WR polarimeter SuperKEKB

Aurelien Martens

November 2020

1 Introduction

Compton backscaterring is a process allowing to measure accurately [1] the electron beam polarization at electron beam energies above 1 GeV. Indeed the cross-section of this process exhibits a polarization dependent behavior [2]. This technique has been successfully employed in the past at SLC [3], at HERA [4, 5], JLAB [6] and was considered for SuperB [7]. In particular it has allowed to demonstrate and optimize high degree of polarization in the HERA ring [8]. It is also considered in other projects as ILC [9], LHeC [10] and EIC [11]. It is also considered for FCC-ee [12] in the context of energy calibration with resonant depolarization as it was done at LEP2 [13]. Large synergies exist with HERA and the EIC project, yet in design phase.

The experimental setup consists of a circularly polarized laser beam which scatters off the electron beam. The photons are scattered within a narrow (<1mrad) cone around the tangent of the electron's trajectory at the interaction plane. A calorimeter can be implemented to measure the scattered gamma ray spectrum and/or a segmented electron counter placed after a dispersive element to measure the transverse electron distribution directly linked to their energy once the magnetic field is known. Both these distributions show sensitivity to the longitudinal electron beam polarization but with different sources of systematic uncertainties. It must be noted that vertical electron beam polarization may also be extracted but would require a vertically segmented detector since the sensitivity comes from spatial asymmetries in the measured energy spectra [8].

2 Strategy

The specificities of the SuperKEKB upgrade, and similarly of EIC, lie in the fact that no permanent regime is reached and that continuous top-up is realized to maintain a very high luminosity. According to these specificities, and also following past experience [5] it will be necessary to measure the beam polarization for every bunch independently on a time scale similar to that of the top-up period in the SuperKEKB ring. It must be noted that this measurement cannot be made at the BelleII interaction point itself, neither in a straight line to it due to too high backgrounds. This measurement of the polarization could be extrapolated to the BelleII interaction point provided that the lattice and alignments are well known [14]. Two possibilities could be considered. The simpler one is to place the Compton interaction point relatively close to the interaction point but far enough from the polarization rotators such that the longitudinal projection electron beam polarization vector is sufficiently large. Alternatively, the polarimeter could be placed in a region of the ring where the polarization is nearly vertical. However in this case, the experience of HERA [4], shows that alignments must be controlled within few tens of microns, in regions of the lattice where the vertical beam size, angular spread and dispersions are negligibly small.

The xxx polarimeter is considered as a baseline solution at this stage of the project. W Where do we place the polarimeter ? Will decide depending on integration possibilities (KEK input required) + risk related to difficulty of transverse polarimetry (vertical alignment).

This measurement may be complemented by measurements prior injection in the SuperKEKB ring since the beam lifetime is smaller than the polarization build-up time in the SuperKEKB ring and to avoid injection of badly polarized beams in the ring. In particular, it is sometimes valuable [REFJLAB, REF] to implement Mott scattering technique at the injection for commissioning and troubleshooting purposes. A dedicated short beam line right after the injector maybe build for this purpose. Additionally one may want to check that the high-energy beam polarization is correctly oriented with a non destructive manner, which could be easily implemented if a damping ring is used [CROSSREF]. This may be useful if it turns out that a bad polarization top-up injection cannot be extracted from real-time data of the main ring polarimeter. Detailed design of the latter is required to address this question.

3 Main ring longitudinal polarimeter design

3.1 Location

The main ring polarimeter could be located right before BLXXXX magnet of the SuperKEKB ring. At this place the longitudinal projection of the beam polarisation vector is expected to be of about XX%.

3.2 Laser system

The laser system could be directly integrated in the accelerator in similar fashion as what was done for HERA LPOL2, see Fig. 1. The laser and and related diagnostics may be directly located below the beam pipe or close to it, assuming that proper shielding against radiations is implemented. The box in which this system will be embedded must be thermally controlled to limit any drifts that could affect the laser performances and particularly pointing and more importantly the laser polarization control that directly contributes as a systematic uncertainty. Industrial systems that can be locked onto the accelerator reference clock delivering few Watts are commercially available. Such pulsed laser (frequency combs) systems are well suited since they naturaly match the bunch pattern at 250MHz of SuperKEKB and may be sufficient to obtain one scattering in average per bunch crossing. These systems can be synchronized on an external reference clock. This configuration is similar to that of HERA LPOL2 where real-time monitoring of the beam polarization was demonstrated [5]. The ability to operate the polarimeter in a regime of, in average, one scattering per bunch crossing needs to be confirmed with detailed estimates of background levels in the detectors. The choice of the laser wavelength, basically *infra-red* of *green* will mainly depend on the detailed design of the detectors. A green laser allows to better separate the scattered electrons from the main beam and the scattered photon maximum energy will be larger such that it is more immune to backgrounds. It however implies to implement frequency doubling of an infrared laser in the accelerator environment which implies some manageable complications. Stable operation, compatible with a precise (per-mille level) control of the laser-beam circular polarization components, needs to be demonstrated in this environment to the best of our knowledge. A schematic describing the components needed for the laser system is shown on Fig. 2. The laser transport will be as short as possible by integrating the laser system in the vicinity of the Compton interaction point. It may be partly under high vacuum, depending on the length of the beam transport required. A careful vacuum chamber design compliant with the requirement to not significantly modify the impedance of the ring can be done, as it was in the past for instance for the HERA LPOL2 optical cavity, see Fig. 1.

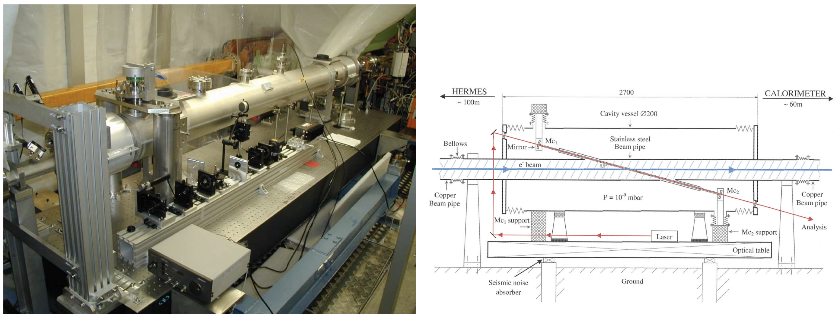

Figure 1: (Left) picture of the LPOL2 cavity installed in HERA tunnel and (right) a schematic of its mechanical integration. No cavity mirrors are required for SuperKEKB but a similar mechanical system could be implemented. A particular was paid to the design of the vacuum pipe for beam impedance issues. Reproduced from Ref. [5].

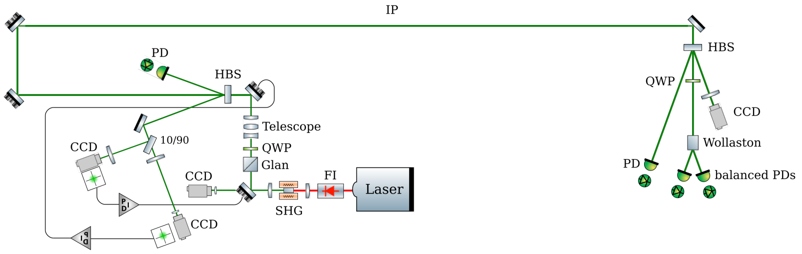

Figure 2: Schematic describing the conceptual design of the laser system in case a *green* laser is used. FI: Faraday isolator; SHG: second harmonic generation module; QWP: Quarterr Wave plate; HBS: holographic Beam sampler allows to extract a small fraction of the beam power independently of the polarisation; PD: photodiode. A position and pointing stabilization is integrated in the schematics.

3.3 Detectors

Two complementary detectors are thought to be implemented. They must comply with the need to measure each bunch independently of the others and potentially high radiation levels due to the signal itself.

The photon calorimeter is designed to measure the energy of the photons scattered in the direction of the incident electron beam. Since it must measure photons at a rate of 250 MHz, a fast scintillating material must be used. BaF2 crystals are well suited for that goal, provided that the slow component is well filtered out by Yttrium doping and/or use of solar blind photodetectors [15]. It it also compliant [15] with the very large integrated dose delivered by the signal itself of about 0.6MGy assuming about 6 months of operation of the system. It is foreseen to implement only one channel for the measurement. This needs to be confirmed by simulation since the use of two or four detectors may allow to better align the detector from data itself. The resolution is not a critical aspect of the measurement and resolution of several $\%/\sqrt{GeV}$ seem to not degrade significantly the precision, according to preliminary estimates. The possible contribution from pile-up that will require careful estimation and subtraction [5], with remaining fluctuations contributing to the detector resolution with magnitudes depending mainly on the decay time of the measured signal. Dedicated test-beam experiment may be needed to validate the design of this detector and its associated electronics. A similar electronics to that implemented at HERA [5] but able to cope with the higher rate of SuperKEKB may be realized. At that time an online extraction of the polarisation was made possible and was checked with offline fits of the measured spectra, an example of which is shown on Fig. 3. Estimates of background levels by dedicated simulations or measurements in the SuperKEKB envrionment will be needed to precisely assert the performance of this detector.

[Wouter et al.] Complementary to that, an electron spectrometer employing

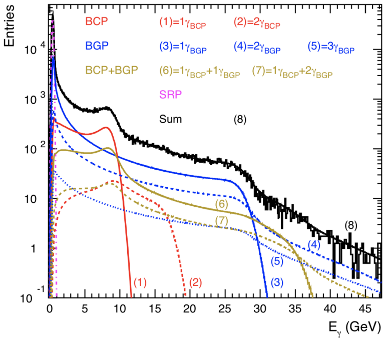

Figure 3: A measured spectrum of photon calorimeter in HERA LPOL2 with data and a fit. Reproduced from Ref. [5].

a electron counter horizontally segmented and the dispersive magnetic element, ideally one already existing in the SuperKEKB lattice, will provide a complementary information. The spectrum of the scattered electrons will be measured by a HVMAPs array. Despite this detector is slow compared to the 4 ns bunch separation, the. occupancy will be much smaller compared to that of the photon calorimeter, assuming one one scattering per bunch crossing. Thus each bunch crossing may still be well separated. Alternatively diamond strips could be used, which will be naturally radiation hard and fast. However there is at present no commercial solution for that technology. Some pictures and results from JLAB experience ?

Vacuum chamber for gamma and electron beams up to the detectors ?

3.4 Expected performance

Signal only preliminary estimates suggest that the polarization may be estimated with less than 1% statistical precision within a minute for each bunch, provided that about one scattering takes place at each crossing of electron and laser bunches. A major common source of systematic uncertainties for both detectors is the knowledge of the laser polarization. This aspect will need to be controlled at the per-mille level for SuperKEKB thanks to dedicated diagnostics as mentioned in the previous section. Expected systematic uncertainties have partially different sources for the two detectors. For the photon detection [5], knowledge of backgrounds, precise knowledge of the calibration and alignment of the detector, and associated electronics contribute with an overall systematic uncertainty well below 1%. These will need to be re-assessed precisely in the present case, in particular in view of the potential impact of pile-up related to the short bunch separation in time. Data-driven calibration and alignment techniques may be investigated to reduce these systematic uncertainties. For the electron spectrometric measurement [6], the knowledge of the magnetic field, the residual angular mis-alignment of the detector, knowledge of the beam energy, knowledge of the detector response are expected to contribute within 0.6%.

4 Summary of required R&D before Technical design report

The studies performed at this stage give confidence that commercial laser systems can be used to interact with the electron beam of SuperKEKB to realize a measurement of electron beam polarization with Compton back-scattering . One of the key aspect related to the laser beam is the control and survey of its polarization components that enter in the systematic uncertainties for the extraction of the polarization of the electron beam. Some limited R&D work needs to be performed on this topic to ensure a stable and precise estimation in the environment of SuperKEKB with the laser system that is considered. It is planned to use the existing/upgraded SuperKEKB lattice without modification beyond the insertion of the laser system. Existing technology based on HVMAPS can be implemented for the counting of electrons, with no specific need for a dedicated R&D. A measurement of the scattered photons spectrum using a BaF2 crystal coupled to a PMT could complementarily be implemented. It is expected to be compliant with the short time-separation of bunches at SuperKEKB. This may be confirmed with some limited R&D to ensure the performance of this system.

References

[1] A. Denner and S. Dittmaier. Complete $\mathcal{O}(\alpha)$ QED corrections to polarized Compton scattering. *Nuclear Physics B*, 540(1):58 – 86, 1999.

[2] I.F. Ginzburg, G.L. Kotkin, S.L. Panfil, V.G. Serbo, and V.I. Telnov. Colliding γe and $\gamma\gamma$ beams based on single-pass e$^+$e accelerators II. Polarization effects, monochromatization improvement. *Nuclear Instruments and Methods in Physics Research*, 219(1):5 – 24, 1984.

[3] The SLD collaboration represented by R.C. King. A precise measurement of the left-right asymmetry of Z boson production at the SLAC linear collider. *Nuclear Physics B - Proceedings Supplements*, 37(2):23 – 31, 1994.

[4] D.P. Barber et al. The HERA polarimeter and the first observation of electron spin polarization at HERA. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 329(1):79 – 111, 1993.

[5] S Baudrand et al. A high precision fabry-perot cavity polarimeter at HERA. *Journal of Instrumentation*, 5(06):P06005–P06005, jun 2010.

[6] A. Narayan et al. Precision Electron-Beam Polarimetry at 1 GeV Using Diamond Microstrip Detectors. *Phys. Rev. X*, 6:011013, Feb 2016.

[7] SuperB Collaboration, M. Baszczyk, et al. SuperB Technical Design Report, 2013.

[8] D.P. Barber et al. High spin polarization at the HERA electron storage ring. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 338(2):166 – 184, 1994.

[9] S Boogert et al. Polarimeters and energy spectrometers for the ILC Beam Delivery System. *Journal of Instrumentation*, 4(10):P10015–P10015, oct 2009.

[10] J L Abelleira Fernandez et al. A large hadron electron collider at CERN report on the physics and design concepts for machine and detector. *Journal of Physics G: Nuclear and Particle Physics*, 39(7):075001, jul 2012.

[11] Wouter Deconinck. Polarization Upgrade and Polarimetry at the SuperKEKB Belle II Facility.

[12] Alain Blondel et al. Polarization and Centre-of-mass Energy Calibration at FCC-ee, 2019.

[13] The LEP Energy Working Group. Calibration of centre-of-mass energies at LEP 2for a precise measurement of the W boson mass. *The European Physical Journal C - Particles and Fields*, 39(3):253–292, 2005.

[14] M Beckmann, J List, A Vauth, and B Vormwald. Spin transport and polarimetry in the beam delivery system of the international linear collider. *Journal of Instrumentation*, 9(07):P07003–P07003, jul 2014.

[15] Ren-Yuan Zhu. Ultrafast and Radiation Hard Inorganic Scintillators for Future HEP Experiments. *Journal of Physics: Conference Series*, 1162:012022, jan 2019.