

Touscheck Polarization Experiment Discussion



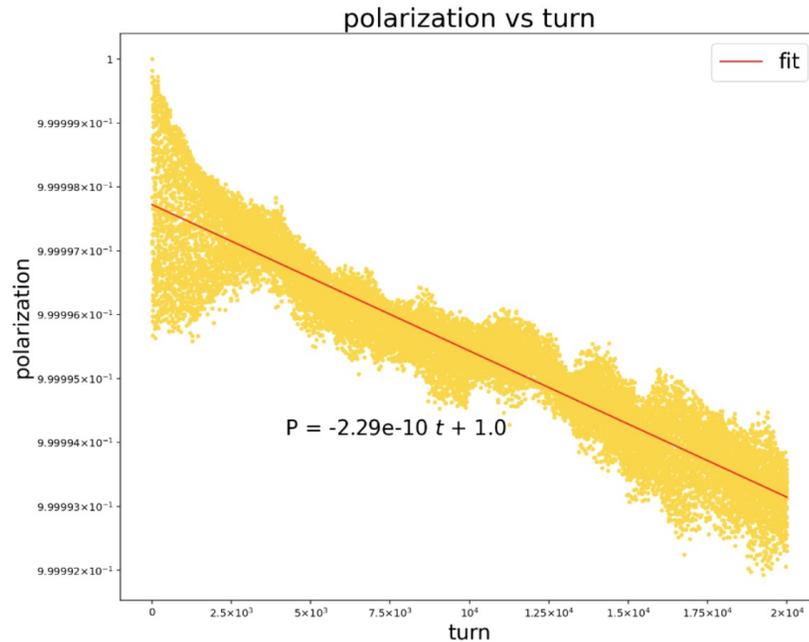
Touschek Polarization Experiment

Draft Proposal Outline

- Motivation for performing Touschek Polarization Experiment
 - Summary of Physics motivation for Chiral Belle
 - Time now to test the long term tracking studies with data
 - Long term tracking studies, which capture non-linear beam and spin dynamic effects, demonstrate that we have a spin rotator solution that is 'transparent' to the rest of the lattice with minimal disruptions to the existing lattice, as well as the possibility of easily changing to operations without the spin rotator solenoid and skew quads
 - Validate long term tracking studies of beam dynamics and spin tracking that indicate
 - Transverse polarization is preserved from the source through to the HER
 - Very long polarization lifetimes for HER beam injected with polarized electrons
 - Measure the impact of collisions on the polarization lifetime of the beam
 - Compare measurements to predictions of the long term tracking studies
 - Measurements of polarization lifetime at several energies provide information of absolute beam energy

Transverse polarization survival rate in HER

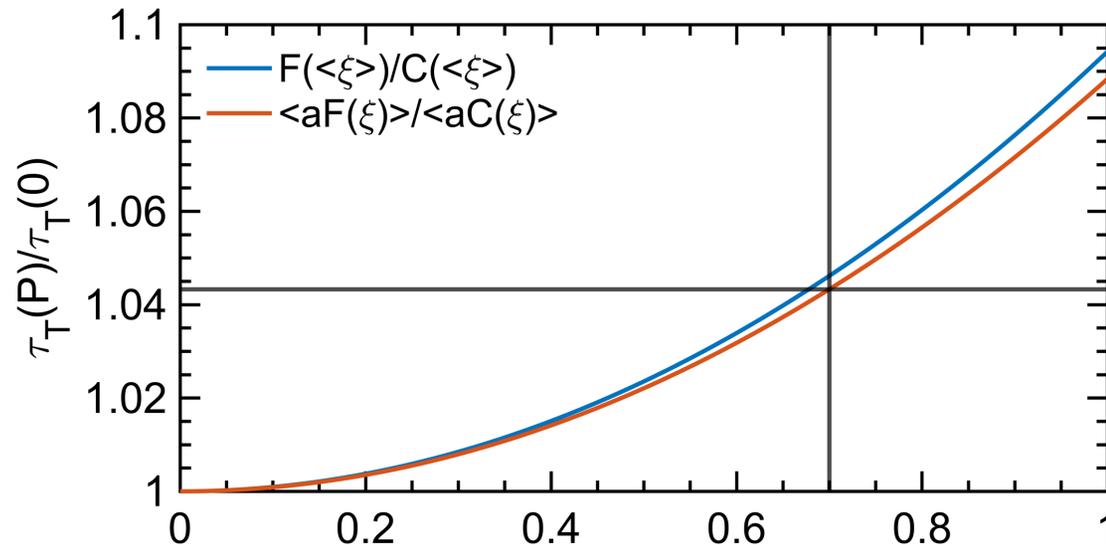
Y. Peng's (UVictoria)



- Tracking 100 particles for 20000 turns in the HER with BMAD
- This study estimates polarization lifetime > 10 hours

For SuperKEKB

From
Farah MAWAS
Aurélien MARTENS
Slides at Feb
Chiral Belle meeting



- It is $\sim 4\%$ effect assuming (overall) momentum acceptance of 0.6% , and using her_2021-06-09_231636.388_MeasOpt

Touschek Lifetime Studies

Andrii Natochii (BNL) Presentation this B2GM

Background Group Data –

the Touschek Lifetime in the HER has been measured at the few per-mil level – sufficient for measuring polarization effects which are at the 4% level

Described in current draft of Chiral Belle CDR

Period	Experimental Touschek Lifetime (minutes)	Ratio of Experimental to SAD Simulation lifetimes
May 2020	37.929 ± 0.057 (0.15%)	0.642 ± 0.002
June 2020	33.656 ± 0.064 (0.19%)	0.746 ± 0.005
June 2021	27.93 ± 0.10 (0.36%)	0.601 ± 0.003
December 2021	24.107 ± 0.079 (0.33%)	0.519 ± 0.002

(see Andrii Natochii presentation in this B2GM)

A Touschek polarimeter for SuperKEKB

A. Martens, F. Mawas, A. Natochii, M. Roney, D. Zhou, ...
Institute name in English, Town, Country

Abstract

A stages approach is considered for an upgrade of the SuperKEKB accelerator with a polarized electron beam. In this context the usefulness of a measurement of the beam polarization by means of its Touschek lifetime is investigated here.

Keywords

Touschek lifetime; beam polarization

1 Introduction

An upgrade of the SuperKEKB accelerator with polarized electron beams would enhance the physics reach of the Belle II experiment by otherwise impossible measurements of electroweak asymmetries and tau-vertex as its g-2 [1]. The first step consists in demonstrating that the required current of polarized electron beam can be produced, transported in the linac to the main SuperKEKB ring and stored for a long enough time without loss of vertical polarization. The next stage would consist in actually implementing modifications to the main SuperKEKB ring by inserting spin rotators and a Compton polarimeter to ensure and optimize a longitudinal polarization at the Belle II interaction point. In order to minimize modifications to the main ring prior a demonstration that significantly polarized electron bunches can be stored in SuperKEKB, it is of interest to find a simple, possibly non invasive technique to diagnose the beam polarization in SuperKEKB. We investigate here the possibility to do so by means of Touschek lifetime measurements.

This document is organized as follows. First we introduce the dependence of the Touschek lifetime as a function of beam polarization. We investigate its impact for the SuperKEKB ring. In a second section, we investigate the present status of Touschek lifetime measurements in the SuperKEKB ring that are presently made in the context of beam background diagnostics for the Belle II experiment. We finally list the needs for a meaningful polarization measurement at SuperKEKB.

2 Touschek lifetime and polarization

Touschek described the lifetime of electrons in AdA (accumulation ring) in 1963 [2], as a result of Moeller scattering in between electrons of a beam in a ring. Right after, Baier and Khoze pointed out that the Touschek lifetime is sensitive to polarization [3]. It was then used in the VEPP-2M ring to measure depolarization, and in turn the beam energy, by measuring the counting rate of scattered electrons [4]. It allowed to realize a first precision mass measurement of the J/Psi, that was continuously improved until it reached a few parts per million accuracy on the beam energy measurement at VEPP-4M [5]. Since then it has been continuously used by the accelerator physics community to measure beam polarization, also at the most modern synchrotron light sources, see for instance [6-8] and is planned to be used at FCC-ee too [9].

In order to quantitatively investigate the effect of beam polarization on the Touschek lifetime at SuperKEKB we follow the formalism developed in Ref. [9-11], where a flat beam approximation is being used. It is obtained after calculations that the ratio of Touschek lifetimes with and without polarization reads

$$\frac{\tau_T(P=0)}{\tau_T(P)} = 1 + \frac{\langle \hat{F}(\xi) \rangle_s P^2}{\langle \hat{C}(\xi) \rangle_s} \quad (1)$$

Timeline for Touschek Polarization Experiment

Experiment

- Spring-Summer 2024 planning for polarization and prepare formal written proposal for
 - Procurement of source, power supply
 - Laser/laser control system with
 - Wien filter design
 - Assembling and testing
 - Preparation of beamline

- Submit for other experiments
Proceed with Lifetime

Construction and testing

Necessary alterations to beamline and

of calendar 2025

- The US-Japan proposal is for analysis of data taken (along with ongoing magnet work, etc.)

NEED TO REVISIT THIS SCHEDULE IN LIGHT OF OTHER SuperKEKB Developments

Consider installation of source in FY2026

Chiral Belle Related Funding Status

- Need to submit US-Japan application – last one not funded
- US EPSCoR grant program – Louisville+BNL Feb'24 submission led by S. Banerjee to fund final design of the spin-rotator magnets – awaiting decision
- KEK-TRIUMF Exchange Program for Early Career Researchers (*EPECR*)
 - Awarded support for a Canadian PhD student to come to work with Yoshida-san on the source
- Hiroshima (Z. Liptak) research on source development
- France: AAPG - Appel à projets générique - Coordinated by Aurélien Martens
NEWS: that the project has been accepted at the first phase of the submission process. A more detailed proposal must now be prepared for the second phase of the submission process. This must be submitted for the 27 March.
- Canadian Team holds NSERC operating grant: “*The Belle II and Chiral Belle projects*”
- Canadian Team has now submitted application for Chiral Belle equipment: to fund Compton polarimetry electron detector and spin rotator prototype and part of the from Canadian Foundation for Innovation (CFI)
 - CFI requires matching funds (40% CFI, 60% other sources, e.g. Japan, France, US)

Additional Slides

Proposal for Touschek-Polarization Measurements in the SuperKEKB HER

Draft v1: 2 June 2024

Executive Summary

- Chiral Belle is a project proposed to expand the capabilities of SuperKEKB and the physics goals of Belle II by colliding longitudinally polarized electrons with unpolarized positrons
- The physics is accessed by studying asymmetries between the measurements of processes when the electrons are left-handed compared to when the electrons are right-handed.
- The electrons would be injected into the High Energy Ring (HER) as transversely polarized and the spins rotated to longitudinal before the interaction point (IP) and then rotated back to transverse after the IP.
- The polarization is to be measured in real-time using a Compton polarimeter located between the up-stream spin-rotator magnets and the IP.

Proposal for Touschek-Polarization Measurements in the SuperKEKB HER

Draft v1: 2 June 2024

Executive Summary (continued)

- Before proceeding with the full implementation of the construction and installation of the spin rotator magnets near the IP and the Compton polarimeter, we propose a near-term experiment to be conducted at the end of the 2025c running period to demonstrate the ability to inject and transport transversely polarized electrons in the HER and to validate the long term tracking studies that predict long polarization lifetimes in the HER.
- The polarization lifetime is to be determined using the well-established method of measuring the change in the beam's Touschek lifetime when the beam is polarized compared to when the beam is unpolarized.
- This will test the predictions that the polarized spin vectors are maintained around the main ring with long polarization lifetimes, without installing a Compton polarimeter in the HER.
- In a second stage of this Touschek-Polarization project, once we establish that we have stable polarized beams, the impact of e^+e^- collisions on the polarization can also be measured and the beam energy can also be precisely determined via the well-established resonant depolarization method.

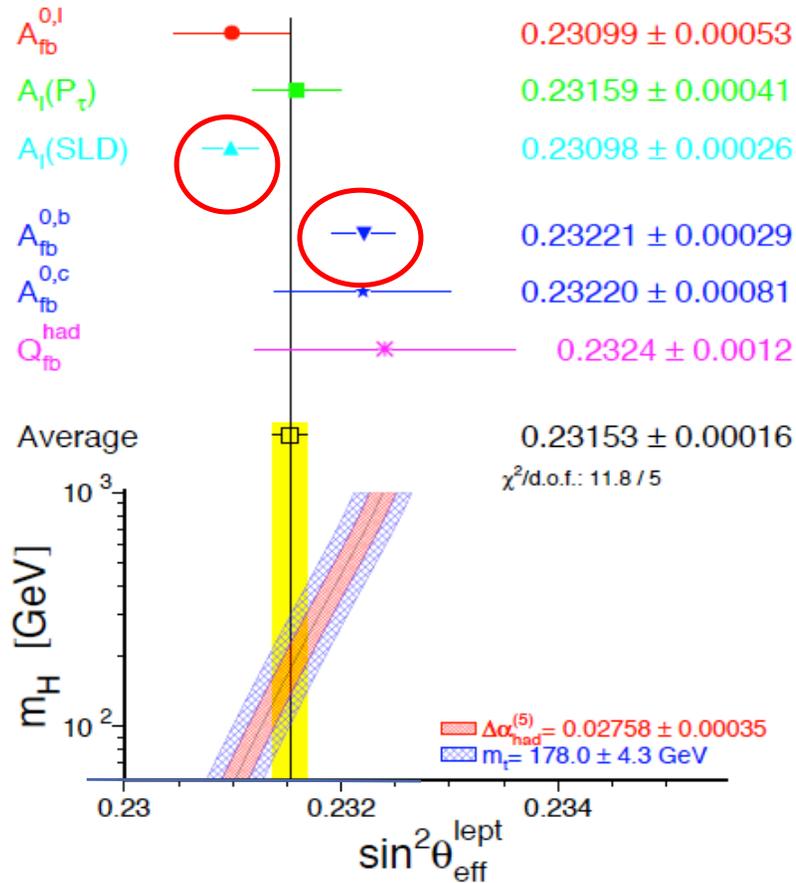
Chiral Belle: Exciting Physics

Very Strong Physics Case:

Unique access to program of precision EW physics ++

- precision $\sin^2\theta_W \pm 0.0002$: same precision as at Z^0 -pole – but at 10GeV
probes the scaling of $\sin^2\theta_W$ & unique probe of dark sector with e, μ , τ , c, b
 - *cf* MOLLER at JLab – electron couplings only; complementary as they are at lower energy
 - $\sin^2\theta_W$ at EIC at BNL in SuperKEKB energy range, but EIC will have lower precision and only for couplings involving 1st generation fermions ($\sigma_{\sin^2\theta_W}$ (EIC) = 0.0012 *cf* 0.0002 @ Chiral Belle)
- Highest precision Z^0 -fermion (neutral current) vector current coupling measurements by many factors for μ , b, c (for e and τ : comparable precision to that at Z^0 -pole)
- Highest precision neutral-current universality measurements by many factors (e.g. b:c universality >14x more precise with 20ab⁻¹ Chiral Belle *cf* World Average)
- Highest precision tau g-2 by many orders of magnitude $\mathcal{O}(10^{-5})$ *cf* $\mathcal{O}(10^{-2})$
- other topics reported in Snowmass Whitepaper

Existing tension in data on the Z-Pole:



Physics Report Vol 427,
Nos 5-6 (2006),
ALEPH, OPAL, L3, DELPHI, SLD

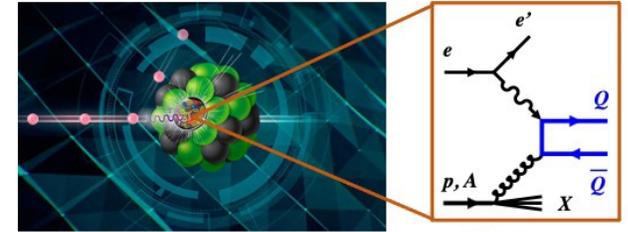
3.2σ comparing only
 A_{LR} (SLC) and $A_{fb}^{0,b}$ (LEP)

Chiral Belle in unique position
to resolve whether this tension
is early sign of e:b universality
violation or a fluctuation

Y. X. Zhao et al.: Neutral Weak Interactions at an EIC

Eur.Phys.J.A 53 (2017) 3, 55

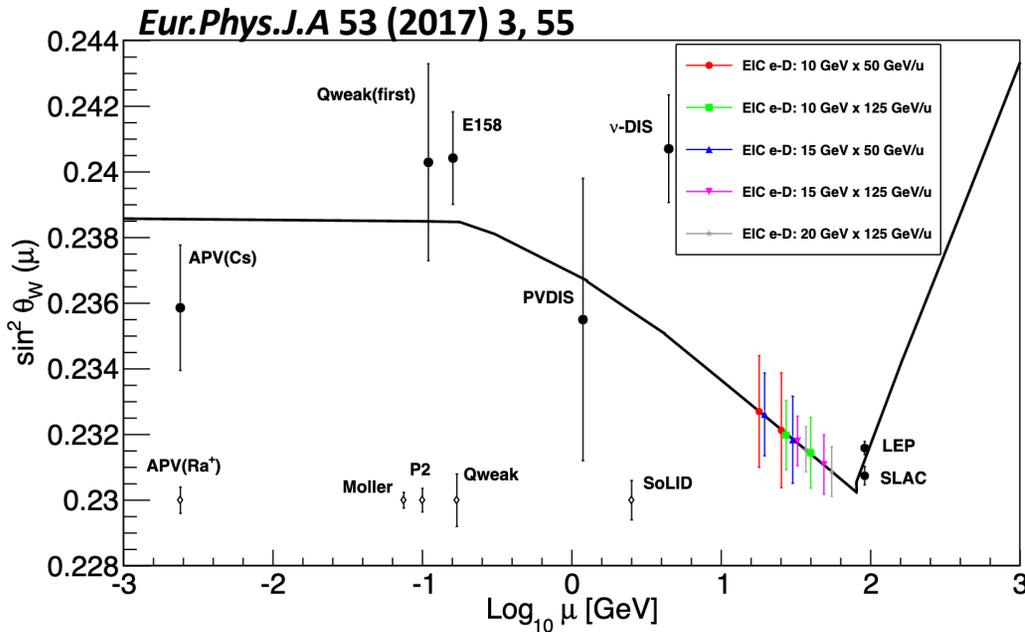
also “Electroweak and BSM physics at the EIC”
talk by Ciprian Gal (Stony Brook)



Opportunities with
Heavy Flavor at the EIC

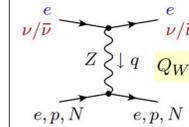


<https://indico.bnl.gov/event/9273/>



Weak mixing angle extractions

Ayres Freitas



$$Q_W(e) = Q_W(p) = 1 - 4 \sin^2 \theta_W$$

$$A_{LR}^{ep} \approx \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha} \left[\frac{F_1^{\gamma Z}}{F_1^\gamma} + (1 - 4 \sin^2 \theta_W) \frac{y(1-y)}{1+(1-y)^2} \frac{F_3^{\gamma Z}}{F_1^\gamma} \right]$$

$$y = 1 - E_e'/E_e$$

Need precise knowledge of PDFs for
100 GeV² < Q² < 5000 GeV²

$$F_1^\gamma = \sum_q q_f (f_q + f_{\bar{q}})$$

$$F_1^{\gamma Z} = \sum_q q_f g_V^f (f_q + f_{\bar{q}})$$

$$F_3^{\gamma Z} = 2 \sum_q q_f g_A^f (f_q - f_{\bar{q}})$$

- Polarized e^- on d for $Q^2 \gg \Lambda_{\text{QCD}}$
- d is iso-singlet \rightarrow PDF dependence approximately cancels in LR asymmetry:
- Assuming valence quark dominance and charge symmetry:

$$f_u \approx f_d,$$

$$f_{\bar{u}} \approx f_{\bar{d}} \approx f_{s,c,b} \approx f_{\bar{s},\bar{c},\bar{b}} \approx 0$$

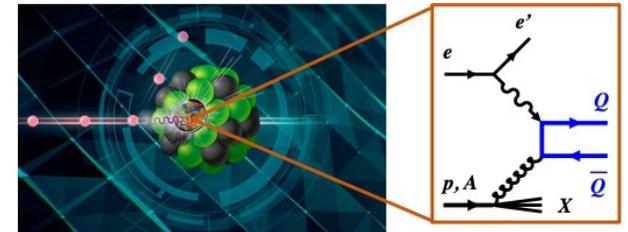
$$A_{LR}^{ep} \approx \frac{G_\mu(-q^2)}{4\sqrt{2}\pi\alpha} \left[\frac{9}{5} - \sin^2 \theta_W + \frac{9}{5} (1 - 4 \sin^2 \theta_W) \frac{y(1-y)}{1+(1-y)^2} \right]$$

- Current studies suggest that PDF uncertainties will be small enough for weak mixing angle extractions to be precisely obtained from ep data

Y. X. Zhao et al.: Neutral Weak Interactions at an EIC

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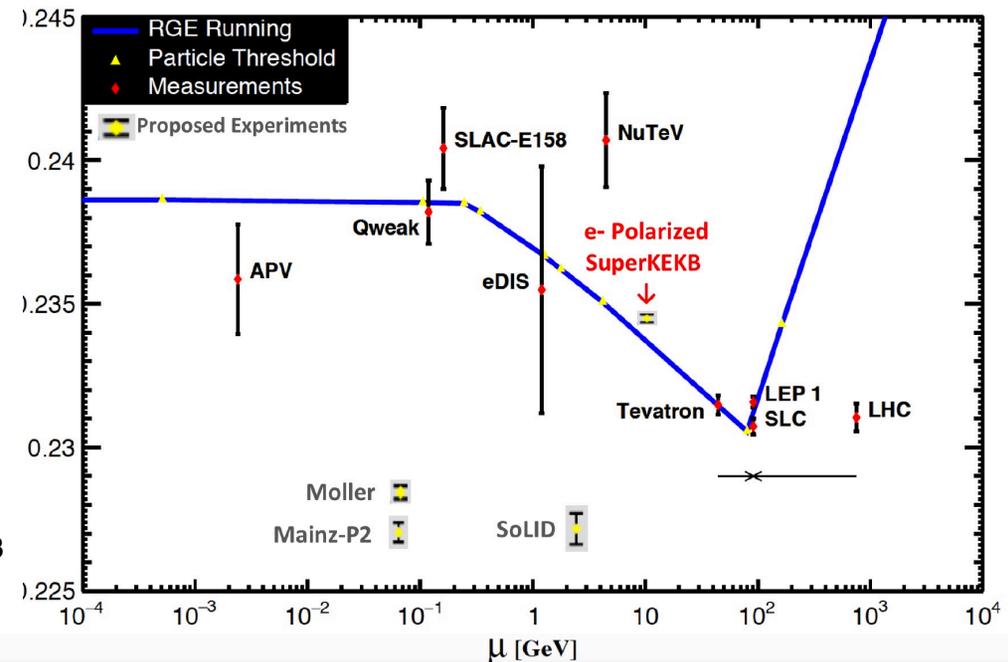
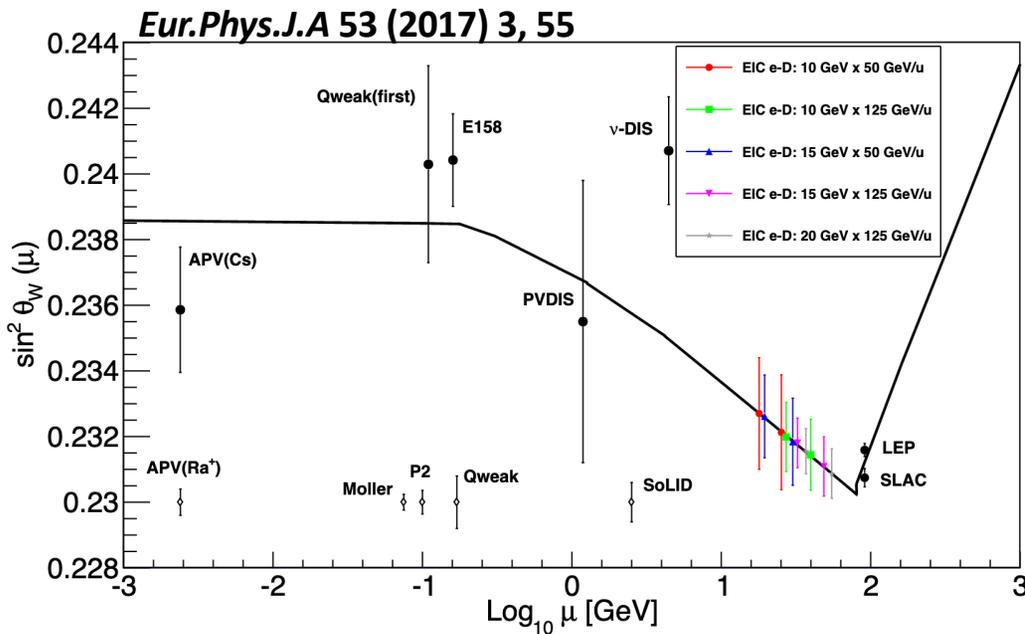
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Opportunities with
Heavy Flavor at the EIC



<https://indico.bnl.gov/event/9273/>



Precision measurement of polarization: Tau Polarimetry Caleb Miller (UVic) presentation this B2GM

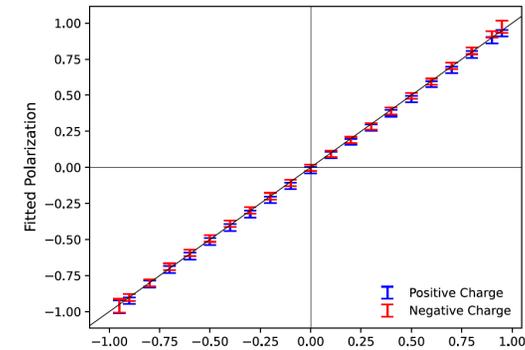
BABAR paper demonstrates that beam polarization can be measured with $0.5ab^{-1}$ to 0.4% at IP with analysis of tau-pair events by exploiting the sensitivity of τ decay kinematics to the longitudinal polarization of the beams

“Precision e^- beam polarimetry at an e^+e^- B factory using tau-pair events” [2308.00774](https://arxiv.org/abs/2308.00774) [hep-ex]

PRD accepted and in-prepress

$$\langle P \rangle = 0.0035 \pm 0.0024_{\text{stat}} \pm 0.0029_{\text{sys}}$$

3 per mil systematic uncertainty
with $0.5ab^{-1}$ of real data



MC sensitivity
validation

TABLE III. Summary of systematic uncertainties associated with the tau polarimetry polarization measurement. The systematic uncertainties are combined across runs, accounting for correlations, to give the ‘Combined’ column and summed in quadrature to arrive at the totals.

Source	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Combined
π^0 efficiency (VII A 1)	0.0025	0.0016	0.0013	0.0018	0.0006	0.0017	0.0013
Muon PID (VII C)	0.0018	0.0018	0.0029	0.0011	0.0006	0.0016	0.0012
Split-off modeling (VII B 1)	0.0015	0.0017	0.0016	0.0006	0.0016	0.0020	0.0011
Neutral energy calibration (VII A 2)	0.0027	0.0012	0.0023	0.0009	0.0014	0.0008	0.0010
π^0 mass (VII B 2)	0.0018	0.0028	0.0010	0.0005	0.0004	0.0004	0.0008
$\cos \alpha$ (VII B 3)	0.0015	0.0009	0.0016	0.0007	0.0005	0.0005	0.0007
π^0 likelihood (VII B 4)	0.0015	0.0009	0.0015	0.0006	0.0003	0.0010	0.0006
Electron PID (VII C)	0.0011	0.0020	0.0008	0.0006	0.0005	0.0001	0.0005
Particle transverse momentum (VII B 5)	0.0012	0.0007	0.0009	0.0002	0.0003	0.0006	0.0004
Boost modeling (VII A 3)	0.0004	0.0019	0.0003	0.0004	0.0004	0.0004	0.0004
Momentum calibration (VII A 4)	0.0001	0.0014	0.0005	0.0002	0.0001	0.0003	0.0004
Max EMC acceptance (VII B 7)	0.0001	0.0011	0.0008	0.0001	0.0002	0.0005	0.0003
τ direction definition (VII A 5)	0.0003	0.0007	0.0008	0.0003	0.0001	0.0004	0.0003
Angular resolution (VII A 6)	0.0003	0.0008	0.0003	0.0003	0.0002	0.0003	0.0003
Background modeling (VII A 7)	0.0005	0.0006	0.0010	0.0002	0.0003	0.0003	0.0003
Event transverse momentum (VII B 6)	0.0001	0.0013	0.0005	0.0002	0.0002	0.0004	0.0003
Momentum resolution (VII A 4)	0.0001	0.0012	0.0004	0.0002	0.0001	0.0005	0.0003
ρ mass acceptance (VII B 8)	0.0000	0.0011	0.0003	0.0001	0.0002	0.0005	0.0003
τ branching fraction (VII A 8)	0.0001	0.0007	0.0004	0.0002	0.0002	0.0002	0.0002
$\cos \theta^*$ acceptance (VII B 9)	0.0002	0.0006	0.0004	0.0001	0.0001	0.0004	0.0002
$\cos \psi$ acceptance (VII B 9)	0.0002	0.0003	0.0002	0.0002	0.0002	0.0003	0.0002
Total	0.0058	0.0062	0.0054	0.0030	0.0026	0.0038	0.0029

(Caleb Miller presentation in this B2GM)

Precision measurement of polarization: Compton Polarimetry - Aurélien Martens (IJCLab) presentation in this B2GM



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Conceptual study of a Compton polarimeter for the upgrade of the SuperKEKB collider with a polarized electron beam

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ABSTRACT: The physics scope of the Belle II experiment currently acquiring data at the SuperKEKB collider will expand with a polarized electron beam upgrade, as recently proposed. Among the required elements for this upgrade, a real time diagnosis of the polarization is necessary to ensure it is large for all bunches in the accelerator during its regular operation. This will be realized by inserting a Compton polarimeter in the accelerator. Its conceptual design is described and no show-stopper for its integration has been identified. An estimation of the sensitivity of the polarimeter is made by means of toy Monte-Carlo studies. The proposed design accounts for the constraint to preserve the performance of the SuperKEKB accelerator and to cope with the short time separation of successive bunches. We show that the polarimeter will measure for each bunch the polarization within five minutes with a statistical precision below 1% and systematic uncertainties below 0.5%. It has the capability of providing this information online on a similar timescale. This work paves the way towards future implementation of real-time Compton polarimetry in several future projects.

KEYWORDS: Accelerator Subsystems and Technologies; Beam-line instrumentation (beam position and profile monitors, beam-intensity monitors, bunch length monitors); Instrumentation for particle accelerators and storage rings - high energy (linear accelerators, synchrotrons)

*Corresponding author.

Table 4. Systematic uncertainties on the extraction of P_z , see text for details. Background modeling and absolute knowledge of the laser polarization dominates.

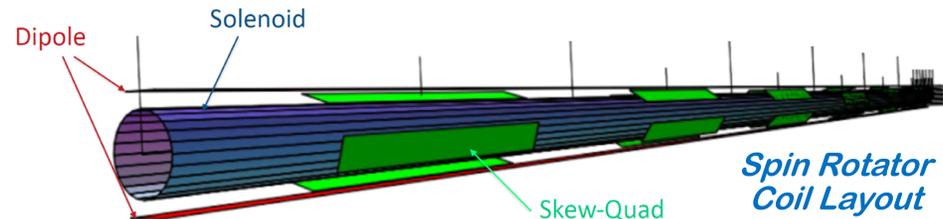
Source	Uncertainty on P_z (%)
Laser beam polarization	0.30
Backgrounds	0.16
Fit procedure	0.080
Beam energy	0.050
Spatial misalignment	0.015
Angular misalignment	0.015
Longitudinal misalignment	0.015
Transverse electron beam polarization	0.015
Total	0.35

Open points

- Systematic uncertainty related to **beam transport** from Compton IP to Belle 2 IP
- **Prototype photon detector** → French National Research Agency call for funding, answer in Spring.
- **Laser synchronization** → possible solution found with relevant KEKB expert, relevant tests may be performed in the coming year at IJCLab and then possibly at KEK on longer timescale.

2023 JINST 18 P10014

Compact spin rotator



Follows Uli Wienands's (Argonne National Laboratory) idea and direction:

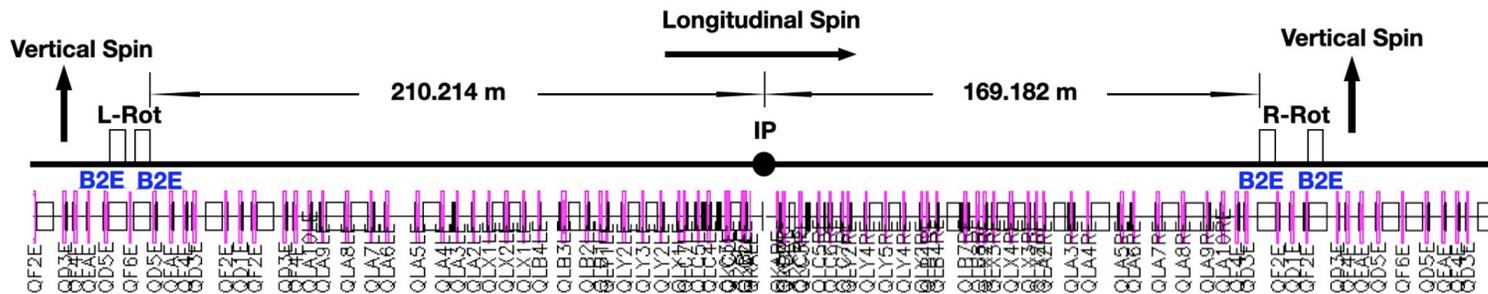
- Replace some existing ring dipoles on both sides of the IP with the dipole-solenoid combined function magnets and keep the original dipole strength to preserve the machine geometry
- Avoids repositioning of other magnets in the ring
- Install 6 skew-quadrupole on top of each rotator section to compensate for the x-y plane coupling caused by solenoids

Original machine can be recovered by turning off solenoid and skew-quadrupole fields + retune with only the dipoles

(BNL expertise in construction of direct wind magnets suitable for these magnets)

Compact spin rotator

Work by Y. Peng (UVic)



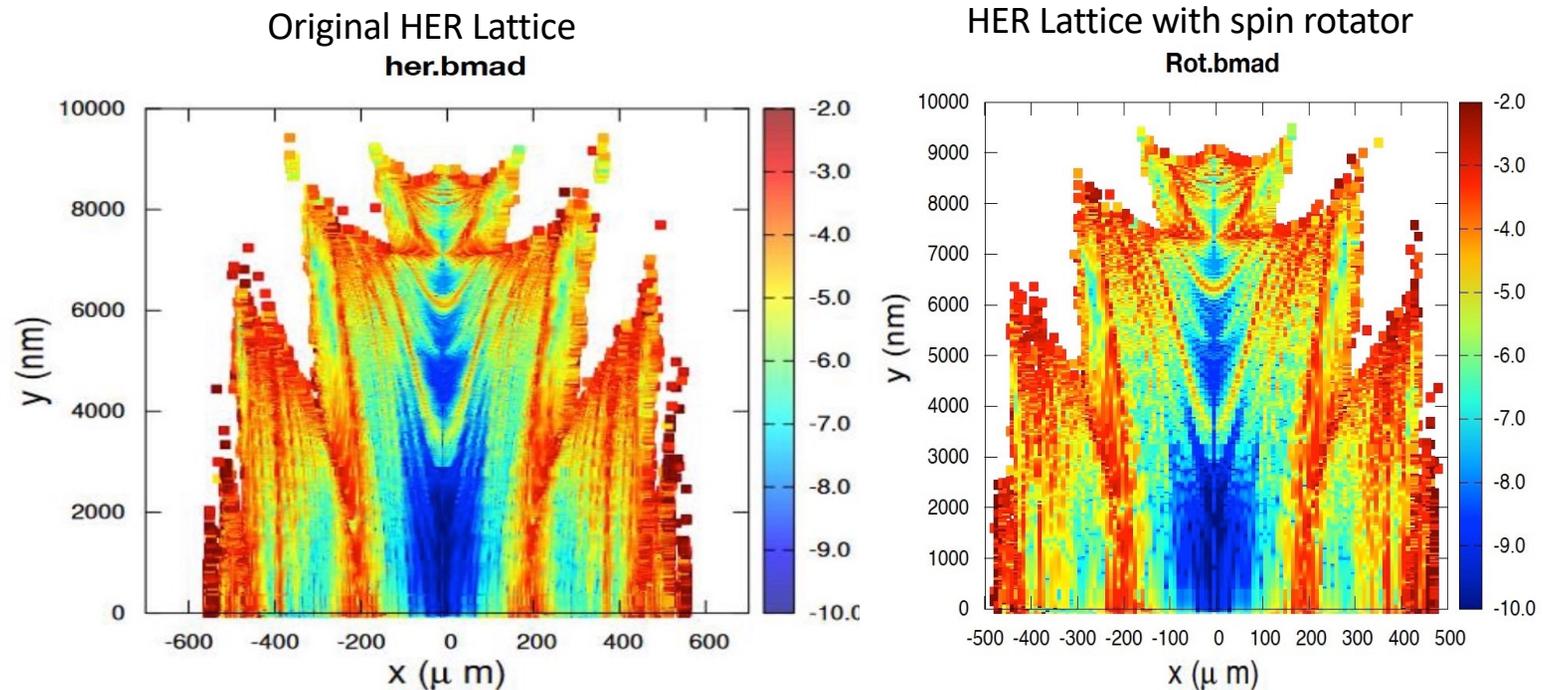
- Left Rotator (L-Rot) rotates the spin from the vertical to the horizontal plane
- Right Rotator (R-Rot) rotates the spin back to the vertical direction
- 4 **B2E** dipoles (using SAD lattice naming convention for HER) shown above to be replaced with the spin rotator magnets

Compact spin rotator

Initial Frequency Map Analysis (FMA)

dynamic aperture studies using BMAD – show no large changes

work by Noah Tessema (UVic)



Compact spin rotator

Long Term Tracking(LTT): Explores *non-linear* features with radiation damping and radiation fluctuations/quantum excitation

Noah Tessema (UVic) working with Uli Wienands (ANL) used BMAD's LTT to study Peng-Wienand spin rotator solution after improving the dipole model in BMAD deployed for these compact magnets

Status of these LLT studies :

- With compact spin rotators, beam is stable (5 million turns with 20 particles – no lost particles)
- HER energy of 7.035 GeV (0.4% [i.e.+28MeV] higher than default energy) has polarization lifetime of ~25 minutes (~10 top-up times)
 - Will continue to use LLT to probe lifetime vs energy to find energy that maximizes polarization lifetime
- Spin tune studies show fractional tune is ~0.1, well away from integer or half-integer

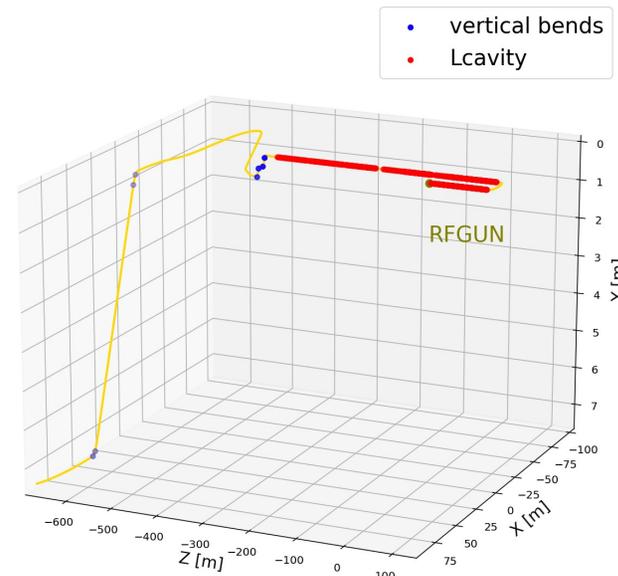
(Noah Tessema)

KEK Injection Linac polarization BMAD studies

Y. Peng's (UVictoria)



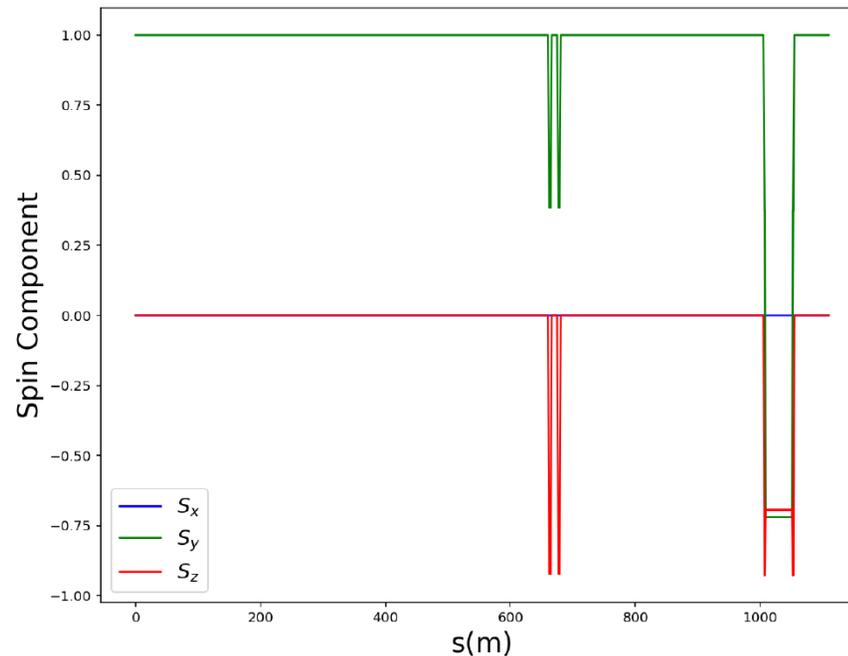
KEK Linac



Need transversely polarized beam at the injection point of the e- storage ring (High Energy Ring -HER)

Spin motion in the KEK Injection Linac

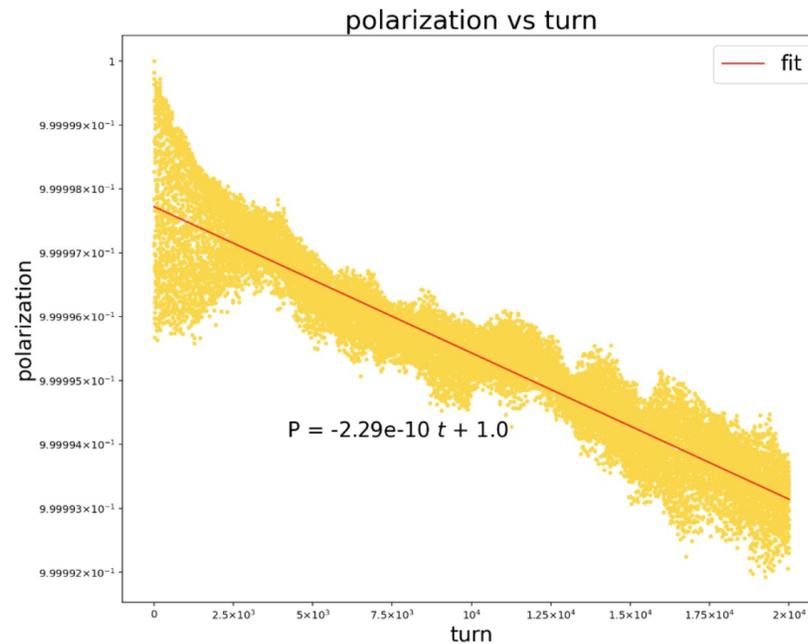
Y. Peng's (UVictoria)



These spin tracking using BMAD show if the electron starts with vertical spin (0,1,0) at the source, after all the vertical beam motion, it will end up with a vertical spin at the injection point, as desired.

Transverse polarization survival rate in HER

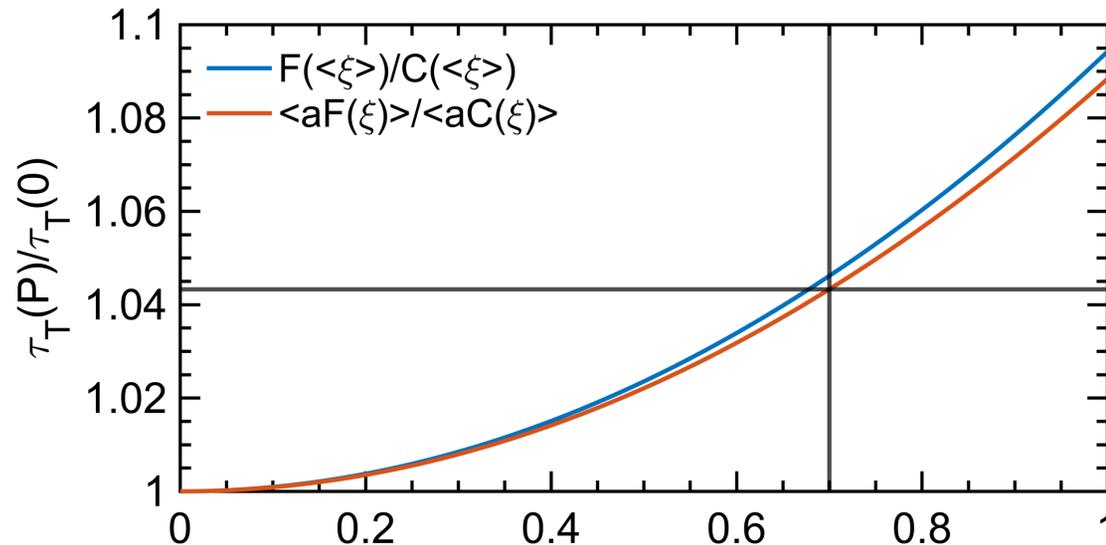
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- Tracking 100 particles for 20000 turns in the HER with BMAD
- This study estimates polarization lifetime > 10 hours

For SuperKEKB

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Andrii Natochii (BNL) Presentation this B2GM

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(see Andrii Natochii presentation in this B2GM)

A Touschek polarimeter for SuperKEKB

A. Martens, F. Mawas, A. Natochii, M. Roney, D. Zhou, ...
Institute name in English, Town, Country

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1 Introduction

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This document is organized as follows. First we introduce the dependence of the Touschek lifetime as a function of beam polarization. We investigate its impact for the SuperKEKB ring. In a second section, we investigate the present status of Touschek lifetime measurements in the SuperKEKB ring that are presently made in the context of beam background diagnostics for the Belle II experiment. We finally list the needs for a meaningful polarization measurement at SuperKEKB.

2 Touschek lifetime and polarization

Touschek described the lifetime of electrons in AdA (accumulation ring) in 1963 [2], as a result of Moeller scattering in between electrons of a beam in a ring. Right after, Baier and Khoze pointed out that the Touschek lifetime is sensitive to polarization [3]. It was then used in the VEPP-2M ring to measure depolarization, and in turn the beam energy, by measuring the counting rate of scattered electrons [4]. It allowed to realize a first precision mass measurement of the J/Psi, that was continuously improved until it reached a few parts per million accuracy on the beam energy measurement at VEPP-4M [5]. Since then it has been continuously used by the accelerator physics community to measure beam polarization, also at the most modern synchrotron light sources, see for instance [6-8] and is planned to be used at FCC-ee too [9].

In order to quantitatively investigate the effect of beam polarization on the Touschek lifetime at SuperKEKB we follow the formalism developed in Ref. [9-11], where a flat beam approximation is being used. It is obtained after calculations that the ratio of Touschek lifetimes with and without polarization reads

$$\frac{\tau_T(P=0)}{\tau_T(P)} = 1 + \frac{\langle \hat{F}(\xi) \rangle_s P^2}{\langle \hat{C}(\xi) \rangle_s} \quad (1)$$