PREPARATION OF CVD DIAMOND DETECTOR FOR FAST LUMINOSITY MONITORING OF SuperKEKB *

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Abstract

The SuperKEKB e^+-e^- collider aims to reach a very high luminosity of 8×10^{35} $cm^{-2}s^{-1}$, using highly focused ultra-low emittance bunches colliding every 4 ns. To meet the requirement of the dithering feedback system used to stabilize the horizontal orbit at the IP (interaction point), a relative precision of 10^{-3} in 1 ms is specified for the fast luminosity monitoring, which can be in principle achieved thanks to the large cross section of the radiative Bhabha process. This paper firstly presents the fraction of detected Bhabha scattering positrons with a new beam pipe arrangement coupled with a Tungsten radiator to be installed in the Low Energy Ring; Then the characteristics of signals from a sCVD diamond detector with thickness of 140 μm coupled with a broadband current amplifier were studied based on tests with a Sr-90 source; Finally, simulated results for the reconstructed luminosity and the relative precision with different assumed luminosities are also reported.

INTRODUCTION

During the second and third phase of the SuperKEKB commissioning [1], with target luminosities of 10^{34} $cm^{-2}s^{-1}$ and 8×10^{35} $cm^{-2}s^{-1}$, respectively, we aim to monitor the train integrated luminosity, as input to a dithering feedback system to maintain the beams in collision in the horizontal plane, as well as bunch integrated luminosity which is important to optimize the injection [2, 3]. In order to reconstruct the peak of dithering frequency by Fast Fourier Transform (FFT), the relative precision at target luminosity should be 10^{-3} in 1 ms. This requires detecting a large enough fraction (f=0.833%) of Bhabha events generated at the Interaction Point (IP) [4, 5]. Because electron and positron bunches will collide every 4 ns and signals from every bunch crossing are needed to realize the two kinds of integrated luminosity monitoring, a very fast signal shape is needed to avoid the overlapping of pulses. A new sCVD diamond detector with thickness of 140 μm (4×4 mm^2) [6] was studied with a Sr-90 electron source. Considering the train integrated luminosity monitoring, the reconstructed luminosity and the relative precision which are expected to be achieved using a ADC and FPGA sampling at 1 GHz were evaluated in simulation.

GEANT4 SIMULATION

Since Bhabha positrons hit the copper beam pipe in the LER (Low Energy Ring) about 10 m downstream of the IP at a very small angle of 5 mrad, the conventional cylindrical beam pipe can't supply a large enough fraction of detected Bhabha positrons, because the shower from primary positrons is essentially absorbed, with very few secondary particles escaping. A new beam pipe section with a 45° window and flat part with a 15 mm depression was suggested by K. Kanazawa from KEK, and it will be installed at the previously optimized position in the LER [7]. To evaluate the ability of a 140 μm diamond detector to meet the specified relative precision, simulation based on Geant4 [8] was implemented to estimate the signals in the diamond detector. The designed window shape and the Geant4 model are shown in Fig. 1.

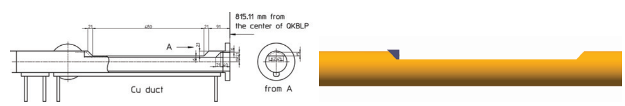

Figure 1: Designed window shape beam pipe (l.h.s) and Geant4 model (r.h.s).

Energy Deposited

Firstly, the energy deposited for MIPs (electrons with energy of 1.6 MeV) in a diamond detector with 140 μm was simulated with Geant4, and the diamond detector coupled with a fast charge amplifier was tested with a Sr-90 electron source, using a scintillator to trigger. The results are shown in Fig. 2.

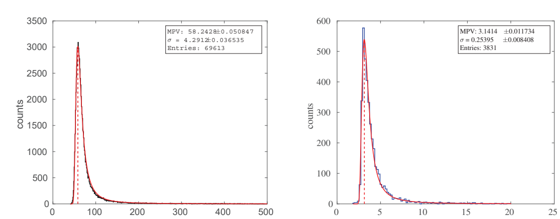

Figure 2: Energy deposited in diamond detector simulated with Geant4 (l.h.s) and test result with Sr-90 source (r.h.s).

Since the gain of the fast charge amplifier which was used is 4 mV/fC, the MPV (Most Probable Value) for the test results is 3.14 mV, which is equivalent to 63.81 keV, while the RMS width is 5.16 keV. Both are larger than the simulated results, which can be explained by the difference of energy and incident direction of particles.

Simulation with New Window Shape Beam Pipe

SAD [9] is used to track the Bhabha particles generated with GUINEA-PIG++ [10] at the IP in the beam line. The

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particle information (type, space distribution, momentum) just before the 45° window mentioned before were used as the input of Geant4 simulation, the energy deposited in the diamond detector per Bhabha and the fraction (f) could then be estimated. A trapezoid shape Tungsten radiator will be installed to maximize the number of charged secondaries, Geant4 based simulation was implemented to study the influence of the thickness of the radiator on the results, see Fig. 3.

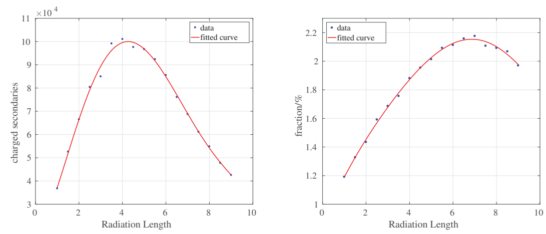

Figure 3: Number of charged secondaries (l.h.s) and fraction (r.h.s) for 140 μm diamond detector after radiator with different thicknesses (for Tungsten: 1RL=0.35 cm).

To maximize the detected fraction (f), also the average energy deposited, a Tungsten radiator with thickness of 5 or 6 Radiation Lengths (RL) will be adopted. In the case of 6RL, the simulated fraction is about 2.1%, which is larger than needed one (0.833%). The distribution of energy deposited and number of charged secondaries per Bhabha are shown in Fig. 4, the average energy deposited per incident Bhabha scattered positron is 776.75 keV.

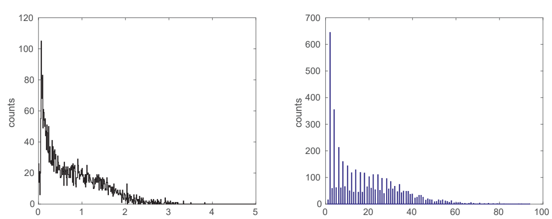

Figure 4: Energy deposited (l.h.s) and number of charged secondaries (r.h.s) per Bhabha.

From the Geant4 simulated results, the 45° window shaped beam pipe coupled with a Tungsten radiator can achieve a sufficient fraction of detected Bhabha events, with large enough energy deposited.

TESTS OF DIAMOND DETECTOR

In SuperKEKB, the RF is about 500 MHz, while the nominal bunch frequency is about 250 MHz, which means bunches from the two beams collide every 4 ns. Fast signals are required for individual bunch crossing integrated luminosity monitoring. To meet the requirement, a new diamond detector with a thickness of 140 μm coupled with a broadband 2 GHz 40 dB current amplifier (C2 from CIVIDEC) [6] is proposed for the front-end of the fast luminosity monitoring system. Its signal characteristics were studied with a Sr-90 electron source in the clean room of LAL.

Amplitude vs Charge

The broadband current amplifier C2 was employed to preserve the timing characteristics. The relationship between signal amplitude and charge in diamond detector should however be clear. After recording signal data with oscilloscope, the charge in the diamond detector can be obtained by integrating the peak area, the result is shown in Fig. 5.

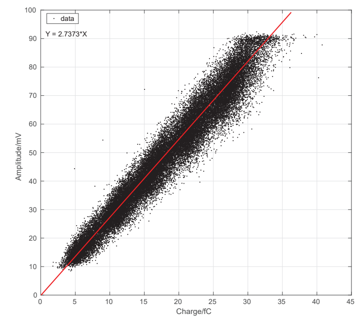

Figure 5: Relationship between signal amplitude and charge in diamond detector.

The result shows that the relationship between signal amplitude and charge in the diamond detector is almost linear, which makes it possible to use the amplitude to calculate the number of detected Bhabhas every bunch crossing.

Rise Time and Full Duration

To evaluate the timing performance (rise time and full duration) of the diamond detector coupled with a C2 current amplifier, the CFD (Constant Fraction Discrimination) method was used with a fraction of 5%. The results are shown in Fig. 6. The rise time has an obvious peak around 0.8 ns, allowing the maximum amplitude to be measured, Those signals with rise time larger than 1 ns almost all have an irregular pulse shape, such cases need further study. About 7% of the signals have a full duration exceeding 4 ns. The impact from the resulting overlapping of pulses at full luminosity, although expected to be limited, will also need further study.

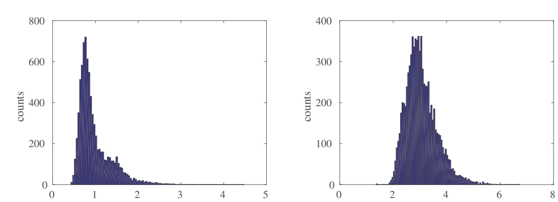

Figure 6: Distribution of rise time (l.h.s) and full duration (r.h.s) of signal from 140 μm DS coupled with C2.

Based on the test results with the Sr-90 source, we find that the characteristics of linear relationship between amplitude and charge, almost fixed rise time and narrow full duration of the signals for 140 μm diamond detector coupled with a current amplifier C2 make this set-up a very good candidate for the front-end of the fast luminosity monitoring in SuperKEKB.

RELATIVE PRECISION AND LUMINOSITY

In Phase-2 and Phase-3, the DAQ system for the fast luminosity monitoring is based on a FPGA with sampling frequency of about 1 GHz. Based on the results of the Geant4 simulation and the tests with the Sr-90 source, almost realistic signal sequences taking into account the expected fill patterns of the accelerator were constructed to simulate the DAQ processing. The scheme of this simulation and an example of such a signal sequence are shown in Fig. 7 and Fig. 8, respectively.

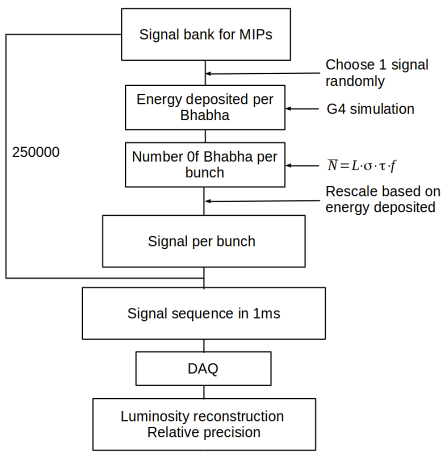

Figure 7: Scheme of simulation of DAQ processing to evaluate relative precision and constructed luminosity.

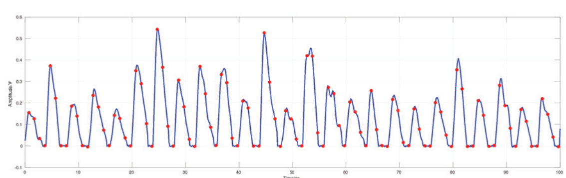

Figure 8: Example of constructed signal sequences with expected fill pattern at target luminosity of the accelerator (first 100 ns).

The DAQ is being proposed to work in two modes. The first one only counts the number of signals in 1 ms and uses this number to calculate the luminosity and relative precision. The second one also takes the amplitudes of signals into consideration, normalizing to the expected average amplitude per Bhabha to compute the number of detected Bhabha events, and thereby the relative precision and luminosity. The relative precision for those two modes is shown in Fig. 9 as a function of luminosity.

For the counting mode, the minimum relative precision is $2{\times}10^{-3}$ because of the maximum number of bunches in 1 ms. For the amplitude mode, at the target luminosity of Phase-3, the relative precision can reach $7{\times}10^{-4}$, which satisfies the requirement of $1{\times}10^{-3}$. At target luminosity of Phase-2, the relative precision is about $6.2{\times}10^{-3}$.

The luminosity was recalculated in the amplitude mode from the number of detected Bhabha events for different

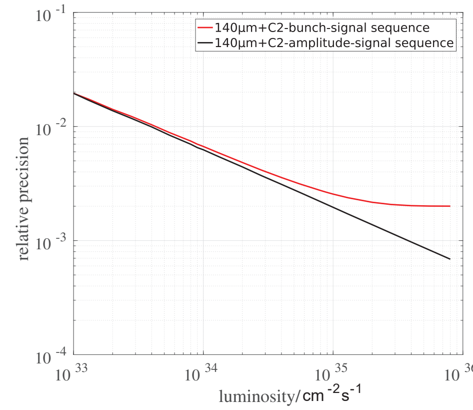

Figure 9: Expected relative precision as a function of luminosity.

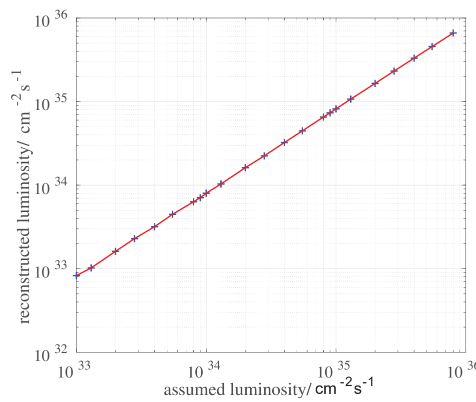

Figure 10: Reconstructed luminosity as a function of assumed luminosity.

assumed luminosities, see Fig. 10. As can be seen, the reconstructed luminosity is proportional to the assumed one, which shows the possibility to monitor the luminosity after calibration in the future. Meanwhile, the reason why we don't get exactly the same luminosity can be explained as: (1), When sampling the signal sequence every 1 ns, not always the maximum of the amplitude is stored, which will cause some loss; (2), Relationship between amplitude and charge is almost linear within some spread; (3), Calculating the number of detected Bhabhas using the average amplitude per Bhabha may also give rise to some error.

CONCLUSION AND NEXT PLANS

We expect to be able to monitor the luminosity with a relative precision within the requirement of 10^{-3} in 1 ms at the nominal luminosity of $8{\times}10^{35}$ $cm^{-2}s^{-1}$ (about $6{\times}10^{-3}$ for the target luminosity of Phase-2) once the window shaped beam pipe and radiator are installed in the LER and the 140 μm diamond detector coupled with a current amplifier C2 are used. For Phase-2 and Phase-3, after the DAQ system based on ADC and FPGA will be available, the performance of fast luminosity monitoring system will be checked, and data will be taken and compared to the simulated one.

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