Touscheck Polarization Experiment Discussion

University of Victoria

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

Timeline for Touschek Polarization Experiment

- Spring-Summer 2024 planning for polarized source development and prepare formal written proposal for:
    - Procurement of source, power supply etc
    - Laser/laser control system with polarizer etc.
    - Wien filter design
    - Assembling and testing before installation; use Mott polarimeter in test setup
    - Preparation of infrastructure to couple into LINAC and related alterations to the beamline
- Submit formal written proposal for EB approval to proceed with other formalities to move the Touschek-Polarization Lifetime Experiment forward
- By summer 2025: Complete design, construction and testing outside source room
- Summer 2025: perform necessary alterations to beamline and install
- Perform runs at end of calendar 2025
- Final year of the US-Japan proposal is for analysis of data taken in this run (along with ongoing magnet work, etc.)

Timeline for Touschek Polarization Experiment

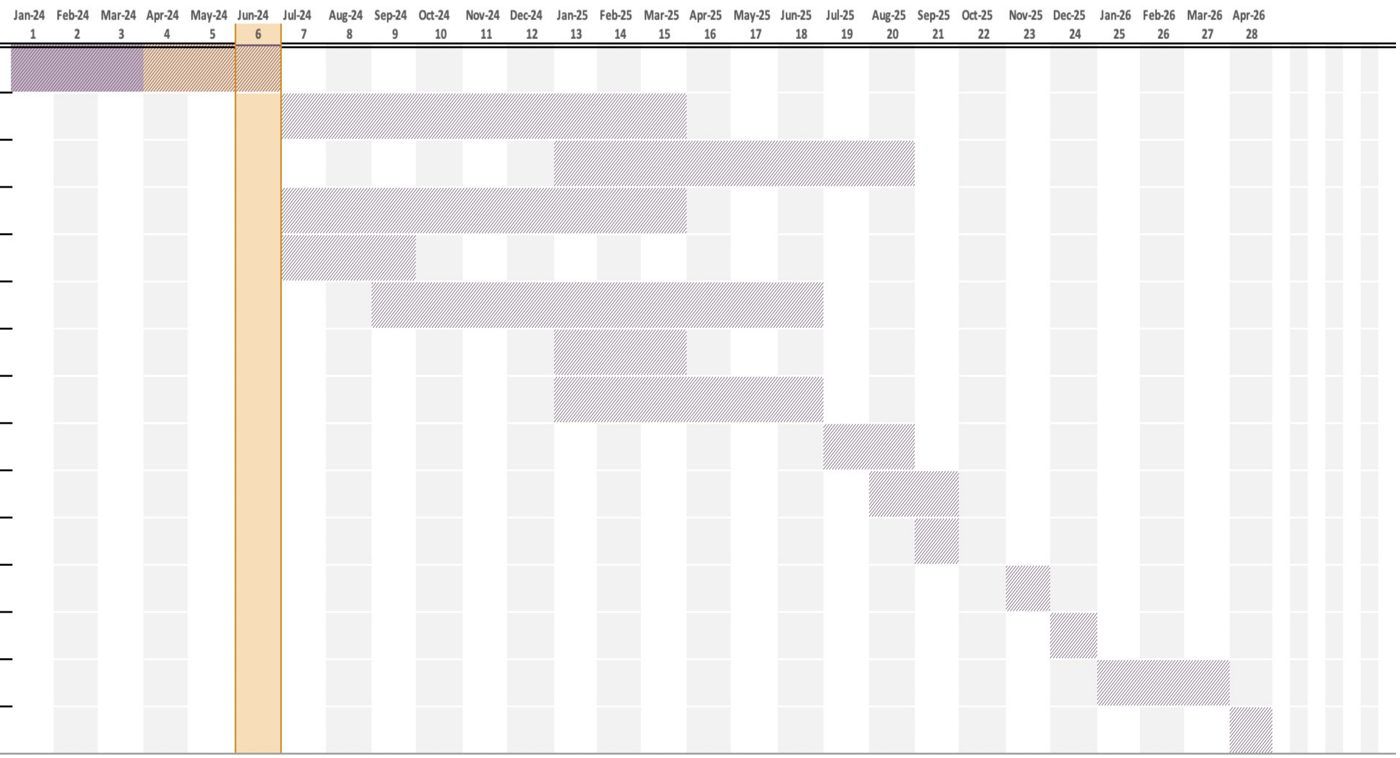
Touschek-Polarization Lifetime Project (Draft v1)

Select a period to highlight at right. A legend describing the charting follows.

Period Highlight: 6

Plan Duration | Actual Start | % Complete | Actual (beyond plan) | % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Proposal with US-Japan	1	3	1	6	0%
Procure pulsed gun + power supply	7	9	0	0	0%
Laser+ control system with polarizer	13	8	0	0	0%
Wien filter design&construction, same as Nagoya	7	9	0	0	0%
Acquire Mott polarimeter	7	3	0	0	0%
Assembling and testing Source in lab	9	10	0	0	0%
Plan alterations to source room	13	3	0	0	0%
Prepare infrastructure to couple to LINAC outside source room	13	6	0	0	0%
Prepare source room	19	2	0	0	0%
Install in source room	20	2	0	0	0%
Complete alterations to couple source to LINAC	21	1	0	0	0%
Collect Touschek Lifetime data in dedicated run w/o polarized beam	23	1	0	0	0%
Measure Touschek Lifetime w/ Transversely Polarized Data	24	1	0	0	0%
Analyse data	25	3	0	0	0%
Publish Toushek Polarization results	28	2	0	0	0%



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 - 2024 (phase 1 submission, Coordinated by Aurélien Martens submitted in Mar'24)
- Canadian Team holds NSERC operating grant:"*The Belle II and Chiral Belle projects"*
- Canadian Team has started the process of applying for Chiral Belle equipment:

  to fund spin rotator components and part of the

  Compton polarimeter from Canadian Foundation for Innovation (CFI)
  - CFI requires matching funds (40% CFI, 60% other sources, e.g. Japan, France, US)

  If successful, it would provide funding starting in ~2028+

Additional Slides

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.

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

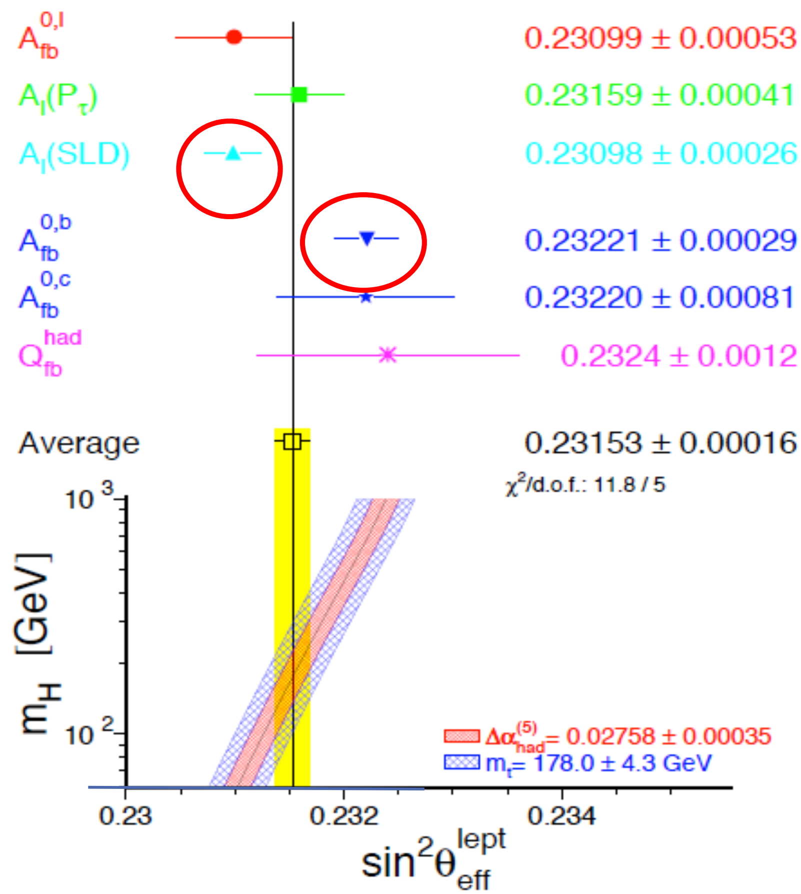
Very Strong Physics Case:

Unique access to program of precision EW physics ++

- precision $\sin^2\theta_W$ ±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:



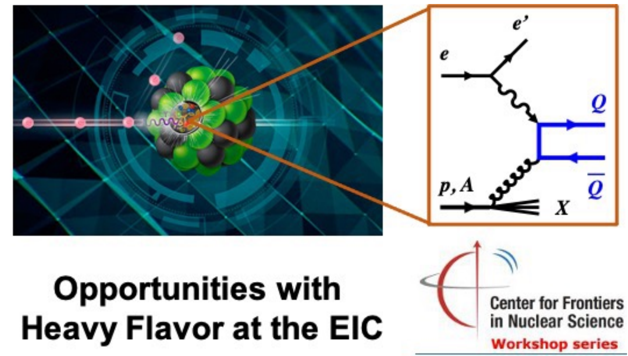
Physics Report Vol 427,
Nos 5-6 (2006),
ALEPH, OPAL, L3, DELPHI, SLD

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

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

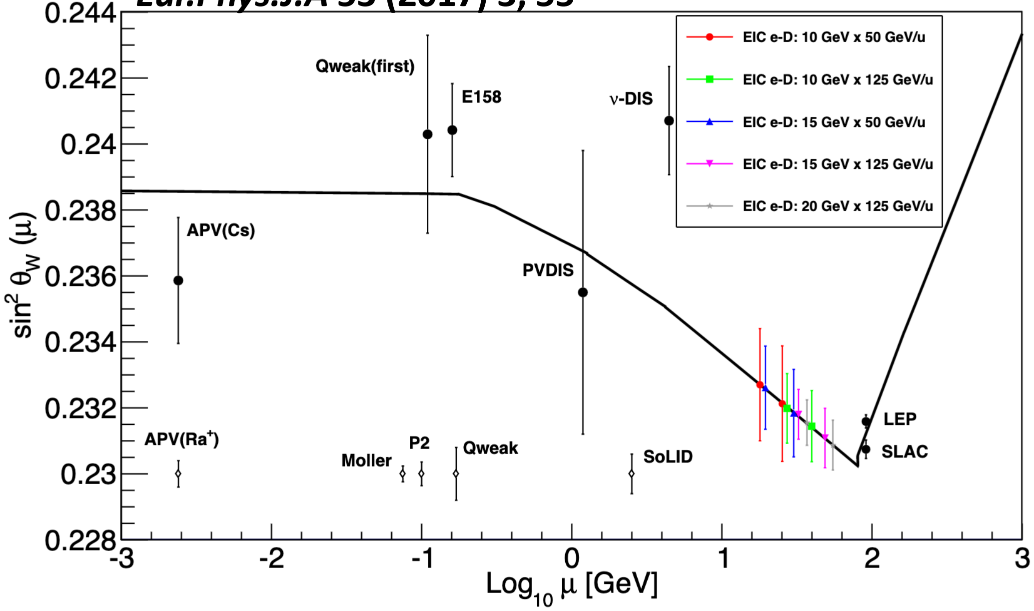
Y. X. Zhao et al.: Neutral Weak Interactions at an EIC
Eur.Phys.J.A 53 (2017) 3, 55

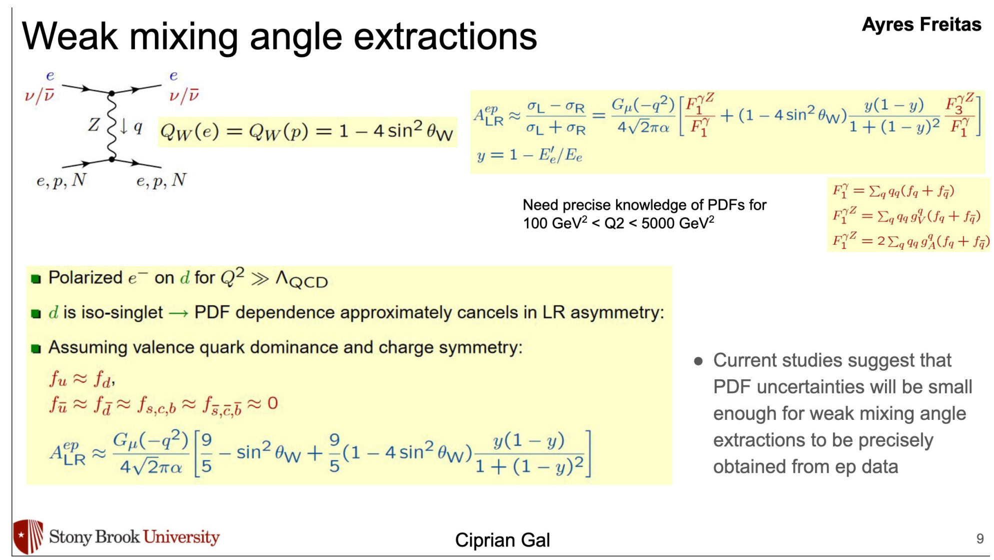
also "Electroweak and BSM physics at the EIC" talk by Ciprian Gal (Stony Brook)



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

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





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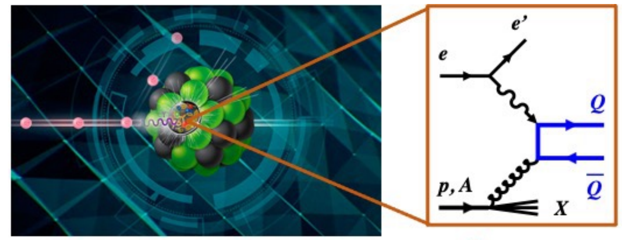
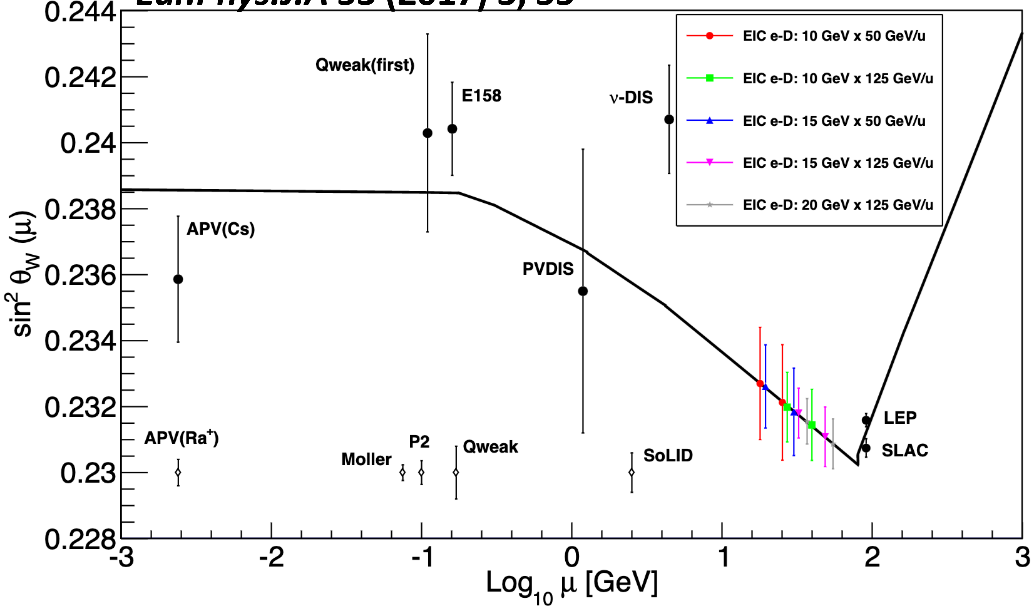


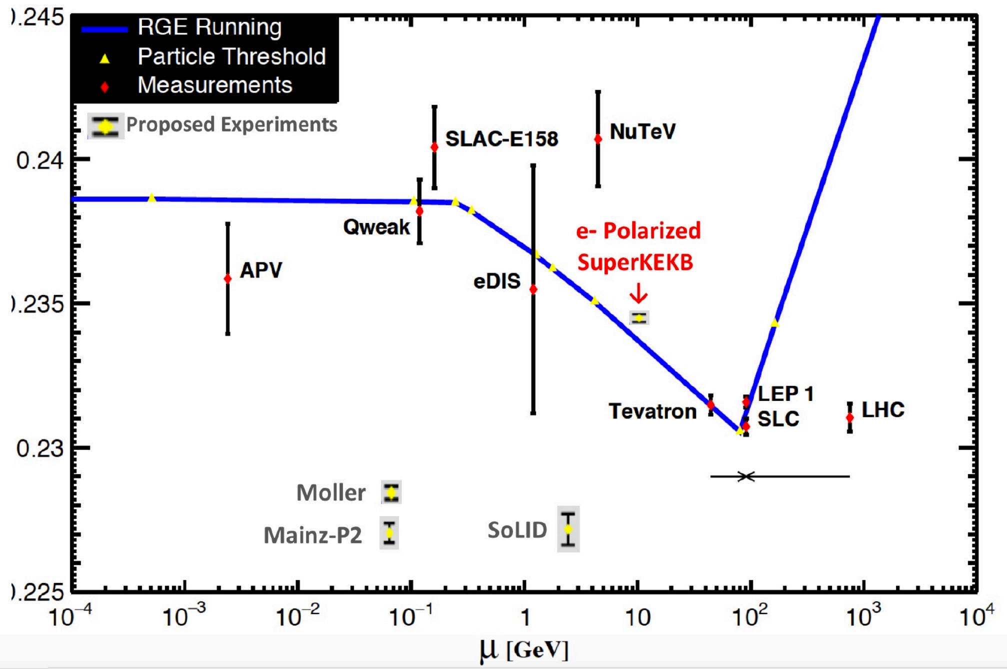
Opportunities with Heavy Flavor at the EIC

Center for Frontiers in Nuclear Science Workshop series

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

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





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

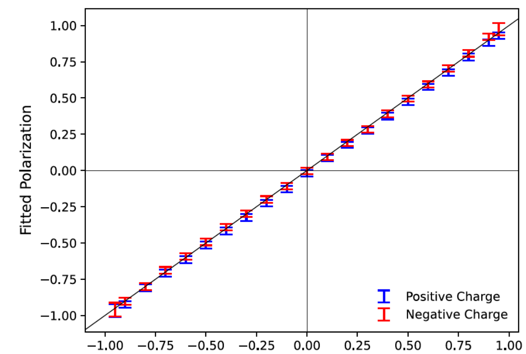
BaBar paper demonstrates that beam polarization can be measured with $0.5ab^{-1}$ to 0.4% at IP with analysis of tau-pair events by exploiting the sensitivity of τ decay kinematics to the longitudinal polarization of the beams

"Precision e^- beam polarimetry at an e^+e^- B factory using tau-pair events" 2308.00774 [hep-ex]

PRD accepted and in-press

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

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**
$\cos\theta^\star$ 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)

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2023 JINST 18 P10014

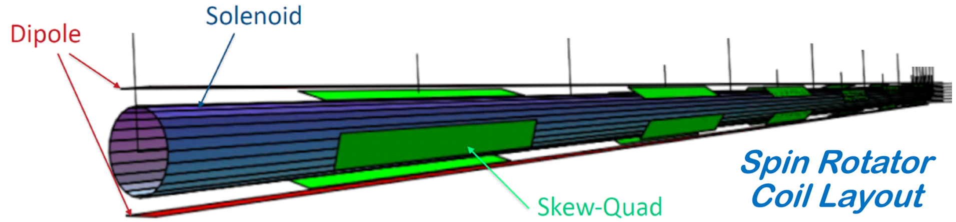
Table 4. Systematic uncertainties on the extraction of P_z, see text for details. Background modeling and absolute knowledge of the laser polarization dominates.

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.

Compact spin rotator



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

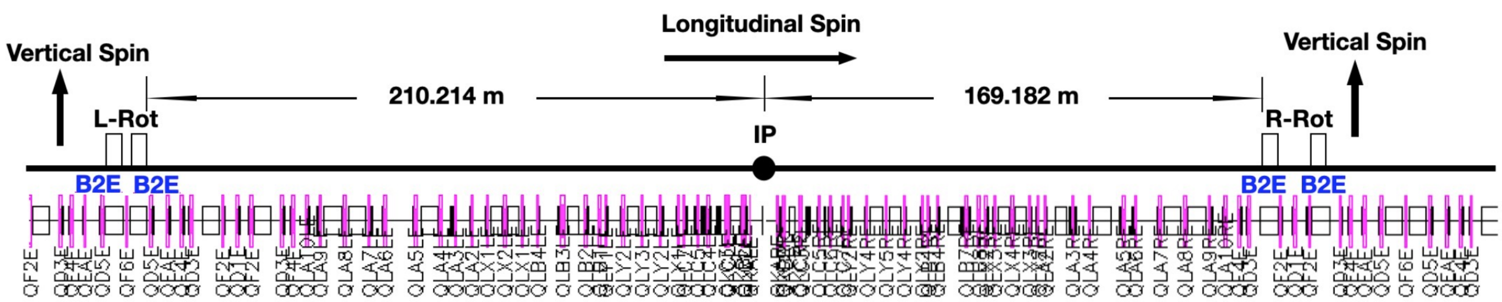
- Replace some existing ring dipoles on both sides of the IP with the dipole-solenoid combined function magnets and keep the original dipole strength to preserve the machine geometry
- Avoids repositioning of other magnets in the ring
- Install 6 skew-quadruple on top of each rotator section to compensate 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)



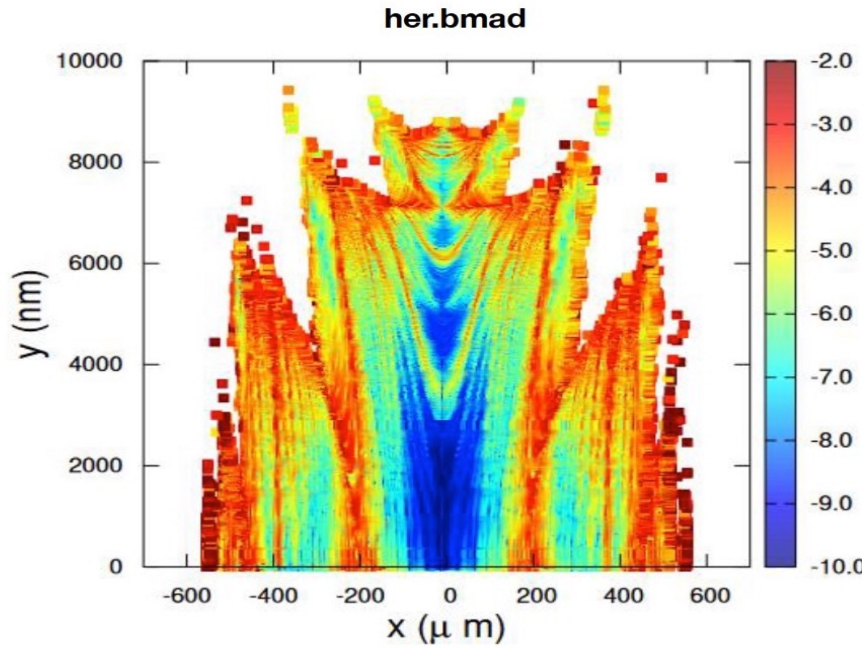
- Left Rotator (L-Rot) rotates the spin from the vertical to the horizontal plane
- Right Rotator (R-Rot) rotates the spin back to the vertical direction
- 4 **B2E** dipoles (using SAD lattice naming convention for HER) shown above to be replaced with the spin rotator magnets

Compact spin rotator

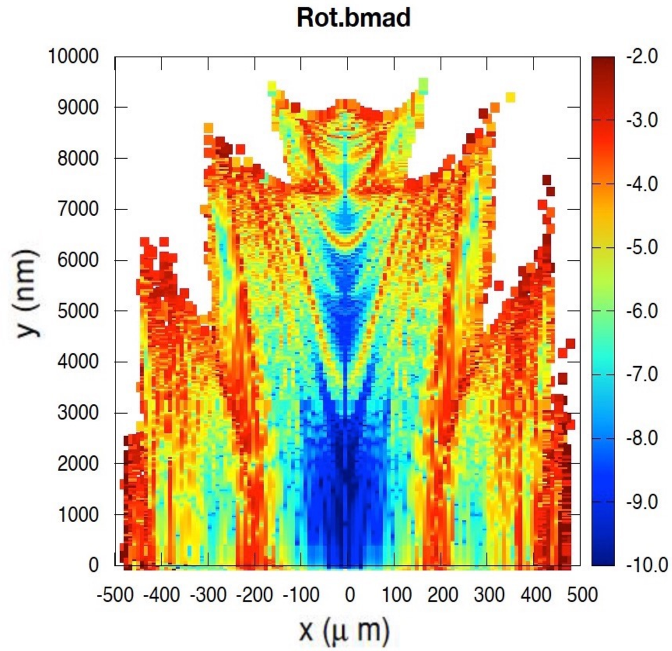
Initial Frequency Map Analysis (FMA)
dynamic aperture studies using BMAD – show no large changes

work by Noah Tessema (UVic)

Original HER Lattice



HER Lattice with spin rotator



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

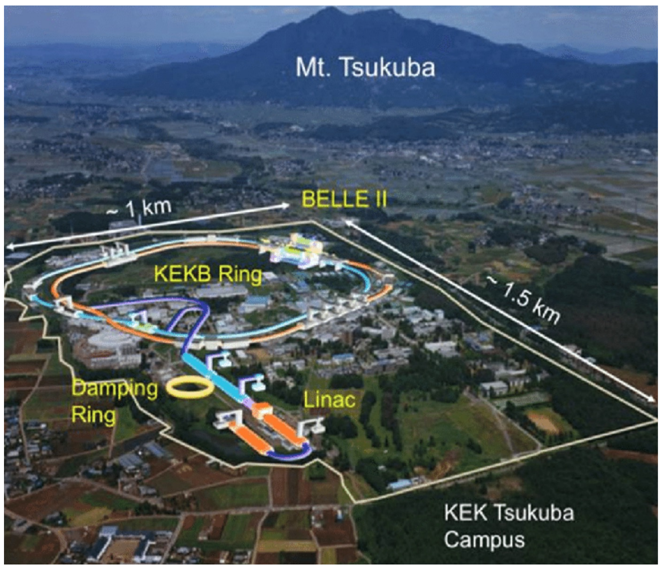
Status of these LLT studies :

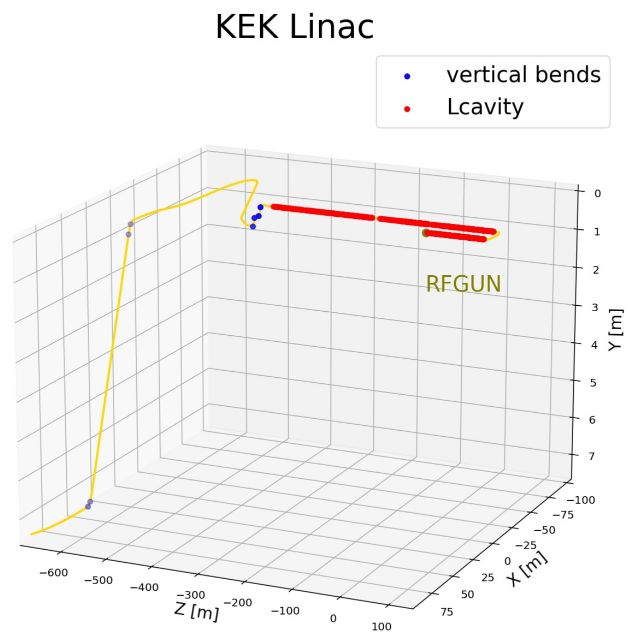
- With compact spin rotators, beam is stable (5 million turns with 20 particles – no lost particles)
- HER energy of 7.035 GeV (0.4% [i.e.+28MeV] higher than default energy) has polarization lifetime of ~25 minutes (~10 top-up times)
  - Will continue to use LLT to probe lifetime vs energy to find energy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

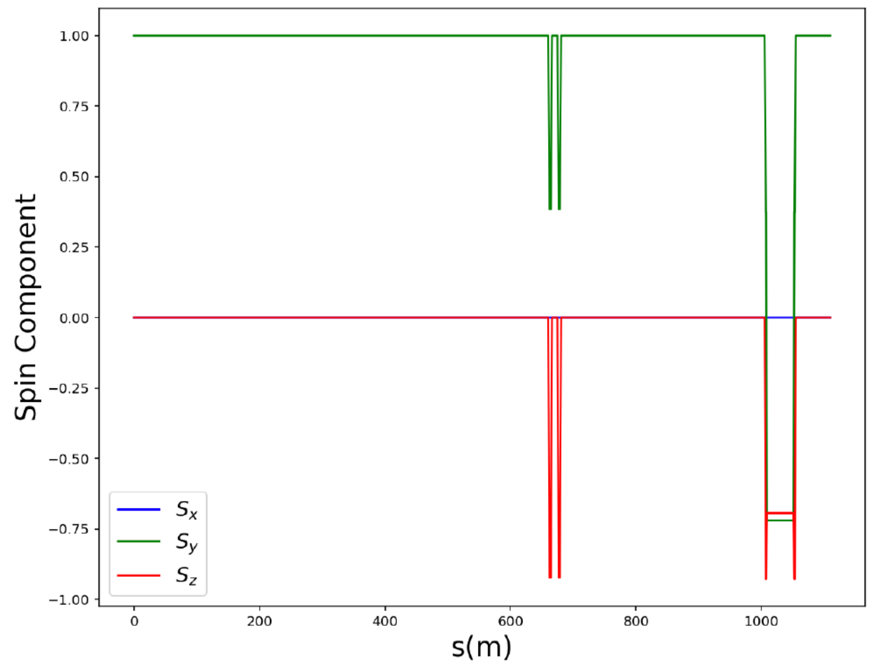




Need transversely polarized beam at the injection point of the e- storage ring (High Energy Ring -HER)

Spin motion in the KEK Injection Linac

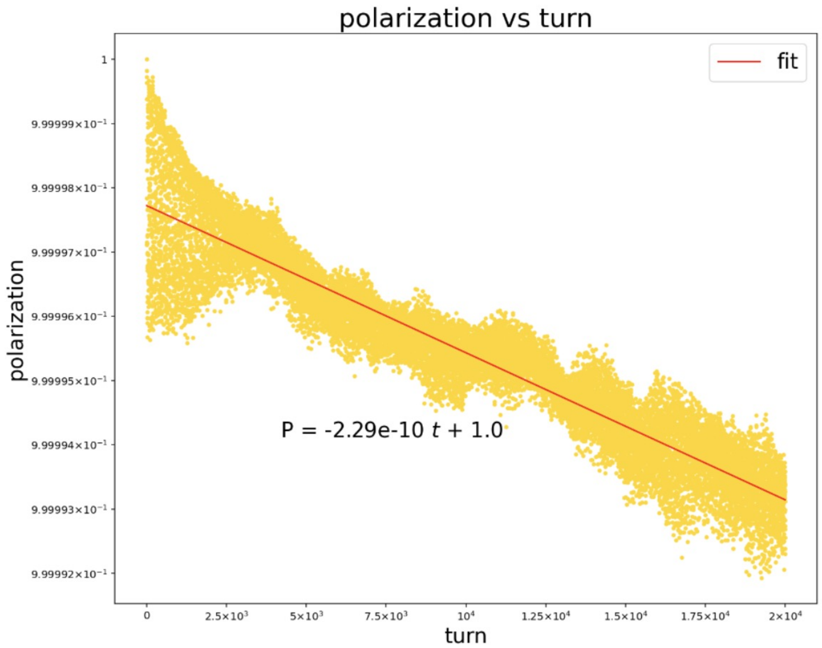
Y. Peng's (UVictoria)



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

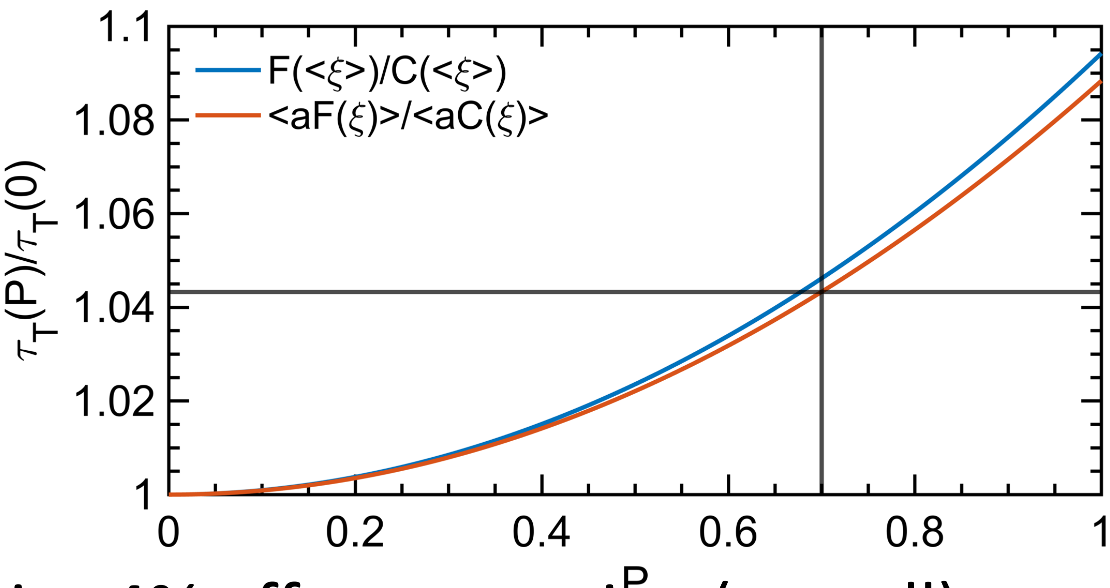
Y. Peng's (UVictoria)



- 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 ~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
June2021	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

$$\frac{\tau_T(P=0)}{\tau_T(P)} = 1 + \frac{< \tilde{F}(\xi) >_s}{< \tilde{C}(\xi) >_s} P^2, \qquad (1)$$