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TESTING ELECTRON POLARIZATION AT SUPERKEKB USING TOUSCHEK LIFETIMES

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Abstract

The Chiral Belle project is a proposed project which aims to expand the capabilities of SuperKEKB and the physics goals of Belle II by injection polarized electrons into the High Energy Ring. Before the full implementation of spin rotator magnets near the interaction point, we propose to demonstrate the injection and transport of polarized electrons in the SuperKEKB Main Ring. By measuring the effect of differing polarization states on the Touschek lifetime, we aim to show the preservation of polarized spin vectors around the main ring without the need for the full apparatus of Compton polarimetry and spin rotator magnets which will be required for the full Chiral Belle project.

INTRODUCTION

The SuperKEKB [1] accelerator began operation in 2016 at KEK in Tsukuba, Ibaraki, Japan, and has been providing electron-positron collisions for the Belle II experiment's full physics data taking operation since 2019. Among the proposals now being considered to extend the lifetime of both the SuperKEKB accelerator facility and the Belle II experiment is the inclusion of polarized electrons in the high-energy ring. This modification would include the addition of a polarized electron source, spin rotator magnets before and after the interaction point (IP), and a Compton polarimetry system. While the design, development and deployment of all the above components is a long-term effort that is planned to be completed in the next SuperKEKB long shutdown, tentatively planned for 2028, we have proposed a smaller-scale project involving only the polarized electron source for installation and testing on a shorter timescale of 1-2 years. This project would serve to demonstrate the feasibility of the project, confirm simulations of polarized beam transport in SuperKEKB, and provide valuable experience for the full proposed project.

Efforts to develop the spin rotator magnets and Compton polarimeter are described elsewhere [2–4].

PHYSICS MOTIVATION

The weak mixing angle θ_W is a fundamental parameter of the Standard Model (SM), and precision measurements of neutral currents are considered one of the highest-priority avenues for discovery of physics beyond the SM. Any measurement finding a deviation of $\sin^2\theta_W$ from SM prediction would be a clear indication of new physics.

The introduction of an electron beam spin-polarized above 70% would open a new avenue for measurement of weak neutral currents in a manner complementary to existing experiments. In particular, a polarized beam would enable Belle II to measure the weak neutral vector coupling constants of the b and c quarks and muon with a substantial improvement in precision over past experiments [5, 6].

Figure 1 displays the predicted precision of weak neutral vector current measurements with a data set of 20 ab^{-1} taken with a polarized beam. In addition to precision, it can also be seen that Belle II's measurements would be in a parameter space of order 10 GeV, complementary to existing higher- and lower-energy range searches.

Furthermore, recent predictions also indicate that measurement of a chiral asymmetry in the process $e^+e^- \longrightarrow \tau^+\tau^-$ at 1% precision would provide a measurement of the τ magnetic moment on the order of the current 4σ tension between the SM and experiment [7]. Such a measurement would be a new avenue at investigating anomalous lepton magnetic moments without the need to build a dedicated accelerator or experiment.

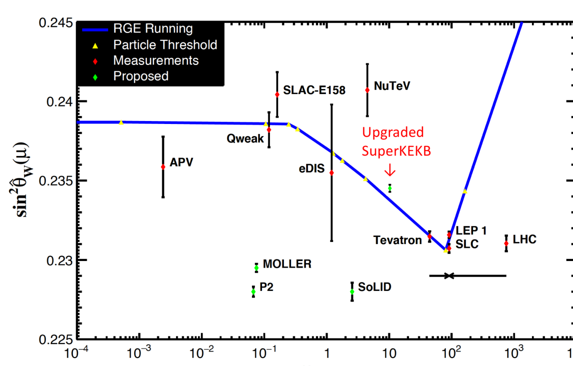

Figure 1: Scale dependence of $\sin^2\theta_W$ (giving the weak mixing angle) defined in the $\overline{MS}$ renormalization scheme. Adapted from reference [8] to include projected errors on proposed/upcoming experiments at particular energy scales, including that at an upgraded SuperKEKB that includes polarized electron beams.

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THE TOUSCHEK LIFETIME EXPERIMENT

While the full physics plan described above will require the inclusion of spin rotator magnets and a Compton Polarimeter, we propose to make use of the effect of polarized electrons on the beam Touschek (intra-beam interaction) lifetime. The relationship between beam polarization and the Touschek effect was first calculated by Baier and Khose in 1967 [9] and is expected to appear as a 1-4% difference between polarized and unpolarized electrons at SuperKEKB (see Fig. 2).

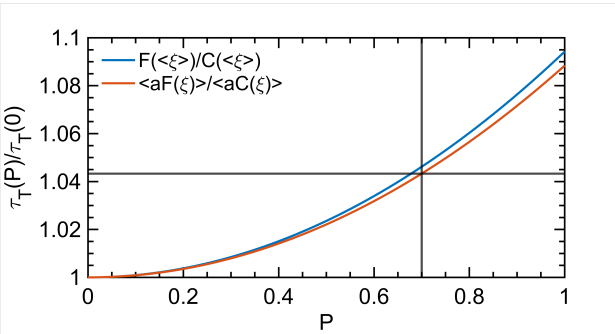

Figure 2: Predicted Touschek lifetime difference by overall polarization rate assuming an overall momentum acceptance of 0.6%. Courtesy of A. Martens.

Because this effect is expected to appear even with electrons polarized in the transverse state, it is possible to measure the beam polarization at the IP without rotating the polarization state to the longitudinal and without a dedicated Compton Polarimetry setup, provided the beam lifetime can be measured sufficiently.

The SuperKEKB background group has demonstrated the ability to assess the contributions to beam lifetimes as a result of Touschek interactions and other sources (e.g., beam-gas interactions) in both the beam commissioning [10] and physics taking [11] phases of SuperKEKB at a level sufficient to discern the effect due to the introduction of polarized electrons.

We propose to use several dedicated shifts at the end of a run period to collect sufficient data to detect differences between unpolarized electrons and those in both vertical polarization states.

Beam Source Generation and Spin Rotation

To achieve the stated physics goals, a high beam polarization (≥ 70%) is desired. GaAs sources have in the past been demonstrated to produce polarization > 90% with a quantum efficiency (QE) of 1.6% [12], but a wide band gap makes accelerating the generated electrons difficult. To alleviate this issue, research is underway in the development of thin-film Negative Electron Affinity (NEA) surfaces applied to the GaAs cathode [13, 14]. While this technique has been in use in the past, cathode lifetimes are notably short. Work is currently ongoing to create more robust cathodes with longer lifetimes while maintaining high polarization rates.

Electrons produced from the cathode have spins aligned (anti)parallel to the direction of beam propagation, and thus to avoid unwanted changes in direction when passing through beamline elements must be rotated to the transverse (vertical) direction. This is to be achieved using a Wien Filter consisting of electric and magnetic fields chosen such that

$$\beta c = E/B, \tag{1}$$

rotating the polarization vector of the electrons while resulting in a net force of 0 on electrons with velocity β.

Spin Transport Simulations

After generation, the beam must be transported first through the SuperKEKB linac, followed by the beam transport lines for injection into the Main Storage Ring, and finally around the circular ring itself to the IP. Several areas along this path may prove challenging: the J-arc is a 180 degree hairpin turn, and the beam transport lines have approximately 10 m of vertical descent before injection into the ring. The Main Ring itself also includes several bending sections before the IP, all providing possible sources of instability.

Beam simulations carried out in the BMAD [15] framework have indicated that spin transport in the vertical state is preserved through the accelerator and can in fact be maintained for very long beam lifetimes [16]. As shown in Fig. 3, apart from brief changes induced by the areas listed above, the desired vertical polarization states are restored after injection and preserved through the ring. In addition, simulations also predict beam polarization lifetime (that is, time to depolarization) at 10 h, as shown in Fig. 4. As this is significantly longer than normal beam lifetimes during operation, depolarization is not predicted to be problematic.

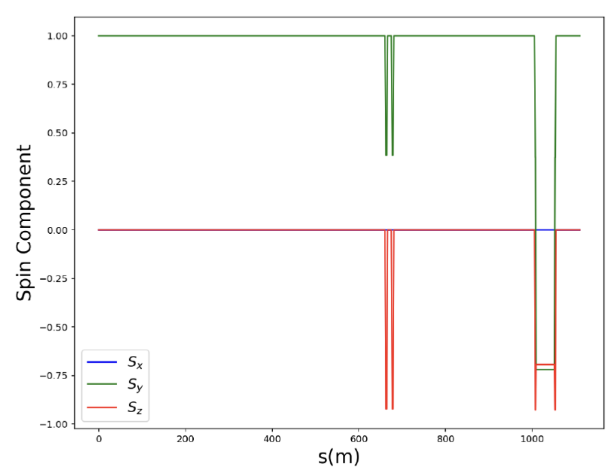

Figure 3: Simulated polarization vectors for electrons moving through the SuperKEKB linac, assuming 100% polarization at generation. The green line represents vertical spin. Brief drops from 100% occur at known positions within the accelerator, particularly the Beam Transport lines [16].

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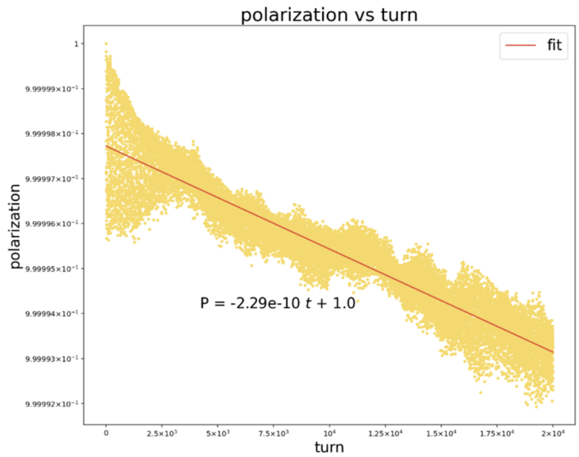

Figure 4: Simulated beam polarization lifetime by number of turns around the Main Storage Ring in SuperKEKB. The fitted line gives a depolarization lifetime of approximately 10 hours [16].

Beam-beam interactions have not yet been fully simulated, and the Touschek Lifetime experiment is expected to provide valuable feedback on the effect of the interacting beams.

Polarimetry

While the full Compton Polarimeter setup will not be used in the proposed Touschek Lifetime experiment, measurement of the polarization at the source is necessary to understand the results of the project. For this purpose we plan to use a Mott polarimeter to measure the polarization rate after generation, while electrons are still at relatively low energy (≈200 keV). Due to space limitations in the SuperKEKB source area, we plan to set up a test bench for polarization measurement.

CONCLUSION

As a first step towards the inclusion of a polarized electron beam at SuperKEKB and a proof-of-concept for the larger Chiral Belle project, we have proposed measuring the beam polarization lifetime with a few hours of operation at the end of a run period. This would entail only the addition of a polarized electron source and low-energy spin rotator at the SuperKEKB source area, with Main Ring spin rotators and Compton Polarimeter to be added at a later phase of the experiment. Utilizing the demonstrated ability of Belle II's detectors to accurately and precisely determine the amount of Touschek scattering in the beam, we expect to be able to differentiate between antiparallel polarization states as well as the unpolarized electron beam.

This project would provide valuable feedback for the proposed extension of SuperKEKB's physics program via the polarization upgrade along with experience and knowhow for the future. In addition, it would confirm polarized beam simulations already carried out as well as provide valuable information about beam-beam effects on the polarized electron beam.

REFERENCES

[1] Y. Ohnishi *et al.*, "SuperKEKB Design Report", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 907, pp. 188–199, 2018.

[2] US Belle II Group and Belle II/SuperKEKB e- Polarization Upgrade Working Group, "Snowmass 2021 White Paper Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation", 2022. `doi:10.48550/arXiv.2205.12847`

[3] D. Charlet *et al.*, "Conceptual study of a Compton polarimeter for the upgrade of the SuperKEKB collider with a polarized electron beam", *J. Instrum.*, vol. 18, p. P10014, 2023.

[4] G. Bardin *et al.*, "Conceptual Design Report of a Compton polarimeter for Cebaf Hall A", Technical report, 2012.

[5] A. Aleksejevs, S. Barkanova, C. Miller, J. M. Roney, and V. Zykunov, "NLO radiative corrections for Forward-Backward and Left-Right Asymmetries at a B-Factory", *Phys. Rev. D*, vol. 101, p. 053003, 2020.

[6] J. M. Roney, "Precision electroweak physics with polarized beams at SuperKEKB", in *Proc. Lepton Photon 2019*, Toronto, Canada, Aug. 2019. `doi:10.22323/1.367.0109`

[7] A. Crivellin *et al.*, "Towards testing the magnetic moment of the tau at one part per million", 2021. `doi:10.48550/arXiv.2111.10378`

[8] J. Erler and A. Freitas, "Electroweak Model and Constraints on New Physics", in M. Tanabashi *et al.*, (Particle Data Group), *Phys. Rev. D*, vol. 98, p. 030001, 2018.

[9] V. N. Baier and V.A. Khoze, "Effect of particle scattering in a beam of polarized electrons in a storage ring", *Soviet Atomic Energy*, vol. 25, pp. 1256–1258, 1968.

[10] Z. J. Liptak *et al.*, "Measurements of beam backgrounds in SuperKEKB Phase 2", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 1040, p. 167168, 2022.

[11] A. Natochii *et al.*, "Measured and projected beam backgrounds in the Belle II experiment at the SuperKEKB collider",*Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 1055, p. 168550, 2023.

[12] X. Jin, B. Ozdol, M. Yamamoto, A. Mano, N. Yamamoto, and Y. Takeda, "Effect of crystal quality on performance of spin-polarized photocathode", *Appl. Phys. Lett.*, vol. 105, p. 203509, 2014.

[13] M. Kuriki, Z. J. Liptak, L. Guo, X .Jin and N. Yamamoto, "GaAs cathode activation with Cs-K-Sb thin film", *J. Phys.: Conf. Ser.*, vol. 2687, p. 2, 2024.

[14] L. Guo *et al.*, "Rugged bialkali photocathodes encapsulated with graphene and thin metal film", *Sci. Rep.*, vol. 13, 2023. `doi:10.1038/s41598-023-30799-2`

[15] Bmad code by D. Sagan, Cornell, "Bmad: A relativistic charged particle simulation library", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 558, pp. 356–359, 2006. `https://www.classe.cornell.edu/bmad/.`

[16] Y. Peng, "Spin Tracking Studies for the SuperKEKB Polarization Upgrade", presented at FCC epol Workshop, 2022