane [6, 7]. BIL signals are useful for machine tuning and beam parameters studies of the successive bunches along the trains. In addition, there is also another luminosity monitoring system named ZDLM (Zero Degree Luminosity Monitor) installed in the immediate vicinity. It uses Cherenkov and scintillator detectors, providing important complementary measurements.

From July 2022 to the end of 2023, SuperKEKB had a long shutdown for maintenance and upgrades. In order to ensure LumiBelle2 satisfactory operation during the 2024ab run, a program of checks and calibrations of the LumiBelle2 hardware and software components was implemented before the restart of the accelerator complex. In this paper, the updated status of LumiBelle2 is reported followed by a report on obtained luminosity monitoring performance, based on the new data.

CURRENT SETUP

Only five diamond detectors are currently installed in the two rings, at locations 10 and 30 meters downstream of the Interaction Point (IP) in the Low Energy Ring (LER) and High Energy Ring (HER), respectively. Detectors with both 500 and 140 µm thickness, coupled to low-noise 10 ns shaping time charge amplifiers and 2 GHz broadband current amplifiers, respectively, are used to take into important account variations in signal acceptances. In the HER, three 500 µm thick diamonds are installed, and in the LER, both 140 and 500 µm thick diamonds are used, as illustrated in Fig. 1. Both the diamond detectors and amplifiers were manufactured by CIVIDEC [8].

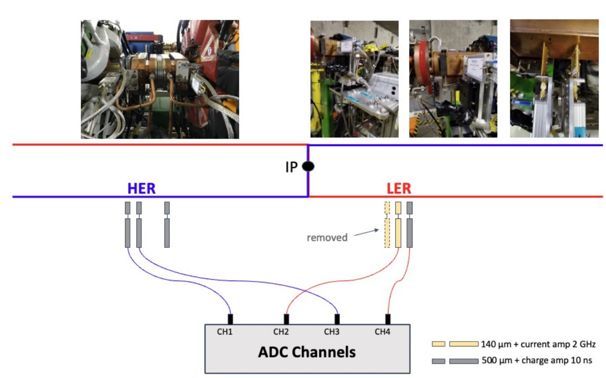

Figure 1: Current setup of diamond sensors and corresponding amplifiers of LumiBelle2 in the HER and LER.

To enhance the detection of Bhabha scattering events in the LER, a Tungsten radiator is positioned after the 45° window-shaped beam pipe. Initially, a sixth diamond detector was placed directly behind the Tungsten radiator to

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capture strong signals, but the close proximity to the radiator caused significant radiation damage, leading to removal. In the current setup, only two diamond detectors remain in the LER, positioned slightly further away, and resulting in somewhat less intense signals.

RESULTS IN 2024ab RUN

Whenever beams were colliding during the 2024ab run, both train integrated luminosity signals (TIL) and bunch integrated luminosity signals (BIL) were provided.

Train Integrated Luminosity Signals

Train integrated luminosity signals integrate the signal amplitude over all the bunches in 1 ms to meet the needs of the dithering feedback system. In the meantime, accumulation of this luminosity signal over 1 s was also processed to provide the relative luminosity information to the SuperKEKB control room, which is quite useful for collision tuning and related studies. Figure 2 shows a comparison of the luminosity signals from three different luminosity monitors over a 24-hour period. TILCH2 and RAWCH4 represent the relative luminosity signals in the LER from channels 2 (140 µm diamond) and 4 (500 µm), respectively. HERLUMI denotes the relative luminosity signals in the HER, which is the sum of luminosity signals from channels 1 and 3. ZDLM_HGCOU represents one of the relative luminosity signals provided by the ZDLM, whose signals are studied along with those of LumiBelle2, for comparison, calibration, and mutual verification. ECL_det represents the absolute luminosity signals provided by the electromagnetic calorimenter (ECL) of the Belle II experiment, it is used to evaluate the performance of our relative luminosity monitors. These luminosity signals from different kinds of luminosity monitors all show the same trends.

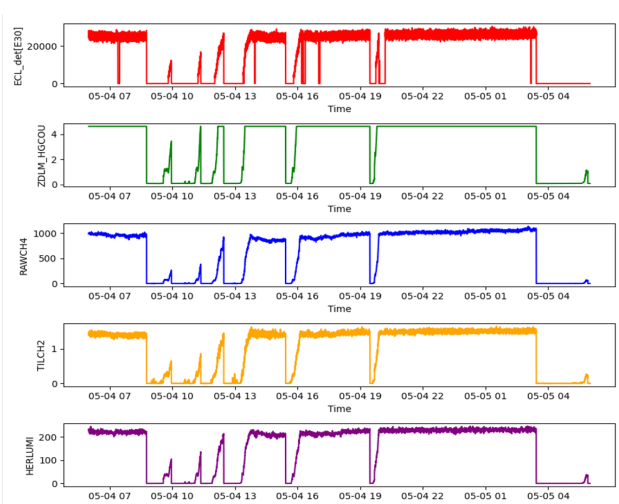

Figure 2: 1 Hz luminosity signals from ECL, ZDLM and LumiBelle2 LER 500/140 µm & HER 500 µm channels over a 24-hour period at the beginning of May 2024.

To evaluate the performance of the LumiBelle2 relative luminosity monitors, the correlation between different channels of the LumiBelle2, ZDLM and ECL was checked. The luminosity signals from Bhabha events at vanishing scattering angle are roughly proportional to the absolute luminosity signals provided by ECL, as shown in Fig. 3, although some saturation of channel 4 is evident. The relation between the two channels of LumiBelle2 and ZDLM is also roughly linear, as shown in the Fig. 4, while this particular ZDLM channel is known to saturate at the highest luminosity values. Overall, our relative luminosity monitors LumiBelle2 based on diamond detectors worked satisfactorily during the 2024ab operation of SuperKEKB, consistent with other standalone luminosity monitors, and provided useful signals used for the tuning of the beams at the interaction point (IP).

We also compared the luminosity signals of the two channels of LER, as well as the signals in HER and the most sensitive channel of the LER, as shown in Fig. 5. The signals from the diamond detectors in the HER are less strong than from those in the LER and moreover exhibit some dependence on the vertical IP electron angle.

The 500 µm diamond detector signal from channel 4 in the LER is the most sensitive and was recommended for IP beam tuning at low luminosity during the 2024ab run, while the 140 µm diamond detector signal of channel 2 is less sensitive but more linear, which is more adequate for the highest luminosities.

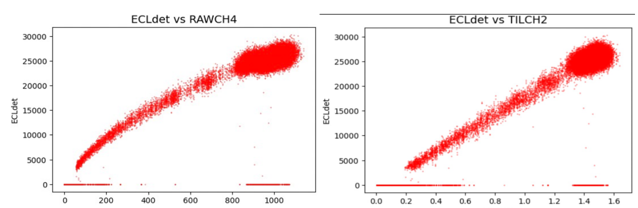

Figure 3: Luminosity signals from the LumiBelle2 LER channels 2 and 4 against ECL (right and left panels, respectively).

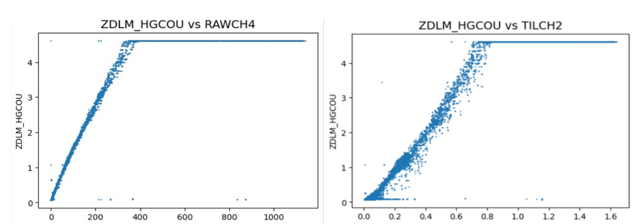

Figure 4: Luminosity signals from the LumiBelle2 LERs channels 2 and 4 against ZDLM (right and left panels, respectively).

We also plotted the luminosity signals measured by diamond detectors of channels 2 and 4 in LER over the entire 2024ab run to check how the performance of diamond detector changes over time, see Fig. 6 and Fig. 7. To obtain meaningful information for these plots based on the entire data set, the Isolation Forest method [9] was used, as follows.

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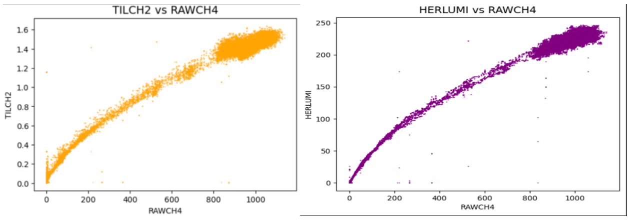

Figure 5: Luminosity signals from the LumiBelle2 LER channel 2 against channel 4 (left panel) and of LumiBelle2 channel 4 against ZDLM (right panel).

At first, a small optimal luminosity data interval with high luminosity and relatively minor variations was selected within the 24-hour ECL 1 Hz data of each calendar day. The exact time corresponding to the highest luminosity in this selected interval was then obtained. Next, the corresponding time in the 1 kHz LumiBelle2 TIL data was located and a 5-second data interval was selected before and after that time. In that way the relative luminosity values measured by diamond detectors of different channels could be determined. The trends of the relative luminosities measured by our luminosity detectors over time are consistent with the trend of the ECL. Based on the variation of the ratio of LumiBelle2 luminosity values to ECL luminosity values over time (Fig. 8 and Fig. 9), it can be observed that the sensitivity of the 140 µm diamond detector remains stable up to June but decreases slightly thereafter. In contrast, the sensitivity of the 500 µm diamond detector initially decreases fast and then appears to somewhat recover after May. Further investigation is required to check these two diamond detectors.

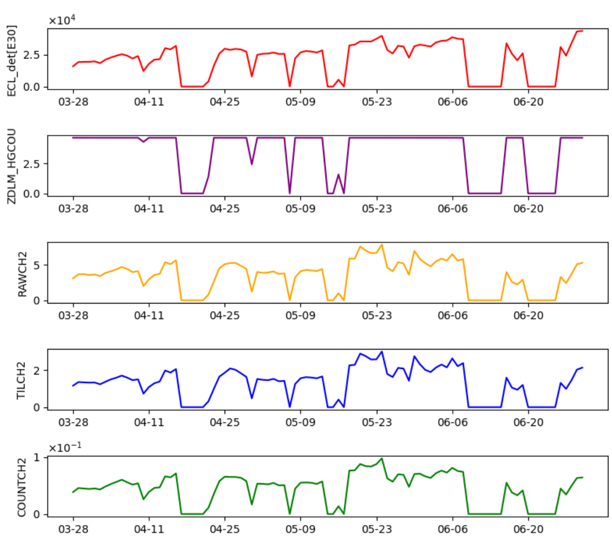

Figure 6: Luminosity sampled history from ECL, ZDLM and LumiBelle2 LER 140 µm channel.

Bunch Integrated Luminosity Signals

With a large number of bunches populating the ring, up to 2500 bunches/turn in the nominal case, variations in the bunch transverse positions and sizes are in principle possible

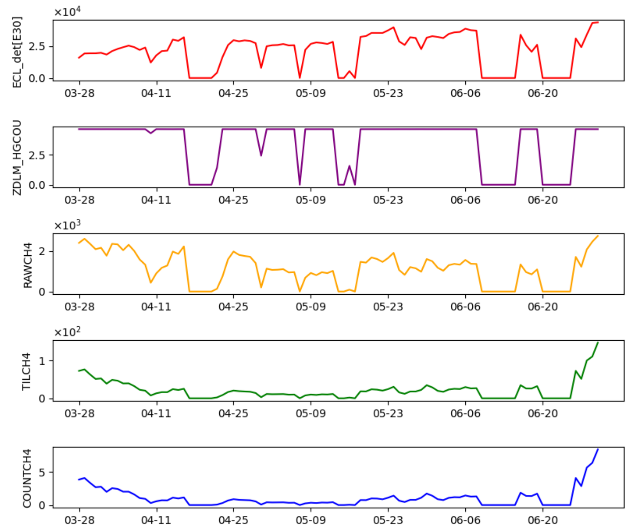

Figure 7: Luminosity sampled history from ECL, ZDLM and LumiBelle2 LER 500 µm channel.

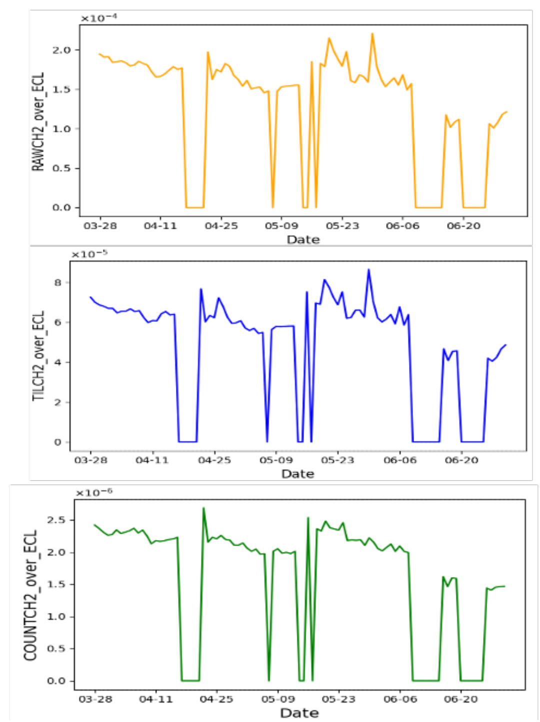

Figure 8: Ratios of LumiBelle2 luminosity values of LER 140 µm channel and ECL sampled histories.

through a variety of effects, causing systematic reduction in luminosity for some of the bunches, and should be monitored, just like the bunch currents. After getting the BIL sums for 5120 buckets, and comparing with the fill pattern of the machine, a display of the integrated luminosity per bunch could be obtained, as shown in Fig. 10.

The beam conditions were set on May 4th, 2024, with an instantaneous luminosity of approximately 2.55×10^{34} cm^2 s^{-1}, with 2346 bunches circulating in each ring.

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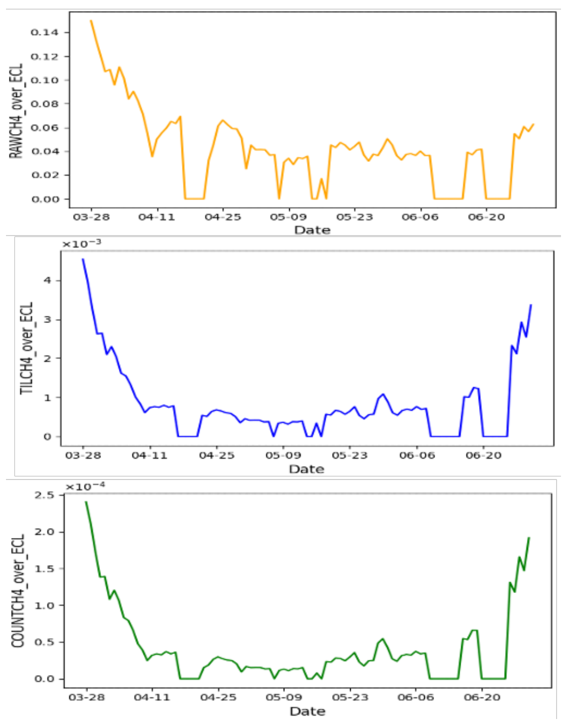

Figure 9: Ratios of LumiBelle2 luminosity values of LER 500 µm channel and ECL sampled histories.

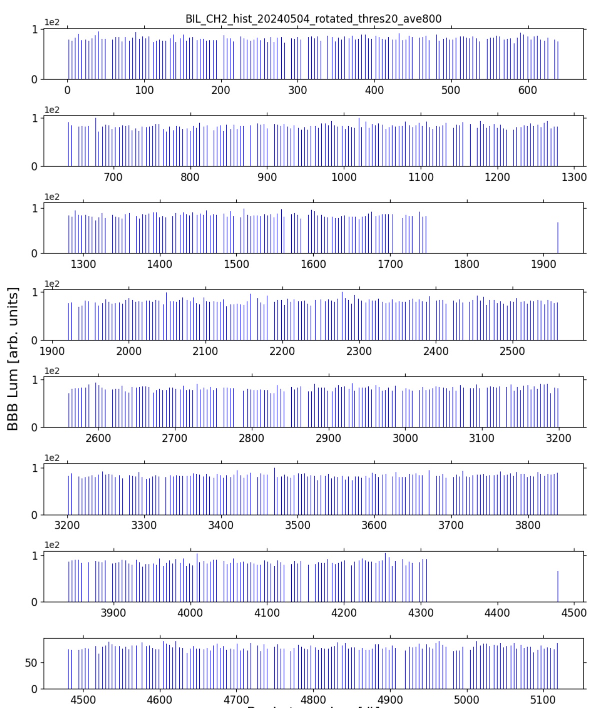

Figure 10: Bunch integrated luminosity signals, 2346 bunches were stored in each of the SuperKEKB rings when this plot was recorded.

CONCLUSION

The LumiBelle2 fast relative luminosity monitor of SuperKEKB operated successfully during the 2024ab run, providing useful signals for the tuning of the beams at the IP. A number of questions will have to be studied for the next runs, especially radiation damage issues for the diamond located nearest to the tungsten radiator in the LER, as well as a number of improvements to the data acquisition and data handling software.

ACKNOWLEDGMENTS

This work was partially supported by the European Union's Horizon Europe Marie Sklodowska-Curie Staff Exchanges programme under grant agreement no. 101086276, by the China Scholarship Council (CSC) and by the CNRS International Research Laboratory "Toshiko Yuasa France Japan Particle Physics Laboratory (TYL)". The authors would like to express their warm thanks to KEK colleagues for fruitful discussions and support.

REFERENCES

[1] Y. Ohnishi *et al.*, "Accelerator design at SuperKEKB", *Prog. Theor. Exp. Phys.*, vol. 2013, p. 03A011, 2013. doi:10.1093/ptep/pts083

[2] Y. Funakoshi *et al.*, "Orbit feedback system for maintaining an optimum beam collision", *Phys. Rev. ST Accel. Beams*, vol. 10 p. 101001, 2007. doi:10.1103/PhysRevSTAB.10.101001

[3] A.S. Fisher *et al.*, "Commissioning of the fast luminosity dither for PEP-II", Stanford Linear Accelerator Center, Stanford, CA, USA, Rep. SLAC-PUB-12608, July 2007. http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-12608.pdf

[4] Y. Funakoshi *et al.*, "Interaction Point Orbit Feedback System at SuperKEKB", in *Proc. 6th Int. Part. Accel. Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 921-923. doi:10.18429/JACoW-IPAC2015-MOPHA054

[5] C.G. Pang *et al.*, "A fast luminosity monitor based on diamond detectors for the SuperKEKB collider", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 931, pp. 225–235, Jul. 2019. doi:10.1016/j.nima.2019.03.071

[6] C.G. Pang *et al.*, "Simulation study on luminosity feedback horizontal beam stabilization at SuperKEKB", in *Proc. 9th Int. Part. Accel. Conf. (IPAC'18)*, Vancouver, Canada, May 2018, pp. 2250-2253. doi:10.18429/JACoW-IPAC2018-WEPAL037

[7] M. Masuzawa *et al.*, "Early Commissioning of the Luminosity Dither Feedback for SuperKEKB", in *Proc. 7th Int. Beam Instrum. Conf. (IBIC'18)*, Shanghai, China, Sep. 2018, pp. 28–331. doi:10.18429/JACoW-IBIC2018-TUPC13

[8] CIVIDEC Instrumentation GmbH, https://cividec.at/

[9] F.T. Liu, "First Isolation Forest implementation on Sourceforge", https://sourceforge.net/projects/iforest/