First Year PhD Thesis Activity Report Of Dima El Khechen

Thesis Title: Fast Luminosity Monitoring Using Diamond Sensors For The Super Luminous Flavour Factory SuperKEKB

Project Goals

-Development of methodology for fast monitoring of the luminosity of the SuperKEKB high luminosity B meson factory.
-Characterisation of diamond sensor technology.
-Beam dynamics simulation to establish optimal measurement locations.
-Generator study of Bhabha cross-section in the limit of zero degree scattering angle.
-GEANT4 simulation to optimise mechanical set-up and define readout of the zero degree luminosity monitor of the Belle II experiment at SuperKEKB.
-Simulation of background processes (Touschek intra-beam hard Coulomb scattering and beam gas Bremsstrahlung)
-Installation and first tests at KEK during beam commissioning.
-Development and implementation of fast analog electronic shaping and fast digitisation for on-line bunch-to-bunch and overall luminosity averaging.
-Digital feedback through synchronous detection ("dithering" algorithm).

Description Of Work Achieved

1) The radiative Bhabha process at zero photon scattering angle corresponds to an electron-positron interaction through the exchange of a quasi-real photon. Although it is one of the main sources of background, this process can be useful for luminosity monitoring since the amount of scattering is large at the interaction point (IP) and proportional to the luminosity. The dynamics of the Bhabha events have been generated by GUINEA-PIG++, a beam-beam interaction simulation tool mainly used for high energy e^+e^- collider studies. Another generator, BBBREM, based on the equivalent photon approximation, is dedicated to the radiative Bhabha process at zero degree angle. It has been used for comparisons and computations of the cross-section under different conditions. Typically 150 mbarn are obtained for a cut at 1% on the ratio of energies of the scattered photon and beam.

2) Bhabha particles were then tracked using SAD, an accelerator beam tracking code developed and used at KEK, in both the Low Energy Ring LER (positrons) and the High Energy Ring HER (electrons) at several locations. After several investigations, at different positions downstream of the interaction point (IP), the optimal position of our diamond sensors was chosen to be in the drift at 13.9 meters from the IP for the LER, where a fraction of Bhabha events in the sensors (1.65 %) is good enough to achieve our aimed precision of 10^{-3} in 1 ms on luminosity measurements. On the other hand, the HER showed non-linear distributions of the transverse position of the particles with their energy and very low rates of intercepted Bhabha particles in the sensors, thus no good candidate position is yet defined. Research for a good candidate place of our sensors in the HER will be going on as a coming step.

3) Large intercepted fractions at the defined sensor position may introduce a problem of pile-up at the nominal luminosity $8\ 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, where we'll have more than one Bhabha event for each bunch crossing

(each 4 ns) in our sensor. In this case, we will lose a lot of precision on our measurements. The charge amplifier which we have acquired has a shaping time of 10 ns (sigma). This is sufficient for initial luminosity, when the average signal rate of intercepted Bhabha events in our counters is significantly less than 1 per bunch crossing. On the other hand, for nominal luminosity, a faster amplifier will need to be developed, with a shaping time of less than 4 ns to separate signals from subsequent pulses. We recently received a 140 μm diamond sensor on which we will carry on some tests in the coming weeks, along with the amplifier in the clean room at LAL, to establish an overall characterization of both.

4) Bhabha particles will exit the 6 mm copper beam pipe with an angle of 5 mrad, crossing a 1.2 meters in the material. In this case, most of the shower particles will be absorbed and very few will exit the beam pipe resulting in a very small signal. As a result, an idea of creating a window at 45 degrees in the drift was considered, to enable sampling the developing shower close to its maximum (by adding a suitable radiator immediately after the window), and hence significantly increase the magnitude of the signal in the sensors. Simulations using GEANT4 were performed, considering different geometries, to estimate the actual number of particles which will hit the diamond sensor and to determine if a window is required. Simulations with a window showed much higher signal, resulting in an improvement of the precision by a factor of 10. However, such a window may cause the impedance of the beam-pipe to change thus creating wake-fields which will affect the beam stability. In consequence, a new design consisting of just decreasing the thickness of the beam-pipe at the chosen position, is under discussion and simulations will take place in the coming days.

5) Our project at LAL is integrated in the Zero Degree Luminosity Monitor (ZDLM) of the Belle II experiment at SuperKEKB. In this context, a close collaboration is developing both with the Belle II physicist in charge of ZDML at KEK (S. Uehara) and with two accelerator physicists in charge of the SuperKEKB operation and optimisation (Y. Funakoshi and M. Masuzawa). The detector to be installed in the defined location 13.9 meters from the IP involves not only our diamond sensor (developed at LAL) but also Cherenkov and a scintillation devices, with small size photomultipliers (developed at KEK). The purpose of having several technologies is not only redundancy for cross-checking but also risk mitigation, as several issues are difficult to anticipate (e.g. background conditions). I have been asked to include these two devices in the GEANT4 simulation, to compare the expected precision with that of our diamond sensor. This simulation is underway. Preliminary results have been obtained and are discussed with our collaborators from KEK.

6) Schools, conferences and workshops attended:
- TESHEP (Trans European School on High Energy Physics), Kharkiv, Ukraine: 9-16 July, 2013
- Belle II week at KEK, Tsukuba, Japan: 4-8 February, 2014
- GEANT4 week at LAL (Laboratoire de l'accélérateur Linéaire), Orsay, France: 19-23 May, 2014
- 2014 Joint Workshop of the France-Japan (TYL/FJPPL) and France-Korea (FKPPL) Particle Physics Laboratories at Bordeaux, France: 26-28 May, 2014
- IPAC14 (International Particle Accelerator Conference), Dresden, Germany: 15-20 June, 2014
- Danube School on Instrumentation in Elementary Particle Physics and Nuclear Physics, University of Novi Sad, Serbia: 8-13 September, 2014

PUBLICATION

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RELEVANCE OF THE PROJECT WITHIN P2IO

The fast luminosity monitoring project aims at developing a very fast instrument in the context of a frontier machine, SuperKEKB, designed to achieve unprecedented luminosity values and presently under construction in Japan. Such luminosities would enable the observation of very rare events for matter-antimatter symmetry violation studies at the Belle II experiment, which constitutes one of the main research areas of P2IO. Our instrumentation is based on mono-crystalline chemical vapour deposition diamonds, whose radiation tolerance and fast signal collection enable usage under very high particle fluxes, for beam diagnostics at several intensity frontier machines, SuperKEKB, and also ILC/CLIC or post LHC machines. It requires fast electronics readout system developments. R & D studies realized in this context contribute to our expertise in both detector and electronics readout technologies at the state of the art. Our work is relevant to prepare our team and laboratory for future projects in which diamond sensors will be needed. Expected outcomes will contribute to enhance the visibility of the P2IO LABEX in the HEP community.