ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME090

FAST LUMINOSITY MONITORING USING DIAMOND SENSORS FOR THE SUPER FLAVOUR FACTORY SUPERKEKB

D. El Khechen*, C. Rimbault, P. Bambade, D. Jehanno, LAL, Orsay, France

Abstract

Super luminous flavor factories, as SuperKEKB in Japan, aim to achieve very high luminosity thanks to a newly employed concept, the nano-beam scheme, where ultra-low emittance beams collide at very large crossing angle. Luminosity optimisation and dynamic imperfections require fast luminosity measurements. The aimed precision, 10^{-3} in 10 ms, can be achieved thanks to the very large cross-section of the radiative Bhabha process at zero-photon scattering angle. As a result of huge particle fluxes, diamond sensors are chosen to be placed just outside the beam-pipe, downstream of the interaction point, at locations with event rates consistent with the aimed precision and small enough contamination by backgrounds from single-beam particle losses. We will present the results concerning the investigation of the optimal positioning of our diamond sensors, taking into account the rate of Bhabha particles as well as their interactions with the beam pipe material.

INTRODUCTION

SuperKEKB [1], the upgrade of KEKB machine at KEK in Japan, is a very high luminosity e^+e^- circular collider, dedicated to B meson physics study experiment Belle II [2]. It consists of a 4 GeV positron ring and a 7 GeV electron ring. The very high luminosity (8 10^{35}cm^{-2}s^{-1}) can be achieved using the nano-beam scheme [3], whereby the ultra-low emittance beams collide at a large crossing angle (83 mrad), thus reducing the effective interaction region longitudinally and β^* parameters without a severe beam blow-up. In this type of rings, beams have relatively short lifetimes, of the order of 10 minutes, mainly due to Touschek large angle intra-beam Coulomb scattering, as well as to the zero angle radiative Bhabha scattering at the interaction point (IP) and should be thus continuously re-injected. Fast luminosity monitoring is needed as input for luminosity optimisation and feedback in presence of dynamic instabilities. To carry on, the radiative Bhabha process at zero photon scattering angle will be considered, because of its large cross-section. Because of its radiation hardness and fast signal collection, diamond sensor (Fig. 1) is chosen for our measurements.

BHABHA RATE REQUIREMENTS

The radiative Bhabha at zero photon scattering angle process (Fig. 2) corresponds to an electron-positron beam particles scattering through the exchange of a quasi-real photon at almost zero angle. It is one of the main sources

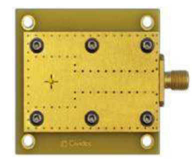

Figure 1: Diamond sensor.

of backgrounds via particle losses in such colliders, as well as a limitation for beam life time. However this process can also be useful for luminosity monitoring since the amount of scattering is large and proportional to the luminosity. The cross-section calculated from the dedicated code BBBrem [4] at the $\Upsilon(4S)$ center of mass energy, with a photon energy cut set to $1\%.E_{beam}$, is about 150 mbarn, including the correction for very small transverse beam sizes (beam-size effect) [6]. To achieve the aimed precisions, from initial luminosity phase to the optimal one, around 7 to 8 $\times 10^{-4}$ of the total Bhabha cross-section should be detected in the sensors as displayed in Table 1.

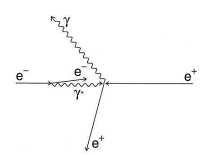

Figure 2: Radiative Bhabha at zero photon scattering angle.

MONITOR LOCATION

The dynamics of the Bhabha events has been generated using GUINEA-PIG++ [5], a beam-beam interaction simulation tool mainly used for high energy e^+e^- collider studies, in which the radiative Bhabha process at very small angle is treated as a Compton scattering process convoluted with a spectrum function for the quasi-real photon. Energy spectrum of the Bhabhas is represented in Fig. 3 for the Low Energy Ring (LER). Low energy Bhabhas will escape the beam thus exiting the beam-pipe at successive locations downstream of the IP at different rates.

The scattered electrons/positrons particles have been then tracked by SAD code [7] developed in KEK, up to 25 meters downstream of the IP (Fig. 4), in order to estimate the rates of the Bhabha particles deflected enough to hit the beam pipe and potentially generating signals in a 5 x 5 mm^2 diamond sensor placed just outside of the 40 mm radius and 6 mm thickness copper beam-pipe. Several locations have been considered, after the first bending magnets, quadrupoles and in the drifts. As a result, the opti-

* elkheche@lal.in2p3.fr

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Table 1: Least Required Fractions of Bhabha Cross-section in the Sensors

Luminosity (cm^{-2} s^{-1})	Number of Bhabha	Aimed precision	Required fraction
10^{34}	1.5×10^7 in 10 ms	10^{-2} in 10 ms	6.7 x 10^{-4}
8 x 10^{35}	1.2×10^9 in 10 ms	10^{-3} in 10 ms	8.3 x 10^{-4}

mal position for our sensor is to be at S=13.9 m from the IP where a fraction of 1.65 % of the total Bhabha cross-section should be, in a first approximation, intercepted in the diamond. While the LER presents a clear proportionality between horizontal deflections of the scattered positrons and their energy (l.h.s of Fig 5), enabling "monochromatic" measurements of 3.4 GeV, the High Energy Ring (HER) showed non-linear distributions (r.h.s Fig. 5), potentially due to chromaticity corrections, in addition to a very low and fluctuating amount of intercepted Bhabha fractions.

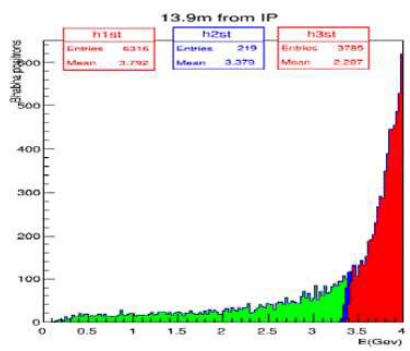

Figure 3: Energy distribution of Bhabha positrons which are already lost (green), detectable (blue) and still in the beampipe (red) at 13.9 m.

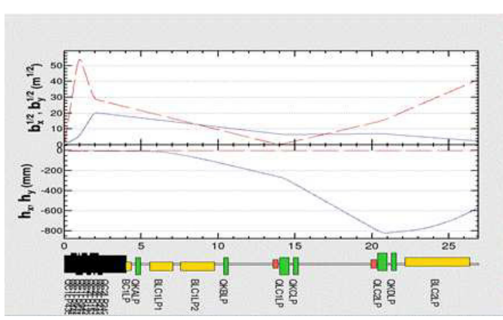

Figure 4: Beta functions and dispersion functions over first 25 m downstream the IP for the LER.

VACUUM CHAMBER GEOMETRY

Bhabha positrons hit the copper beam-pipe at a very small angle of 5 mrad, crossing 1.2 m of the material which corresponds to ≈ 80 radiation lengths. In this case, most of the particles produced in the showers induced by the interaction of the scattered positrons with the beam-pipe are absorbed, and the probability for having charged secondaries exiting the beam-pipe is very small. Nevertheless,

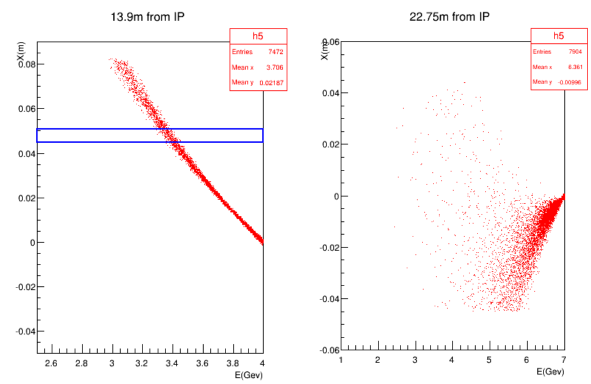

Figure 5: Horizontal extension (in m) of scattered Bhabha particles Vs their energy (in GeV), respectively for the positrons in LER on l.h.s and for the electrons in HER on r.h.s.

the extension of the electromagnetic showers contained in the Molière radius enables few of them to exit. An idea of creating a window (Fig. 6) at 45 degrees in the drift between the two quadrupoles QKBLP and QLC1LP was considered, to enable the exit of the core of the showers and then to increase the signal in the sensors. GEANT4 simulations were performed, considering the material and the vacuum chamber geometry, to estimate the actual number of particles which will hit the diamond sensor and to determine if a window is required. Different geometries of the beam pipe were considered, such the case of a normal cylindrical beam pipe and the case of a window. In the case without a window, simulations showed very low number of signals thus resulting in very low precisions on luminosity measurements even for the nominal luminosity. Simulations with a window showed much higher signals, especially when adding a radiator of iron at shower maximum just in contact with the window.

In SuperKEKB, the repetition frequency is ≈ 250 MHz so the two beams collide every 4 ns. Fast signals are then required for individual bunch crossing luminosity. This could be achieved using a 100μm thickness diamond, enabling a short pulse of 2 ns [8]. The energy deposition per incident particles in such a diamond is displayed in fig. 7. The spectrum corresponds to a Landau distribution with a peak energy at 50 KeV (1 MIP). The figures 8 show the reachable precisions on our measurements for the initial luminosity phase as a function of different energy thresholds for particles detection, respectively for the normal beam pipe and the window case. It appears that the aimed precision can not be reached with a normal beam-pipe, contrary to the window case improving the results by a factor 10.

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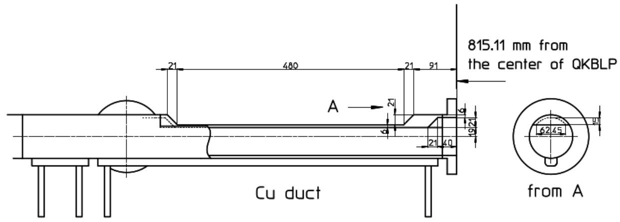

Figure 6: The window designed by K. Kanazawa at KEK - Japan.

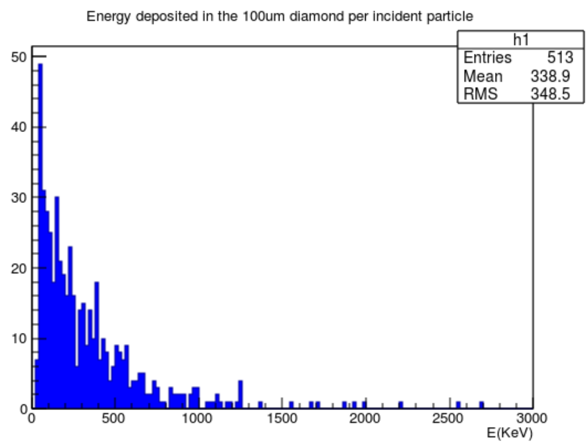

Figure 7: Energy deposition per incident particles in 100μm diamond.

CONCLUSION AND NEXT PLANS

From the simulation results presented in this paper, we were able to specify the best candidate position of our sensor in the LER at 13.9 meters downstream from the IP, where we should have enough Bhabha rates to achieve our aimed precision. A window appears to be necessary to obtain reliable signals in the sensors. On the other hand, candidate places in the HER are still under investigations to find a position which suits our measurements. 150μm diamond sensor characterisation study will start in the next weeks by laboratory test in synergy with the ATF2 diamond sensor project [9]. Furthermore, first prototype sensor and the fast readout electronics which is needed are also ongoing to end up with a setup for beam test at SuperKEKB in 2015 for single beam run.

ACKNOWLEDGMENTS

We would like to warmly thank Yoshihiro Funakoshi, Ken-ichi Kanazawa and Sadaharu Uehara for the fruitful discussions and collaboration we are having and for their encouragements. Part of this work has been funded by the P2IO LabEx (ANR-10-LABX-0038) in the framework "Investissements d'Avenir" (ANR-11-IDEX-0003-01) managed by the French National Research Agency (ANR)

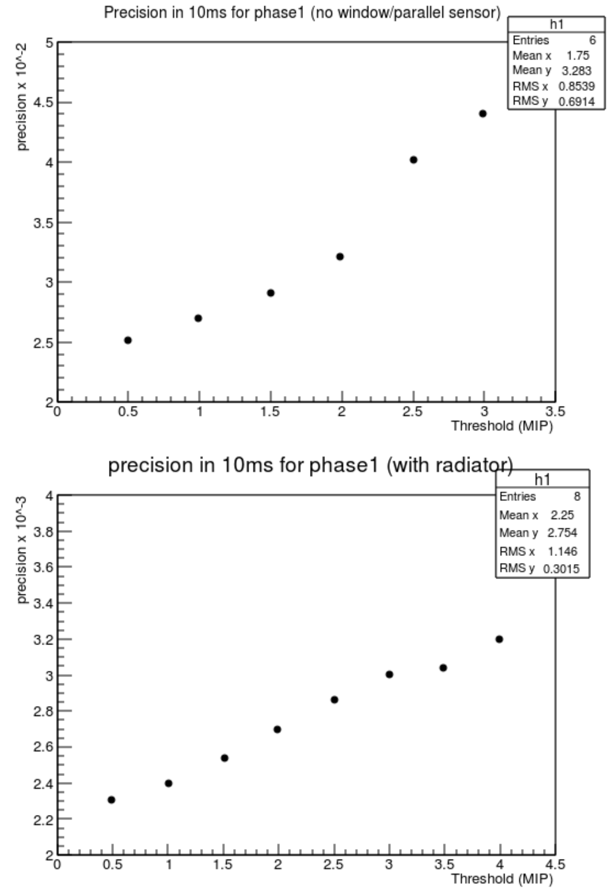

Figure 8: Precision in 10 ms on luminosity (10^{34} cm^{-2} s^{-1}) as a function of threshold applied on the energy deposited per scattered particle in the normal case (upper) and for a window (lower).

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