# The BGO System for Real Time Beam Background Monitoring in BEAST II

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***Abstract*–The SuperKEKB collider has started the beam commissioning this year. The BEAST II project is particularly designed to measure the beam background around the interaction point of Belle II experiment. We developed a system using BGO (Bismuth Germanium Oxide, $Bi_4(GeO_4)_3$) crystals and one FPGA based DAQ board to monitor the background in real time. In this presentation, we will introduce the design of our system and some preliminary results from the BEAST II phase 1 commissioning.**

***Index Terms*—SuperKEKB, Belle II, BEAST, beam background, BGO**

## I. INTRODUCTION

The SuperKEKB $e^+/e^-$ collider at the KEK High Energy Accelerator Research Organization in Japan is designed to supply high luminosity for precision B physics measurements at Belle II experiment [1]-[2]. It is upgraded from KEKB with new technologies to achieve designed peak luminosity at $8x10^{35}$ $cm^{-2}s^{-1}$, 40 times higher than that in KEKB. The target integrated luminosity is about 50 times of the Belle experiment. Due to this significantly higher luminosity, beam-induced backgrounds will be larger in Belle II than in Belle. The BEAST II experiment is designed to study the beam-induced backgrounds prior to the Belle II full installation and commissioning. This is essential for beam control practice in the beginning of beam commissioning and to protect the real Belle II detectors from unexpected high radiation.

The BEAST II experiments consists of several detectors for various background studies [3]. The NTU-HEP group has designed and built a BGO system, as one of the BEAST-II detectors, for the electron and gamma related beam background monitoring. The measured beam background is centralized in the BEAST II DAQ system and fed back to the SuperKBKB control center.

## II. BGO SYSTEM

We use BGO scintillator as the detection sensor. While a charged particle or photon passing through a BGO crystal, it generates electromagnetic showers. The deposited energy is converted to scintillation light peaked at 480nm. Each BGO crystal is about 2x2x13 $cm^3$ and wrapped by Teflon sheet and aluminized Mylar sheet to enhance the light collection efficiency, as shown in Fig. 1. Eight BGO crystals are installed around the designed interaction point of the Belle II experiment (Fig. 2). The signals from BGO are conducted to one HAMAMATSU H7546B MAPMT, whose sensitivity region covers the scintillation light spectrum, via 40m optical fibers with light-tight treatments. To simplify the design and avoid radiation damages to electronics, there is no active components on the detector.

Fig. 1. The BGO crystal in our beam background monitoring system. In the figure, the crystal is half-pulled out from the wrapping material for demonstration purpose.

Fig. 2. The installation of 8 BGO crystals around the interaction point. The R1-R4 crystals are at the +z side and the other 4 the –z side. In the Belle II coordinate system, the +z is close to the direction of the electron beam.

The MAPMT outputs are connected to the readout electronics system, which consists of two parts: a DAQ main board and a FPGA board plugged on it, as sketched in Fig. 3 and Fig. 4. The DAQ system is originated from the Nutel experiment with necessary modifications to improve the noise immunity and signal shaping performance to fit with our needs [4]. The DAQ main board first converts the charge signal from MAPMT to voltage through a converter with 187ns shaping time. The signal is then digitized by a 10-bit ADC before sent to the FPGA.

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The FPGA board is produced by E-element, which is equipped with a SPARTAN FPGA. The FPGA is running at 40MHz clock. With this specific 187ns shaping time, the input pulse height will drop by about 1/8 after one clock (25ns) if there is no new input change. The excess of that will be regarded as the new input charge during that clock (Fig. 5). By this simple algorithm, the input charge during each clock can be easily calculated directly in the firmware. A threshold is applied to each channel inside the FPGA to exclude random electronics noise.

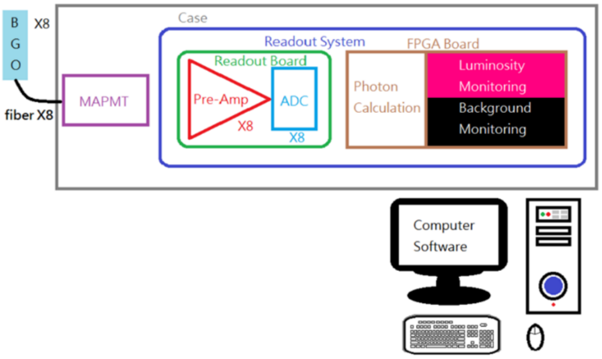

Fig. 3. The diagram of the BGO DAQ system. The DAQ board receives analog signal from BGO-MAMPT and sends the digitized signal to the FPGA for online processing. The calculated background information is delivered to BEAST DAQ system at 60Hz rate.

Fig. 4. The inside of BGO DAQ system box. Near the bottom of this picture is the MAMPT. The FPGA board is plugged on top of the main DAQ board.

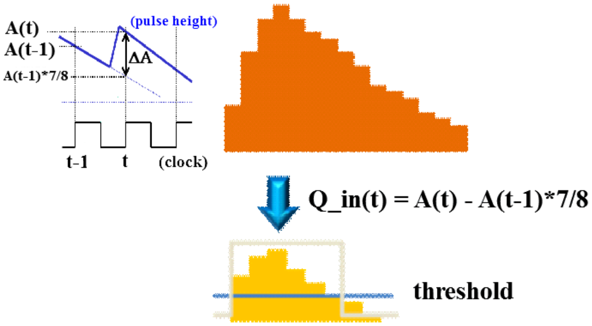

Fig. 5. With 187ns shaping time constant, the input charge during each clock can be easily calculated. After converting the pulse height to the input charge, a threshold is applied to exclude contribution from noise.

The output of the BGO DAQ system is sent to the central BEAST II DAQ system PC via UART connection. To reduce the data rate, we send the accumulated background at 60Hz rate.

The measured gain of the MAPMT is about 11 ADU (analog-to-digital unit) per photoelectron at 700V operation voltage, with a small variation from channel to channel. A test run for system validation is pursued at the Institute of Nuclear Energy Research in Taiwan using Co60 source. The result proves that this system can work at fairly high radiation condition without serious saturation or other problems. A preliminary result of the conversion factor is about 22 photoelectron/GeV with 10m long fiber for transmission.

## III. BEAST II PHASE 1 COMMISSIONING

SuperKEKB started the phase 1 commissioning since February this year. This is a big milestone of the SuperKEKB/Belle II project. The main purpose of phase 1 operation is for beam control practice to get stable storage beams. There is no plan for beam collision in the phase 1 operation. However, while a beam bunch passing the interaction point region, a lot of background will be induced due to the collision of beam particles with gas or other materials, or due to other physics processes.

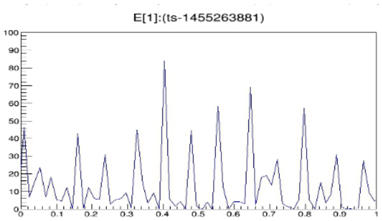

Fig. 6. With 60Hz beam background accumulation rate, the BGO system can clearly see the injection bunch at 12.5Hz injection rate.

By recording the background condition with precise time information, we can check the beam background induced due to different beam conditions. This information is also fed back to the SuperKEKB accelerator control center, so it is possible to compare the beam configuration with the beam induced background near the Belle II interaction point in real time. With 60Hz data rate from the BGO system, we can even clear see the bunch structure during low rate injection (Fig. 6).

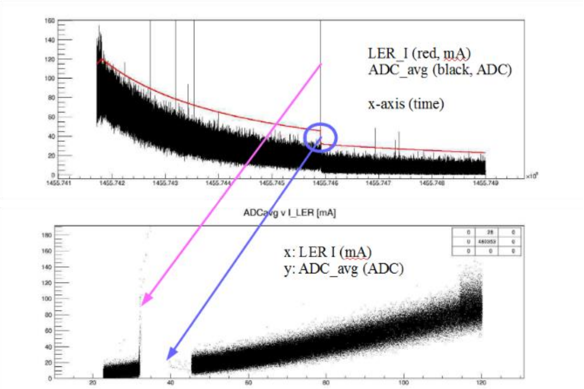

Fig. 7. The response of accumulated charge (in ADU) to the beam current. The response to the beam trip and correspondent noise due to beam gas is clear seen in the bottom plot (the gap region).

After stable storage beams achieved, several dedicated accelerator machine studies were pursued to study the background versus different beam configurations, e.g. beam current, beam size, and beam pipe gas pressure … etc. Some preliminary results are shown in Fig. 7-10. As expected, the background increases proportionally to the product of the beam current and the beam gas pressure. The slight beam background increasing due to Touschek scattering (large angle particle-particle Coulomb collisions within a bunch) is also observed. More detail offline analyses will be done in the coming months. A more precise energy to ADU calibration will also be performed too.

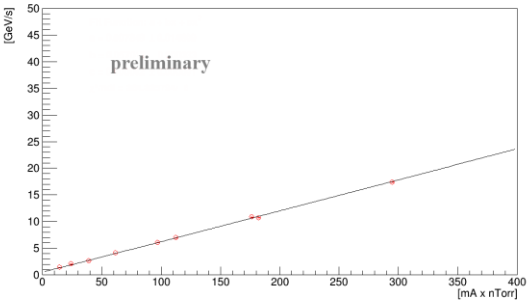

Fig. 8. The mean deposited energy per second (y-axis) versus (the beam current * the beam gas pressure). A quite good linearity relation is observed.

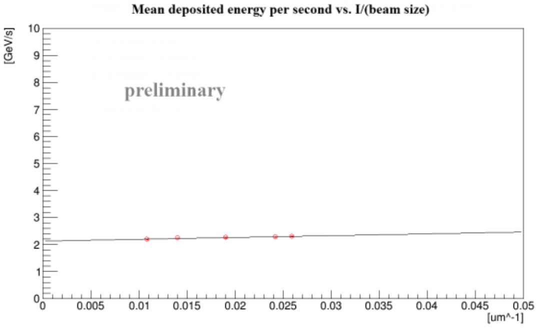

Fig. 9. The average deposited energy per second versus the inverse of the beam size. The beam background increases slightly while the beam size is reduced due to the Touschek effect. By a liner fitting, the estimated beam background without Touschek contribution is roughly 2.1 GeV/s during this experiment.

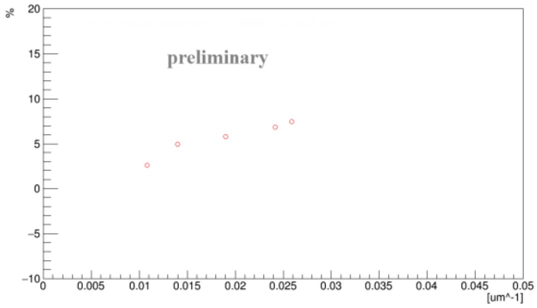

Fig. 10. The percentage of background contribution due to Touschek effect versus beam size in the same experiment for Fig. 9.

## IV. SUMMARY

The SuperKEKB/Belle II phase 1 beam commissioning opens a new era for the B factory. We have deployed a beam background monitoring system for the BEAST II experiment in the phase 1 operation. This system adopts BGO crystal sensor for charged particles and photon background detection. The scintillation light from the BGO is guided to a MAMPT and FPGA based DAQ system via optical fibers. The accumulated background energy is sent to the central BEAST II DAQ system at 60Hz rate.

Several dedicated accelerator machine studies are pursued to check the beam background at different beam configurations in the phase 1 commissioning. This system is proved to be working well. The beam background response is fed back to the SuperKEKB accelerator group in real time. More detail analyses and a more precise energy calibration will be done in the near future.

## ACKNOWLEDGMENT

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