

EARLY PHASE 2 RESULTS OF LUMIBELLE2 FOR THE SUPERKEKB ELECTRON RING

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Abstract

We report on the early SuperKEKB Phase 2 operations of the fast luminosity monitor (LumiBelle2 project). Fast luminosity monitoring is required by the dithering feedback system, which is used to stabilize the beam in the presence of horizontal vibrations. In this report, we focus on the operations related to the electron side of LumiBelle2. Diamond sensors are located 30 meters downstream of the IP, just above, beside, and below the electron beam pipe. During early Phase 2, the sensors are used to measure the background, arising from beam-gas scattering. We present the hardware design, the detection algorithm, and the analysis of the background measurements taken up-to-date. The results are then compared with a detailed simulation of the background, in order to well understand the physical processes involved. The simulation is performed using SAD for generation and tracking purposes, while Geant4 is used to calculate the energy deposition in the diamond sensors.

INTRODUCTION

The LumiBelle2 is a luminosity monitor developed to provide a fast measurement of the luminosity for SuperKEKB. SuperKEKB is a new electron-positron collider that is currently under commissioning and will be fully operational in 2019 [1]. The main goal for SuperKEKB is to achieve the very high design luminosity of $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ [1]. SuperKEKB is the upgrade of KEKB, and it has been designed to have a luminosity 40 times larger than its predecessor. A factor of 2 will be gained from the increase in the beams currents and a further factor of 20 from the nano-beam collision scheme [1]. The nano-beam collision is an innovative scheme that is characterized by very small beams ($\sigma_y \approx 50 \text{ nm}$ is the design value) and a large crossing angle of 83 mrad, in order to significantly shorten the interaction region[2, 3]. The main purposes of the Phase 2 commissioning will be to verify the nano-beam collision scheme by achieving the expected luminosity and study the level of background to ensure that the vertex detector can be safely installed in Phase 3 [4], during which SuperKEKB is expected to reach its ultimate parameters. The very high luminosity aimed by SuperKEKB represents a serious technical challenge and it is clear that the success of the project depends strongly on the capability to properly monitor and control the position and size of the beams. For these reason, SuperKEKB is equipped with many pieces of instrumentation that will provide information about the beams conditions along the ring and at the IP [5]. Critical importance has the interaction point orbit feedback system, which will monitor

and control the position of the beams at the IP [6]. Mechanical vibrations induced by the ground motion have been investigated in the past for KEKB and, because of the nano-beam scheme, they can potentially affect the collision of the beams for SuperKEKB [7]. In order to control this potentially detrimental effect, SuperKEKB employs the same dithering system that was used for PEP-II [8]. Several luminosity monitor systems will be operating, among which the electromagnetic calorimeter luminosity on-line measurement (ECL LOM) [9], the zero degree luminosity monitor (ZDLM) [10], and the LumiBelle2. The LOM is installed in the backward and forward end-caps of the Belle2 detector, it will measure coincidence rates in opposite sectors for Bhabha events, and it will provide, after proper calibration, an absolute value of the luminosity at 1-10Hz with precision 0.1-5%, depending on the luminosity[11]. The ZDLM is installed downstream of the IP at almost zero degree, it will measure forward radiative Bhabha events by means of Cherenkov and scintillator sensors, and it will provide a relative value of the luminosity[10]. The ZDLM can be used, together with the dithering system, to monitor the horizontal vibrations of the beams. The LumiBelle2 also detects the forward radiative Bhabha events, specifically the recoil positron for the positron ring and the photon from the electron for the electron ring. It is a sophisticated and versatile monitor that aims to provide a fast and very precise measurement of the relative luminosity from Phase 2 to the design configuration that will be achieved during Phase 3. These measurements, carried out with diamond sensors, allow a very fast monitoring of the luminosity at 1kHz with 0.1% precision. The versatility is determined by the many possibilities allowed by the design of the detector, with adjustable positions, many configurations for sensors and signal amplifiers, and different rates for signal and backgrounds for each configuration. Because of its unique features, the luminosity measured by LumiBelle2 can be used as an effective input for the dithering feedback system. Moreover, due to its fast response, the LumiBelle2 also allows studying the bunch by bunch luminosity over the full parameter range. In this paper we will discuss the early Phase 2 results, measurements and simulations, carried out for the electron ring. First measurements obtained in the positron ring are described in another paper in the proceedings of this conference[12]. In the first part of the paper we present the experimental setup, while in the second part we discuss the background measurements. A detailed simulation was performed using GuineaPig[13], SAD[14], and Geant4[15], and it will be used as a comparison to understand the results.

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EXPERIMENTAL SETUP

The purpose of the experimental setup is to measure the photons emitted in forward radiative Bhabha events. The LumiBelle2 platform is 30 cm long and it is located between 30.5 and 30.8 meters downstream of the SuperKEKB interaction point, on the outside of the ring. The distribution of Bhabha photons against the position downstream of the interaction point was simulated and shows a peak at 28 meters, while the actual position of our platform corresponds to the tail of the distribution. Therefore, the position of the platform does not correspond to the position with the maximum rate of Bhabha photons, but it was the closest location available along the beam-pipe at the time of the installation. On the other hand, being in the tail of the distribution, we expect to be less sensitive with respect to the position of the electron beam. At the location of the platform, the beam pipe has a peculiar shape: round in the central region, as a normal pipe, with antechambers on each side in the horizontal plane. The antechambers were introduced to improve the cooling power, since for SuperKEKB the synchrotron radiation power is expected to be 2 times higher than it was for KEKB [16]. The platform supports three diamond sensors, respectively positioned on the top, bottom, and side of the beam-pipe's antechamber on the outside of the ring. All the diamonds have a surface of $4 \times 4 \text{ mm}$, while the thickness is $500 \mu\text{m}$ for top and bottom and $140 \mu\text{m}$ for the side. The diamond sensors have proven to be very suitable for fast detection in a high radiation environment, and they are extensively used at LHC [17]. Diamonds can be operated as semiconductor devices, and their electrical properties are determined by the large bandgap of 5.45 eV, which, together with the strong atomic bond, make them relatively insensitive to high doses of radiation [17]. The electrons and holes produced by ionisation have a high drift velocity, which makes them relatively fast detectors [17]. When a photon hits the beam pipe close to the diamond sensor, it produces a shower of secondary particles that, with very low probability, can significantly ionize the diamond and generate charge carriers. The charge is then collected and amplified by a fast charge amplifier with a gain of $4 \text{ mV}/f\text{C}$ and a shaping time of 10 ns. If the voltage induced is higher than the threshold, 4.5 mV for the measurements presented here, the signal is recorded. The LumiBelle2 DAQ, consisting of ADC and FPGA, samples the signal every 1 ns and provides several processed quantities, as for example the sum of the measurements (raw sum) every 1 ms. The raw sum will be the quantity presented in this work.

BACKGROUND MEASUREMENTS

SuperKEKB is currently undergoing Phase 2.0, and no collisions have taken place to date. Nevertheless, the LumiBelle2 has measured the background since the beginning of the operations. The background is produced by the typical processes that are well described in the literature [18]: Bremsstrahlung scattering, Coulomb scattering, and the Touschek effect. The rate of Bremsstrahlung and Coulomb scat-

tering is proportional to the beam current and the vacuum pressure inside the beam pipe [18]. The Touschek effect depends on the beam current and size [18, 19]. As explained in the next section, the only expected significant source of background for the electron side of the LumiBelle2 in Phase 2.0 are the photons produced in beam-gas Bremsstrahlung. We will present here only the results for one of the three sensors, which is referred here as channel 3 (CH3) and corresponds to the sensor positioned on the top of the beam-pipe's antechamber.

Gas "Desorption"

The beam-pipe walls are known to contain a significant number of gas molecules that are absorbed during manufacturing. When the beam circulates inside the beam-pipe, some of these molecules are released from the walls, a phenomenon that is known as gas "desorption". The main process causing gas desorption at SuperKEKB is the emission of synchrotron radiation photons [16], with the number of photons being proportional to the current. These photons hit the beam-pipe walls, causing the desorption of gas molecules and therefore increasing the pressure inside the beam pipe. This behavior is shown in Figure 1, where the pressure is plotted against the beam current. We notice that the relation between pressure and current is linear in the present conditions.

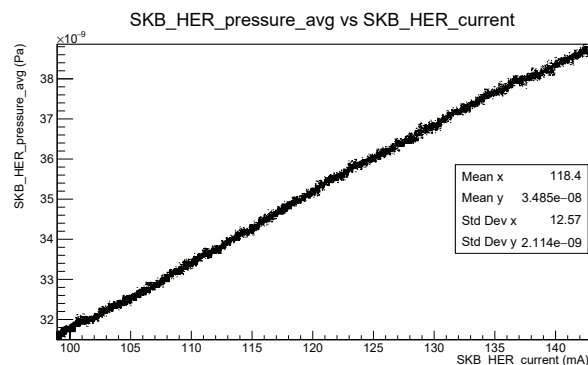


Figure 1: Average pressure against beam current for the electron ring.

Signal-current Correlation

In order to prove that what we are measuring is effectively the background due to beam loss, we need to exhibit a well defined correlation between the measured signal and the beam current. Figure 2 shows the current (top) and the LumiBelle2 measurement (bottom) as a function of the time, and we can appreciate how the two quantities are well correlated.

Since the relation between pressure and current is linear, we expect the beam-loss rate to increase linearly with the product of the current and the pressure. Figure 3 shows the LumiBelle2 measurement against the product of the current and the pressure, and we notice that the relation is linear.

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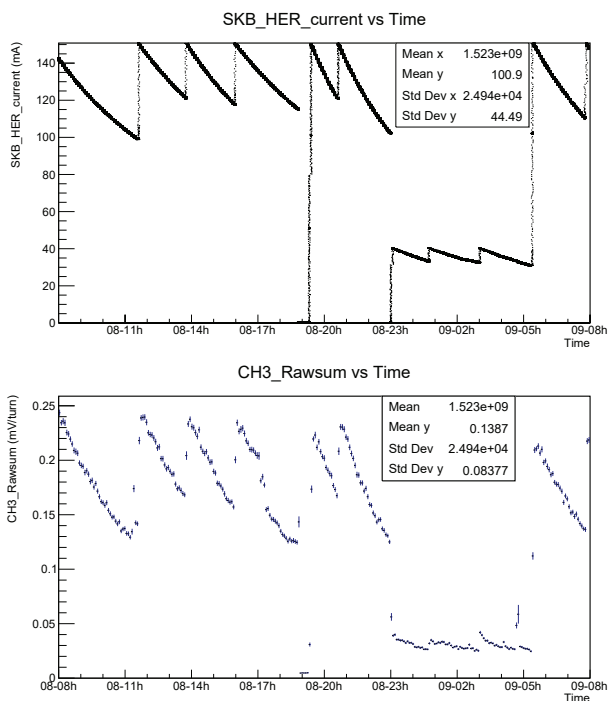


Figure 2: Top: beam current against time. Bottom: LumiBelle2 signal rate (raw sum in channel 3) against time.

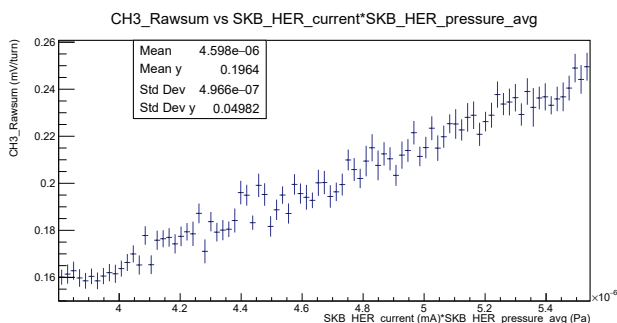


Figure 3: LumiBelle2 signal rate (raw sum in channel 3) against the product of current and pressure.

COMPARISON WITH SIMULATION

A comprehensive simulation has been carried out in preparation for the actual measurements of LumiBelle2 during Phase 2. The background has been simulated using SAD [14], considering Bremsstrahlung scattering, Coulomb scattering, and the Touschek effect as possible mechanisms of beam loss. The energy deposition in the diamond sensor was simulated using Geant4 [15], where we carefully reproduced the actual geometry of the experimental setup. The rate measured at the LumiBelle2 sensor is very sensitive to the chemical composition of the residual gas inside the beam pipe and to the profile of the pressure around the IP, and therefore a detailed study of the SuperKEKB vacuum in the interaction region was used as input to the simulation[20]. Figure 4 shows the comparison between the measured and simulated background rate as a function of the product of beam cur-

rent and average pressure inside the vacuum chamber. The simulation reproduces reasonably well the measurements, and predicts that the background measured by LumiBelle2 in Phase 2.0 consists only of Bremsstrahlung photons, while the rate of electrons produced by Bremsstrahlung, Coulomb, and Touschek processes are calculated to be much smaller than 1Hz.

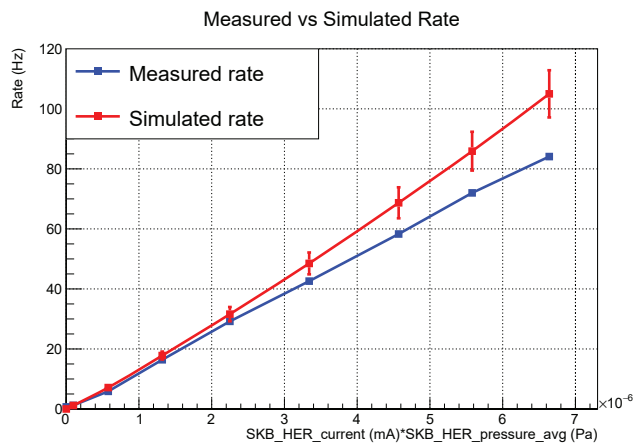


Figure 4: Comparison between measured and simulated background rate.

CONCLUSION

In this work we have reported on the first operations of the fast luminosity monitor LumiBelle2 at SuperKEKB during the early stages of Phase 2 commissioning, focusing on the electron ring. We have presented the experimental setup, the background measurements, and a comparison with the simulated results. The measurements show single beam background caused by the interaction of the beam with the residual gas inside the beam pipe. The comparison with the simulation shows that we are able to make a realistic prediction for the expected rate that is in reasonable agreement with the measured one. The simulation shows that the background measured is produced by Bremsstrahlung photons, while other sources of background are negligible. Overall, the LumiBelle2 monitor works as expected, and we were able to measure and explain the linear correlation between the beam loss rate and the product of the beam current and pressure inside the vacuum chamber. The first collisions will take place in the following weeks, and therefore we postpone the presentation of the first measurements of the luminosity to a later publication.

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