Chiral Belle: Polarized e^- Beam Upgrade for SuperKEKB

Michael Roney

BPAC Meeting

February 2024

Chiral Belle:
A Unique Opportunity for New Physics Discoveries

SuperKEKB's HIGH LUMINOSITY drives the rich research program of Belle II and getting to the design luminosity is our highest priority

FORTUITOUSLY, SuperKEKB's HIGH LUMINOSITY also enables an entirely new, rich and unique way to probe new physics when we POLARIZE THE ELECTRONS BEAM

Chiral Belle Physics Program

Unique New Physics Probe into Dark Sector via Precision measurement of weak mixing angle @ 10GeV

6x precision of BNL's EIC

Going beyond muon g-2 Measured at BNL & FERMILAB:

Tau g-2

100x more precise than can be reached elsewhere

Worlds Highest Precision Weak Neutral Current Measurements with μ, c and b

Many times more precise than World Average of CERN & SLAC measurements

Avoids LHC hadronization uncertainties

Worlds Highest Precision Weak Neutral Current Universality Measurements with e, μ, τ, c and b many times more precise than CERN & SLAC measurements

Polarization in SuperKEKB

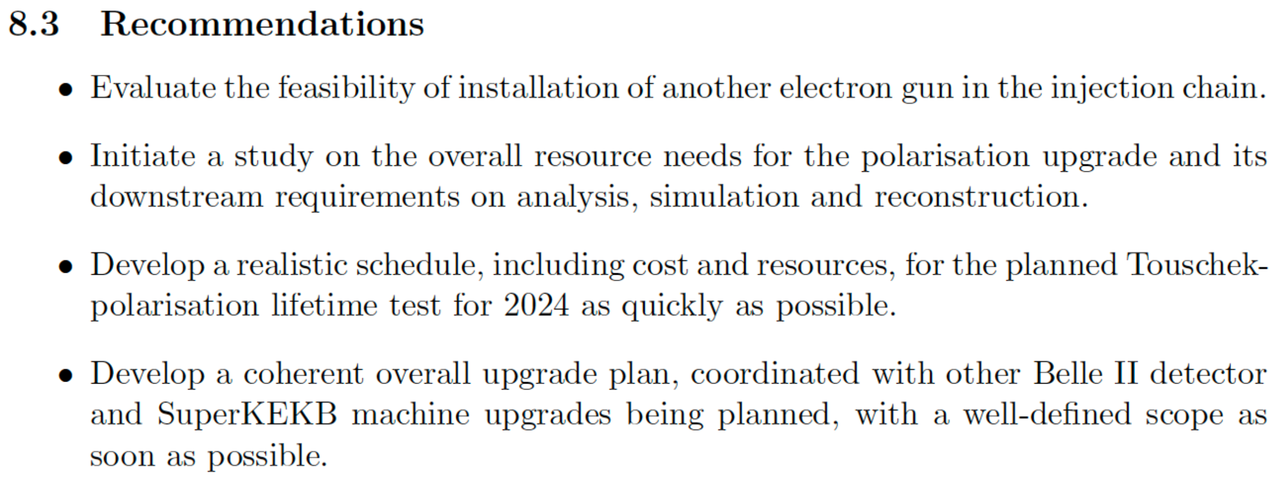
- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment) producing longitudinal electron spins at source
- Electron helicity would be changed for trains of bunches by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject transversely (vertically) polarized electrons into the High Energy Ring (HER) - needs spin rotator just after photocathode source, e.g. Wien Filter
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields – **requires Spin Rotators**
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry
- Use tau decays to get absolute average polarization at IP

e- Beam Polarization Upgrade in SuperKEKB

- Requires high SuperKEKB luminosity AND e- beam polarization
- Source R&D highly synergistic with other international efforts, e.g. EIC
- Requires spin rotators in HER that do not reduce the luminosity (i.e. transparent to the lattice) – high luminosity is required for Chiral Belle
- Requires Precision measurement of polarization (0.005 precision needed)

BPAC Recommendations

From Report of
Oct 2023
BPAC meeting



8.3 Recommendations

- Evaluate the feasibility of installation of another electron gun in the injection chain.
- Initiate a study on the overall resource needs for the polarisation upgrade and its downstream requirements on analysis, simulation and reconstruction.
- Develop a realistic schedule, including cost and resources, for the planned Touschek-polarisation lifetime test for 2024 as quickly as possible.
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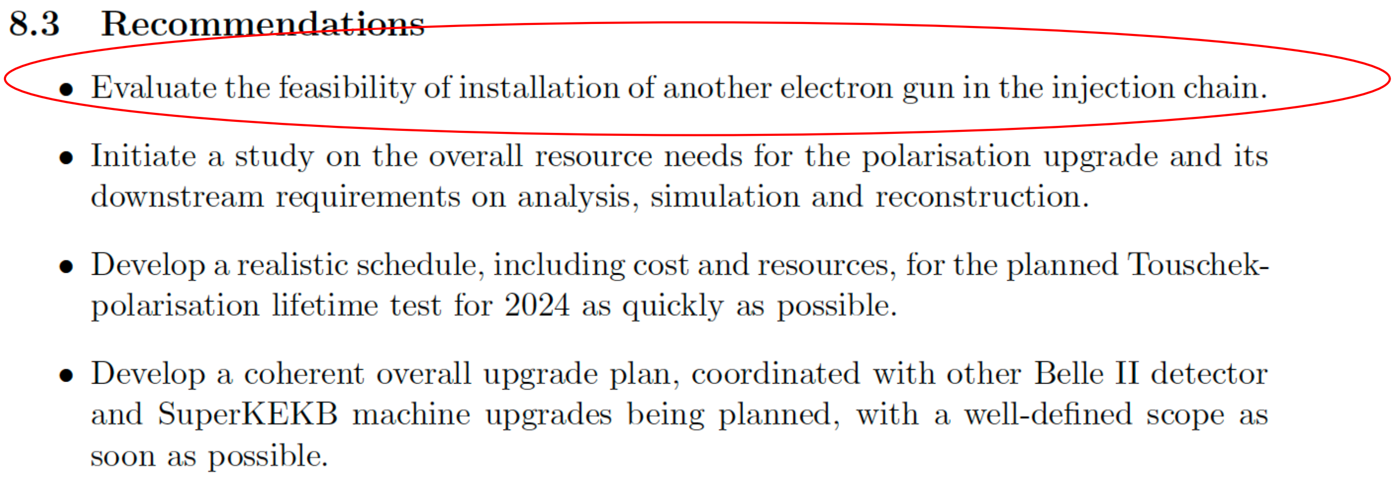

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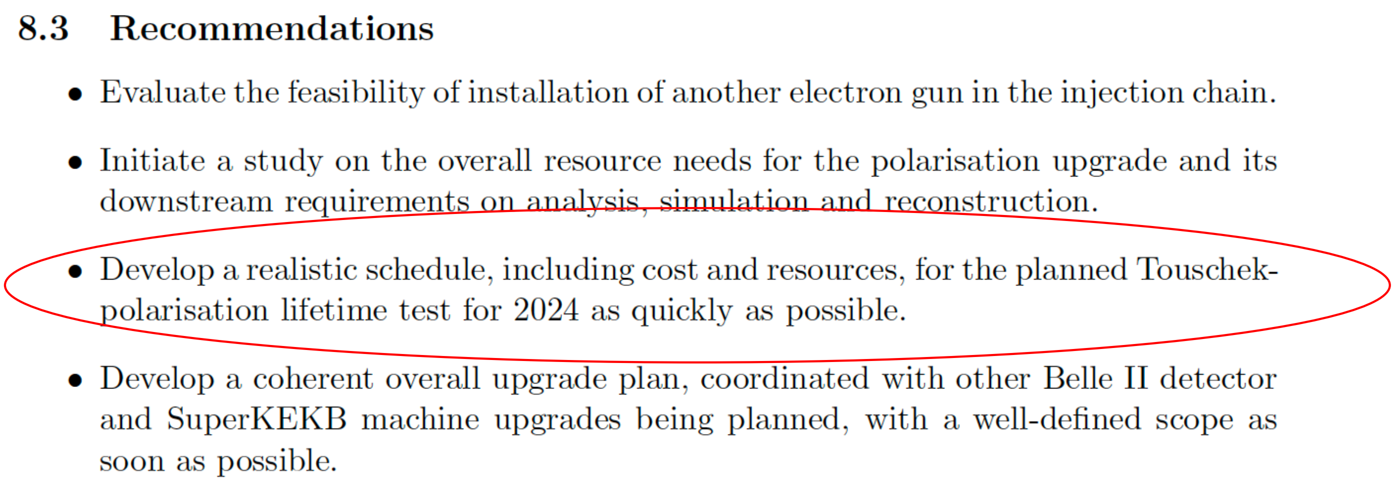

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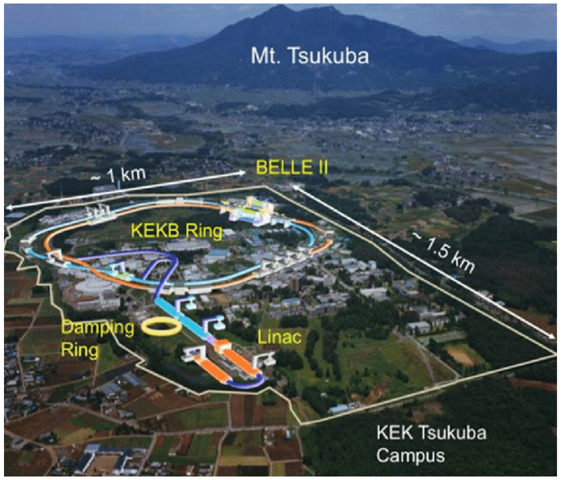
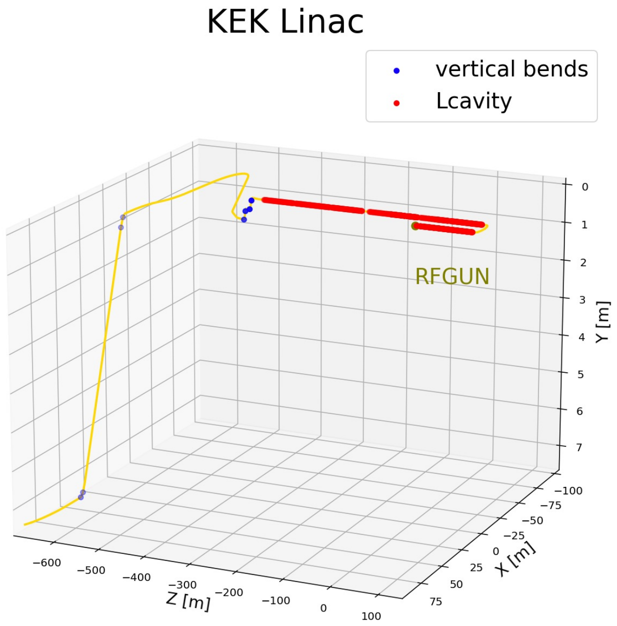
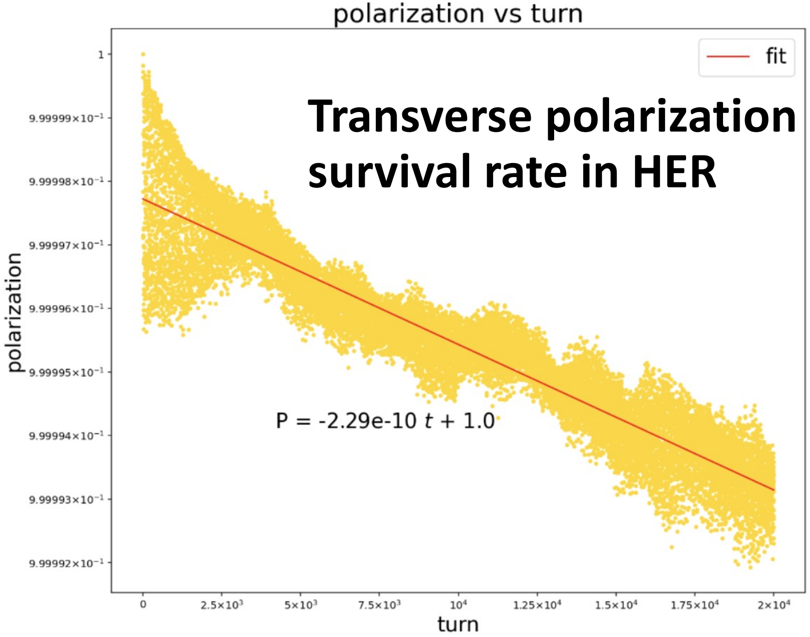
KEK Injection Linac polarization BMAD studies

Inject transversely polarized beam at the HER injection point





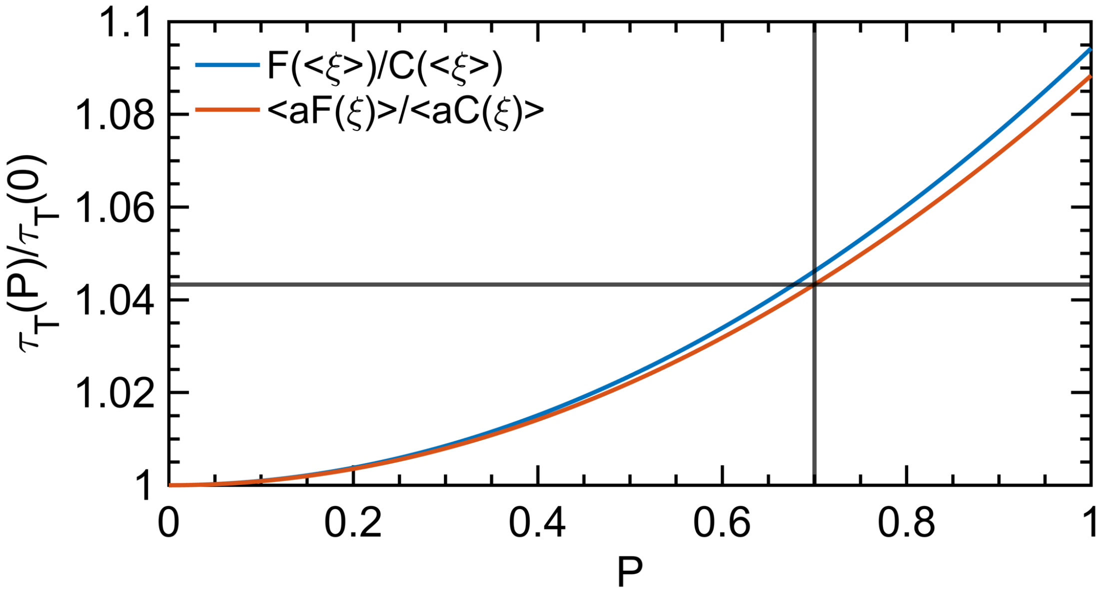
Y. Peng's (UVictoria)



Transverse polarization survival rate in HER

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

For SuperKEKB



For 70% polarization this is a ~4% effect assuming (overall) momentum acceptance of 0.6%

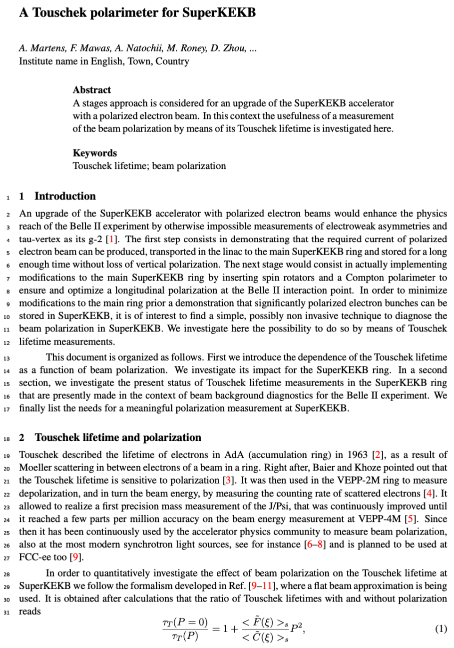
[Aurélien Martens (IJCLab) presentation in Feb 2023 B2GM and described in current draft of Chiral Belle CDR]

Touschek Lifetime Studies

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

Period	Experimental Touschek Lifetime (minutes)
May 2020	37.929 ± 0.057 (0.15%)
June 2020	33.656 ± 0.064 (0.19%)
June2021	27.93 ± 0.10. (0.36%)
December 2021	24.107 ± 0.079 (0.33%)

[Andrii Natochii (BNL) presentation in Oct 2023 B2GM and described in current draft of Chiral Belle CDR]



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

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

Engagement of KEK Accelerator Team

Presented
at EB last week

- Met with Zhanguo Zong, Ohuchi-san and Masuzawa-san on 26 Oct 2023 following the last EB meeting (Karim Trabelsi, Aurelien Martin and Michael Roney)
  - KEK team expressed interest in the Touschek Polarization Measurement Experiment proposal & put us in touch with Ego-san, Linac head
- Met with Ego-san Nov 22 (Karim Trabelsi and Zachary Liptak in person, Michael Roney called in)
- Yoshida-san assigned to & working with us, as he is in charge of the electron guns of the Linac
  - He signed this years' related US-Japan request and prepared content for it
- Zhanguo Zong is KEK PI for related US-Japan request

Timeline for Touschek Polarization Experiment

- Winter-Spring 2023/24: Submit proposal to US-Japan committee.
    - US-Japan Submission includes request for funds at KEK for Touschek Polarization Experiment; funds at BNL for spin rotator R&D; and modest funds at Hiroshima for further source R&D
    - Hearing will be in early March this year – preparing for this now
- Spring-Summer 2024 complete planning & start work on polarized source;

  prepare formal written proposal for Touschek Polarization Experiment
    - Procurement of source (possibly existing DC gun), DC 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
- Before summer 2025: Complete 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.)

Touschek Polarization Experiment Status

- Spring 2024 complete planning for polarized source development and prepare formal written proposal for:
    - Procurement of source (possibly existing DC gun), DC 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

- Yoshida-san proposing use of pulsed DC gun – put together over summer 2024
- Will engage the Nagoya group who have a Mott polarimeter
- PhD student coming to KEK to work as part of Yoshida-san team on testing of polarized source in test setup: autumn 2024-spring 2025

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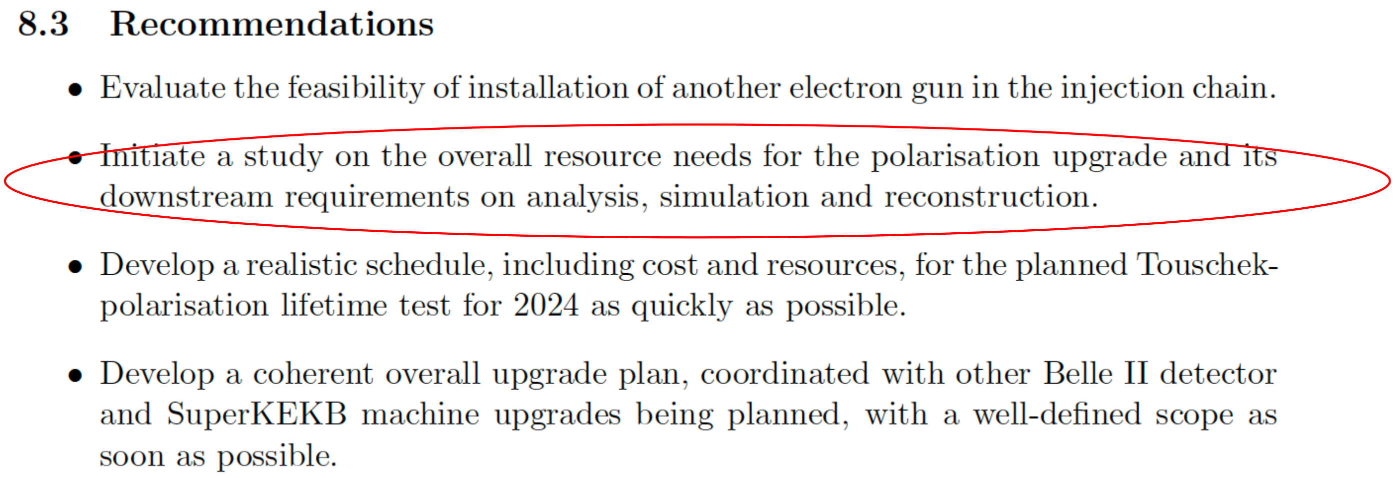

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Some clarifications

Running with polarized e- beams will have a negligible impact on the downstream resource requirements of the collaboration:

Belle II is used ‘as is’: identical reconstruction and processing – and all polarization data will be used for conventional Belle II analyses

The data size does not change, apart from adding per-event information indicating whether the colliding e- beam of the event is nominally left-handed, right-handed or unpolarized

The MC samples do not significantly change since, apart from tau-pairs, the e- polarization does not have an impact on the event kinematics

Some clarifications

For the tau-pairs, we will generate left-handed and right-handed samples as this is needed to measure the beam polarization

- BaBar has done this and published the results on tau beam polarimetry last year – clear demonstration that it will have a negligible impact on the downstream resources

Note: Chiral Belle has attracted new members into Belle II with interest in this new precision neutral current electroweak program

→ this has already been a net gain of personnel into the collaboration.

Bottom line: The demands on the downstream resources are essentially no different than any other physics analysis of Belle II data

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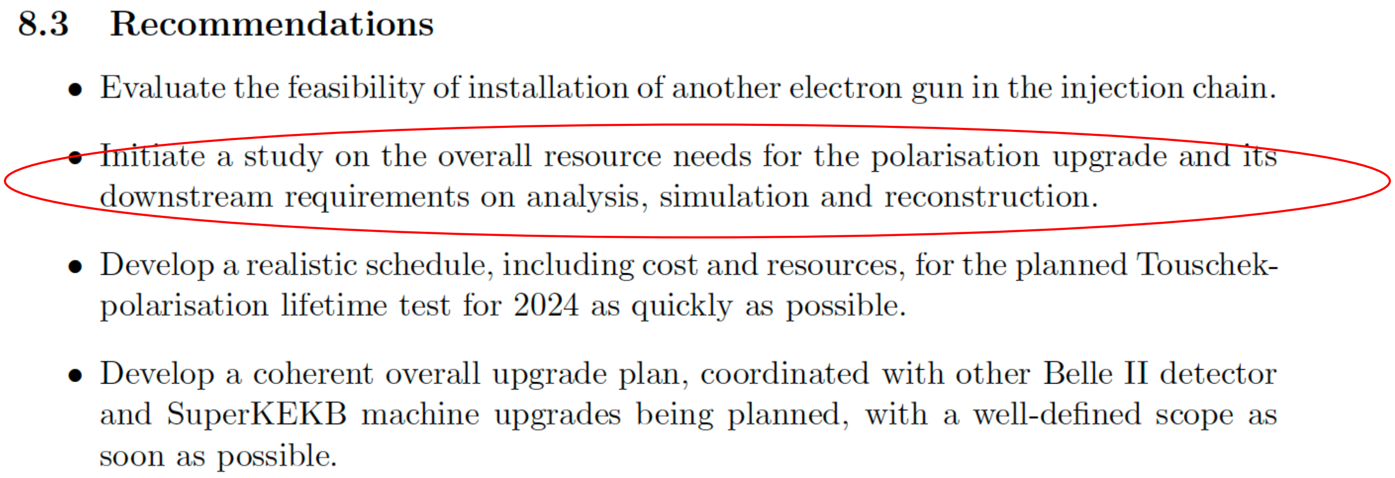

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Determining upstream requirements are in progress and focus of this year's US-Japan request

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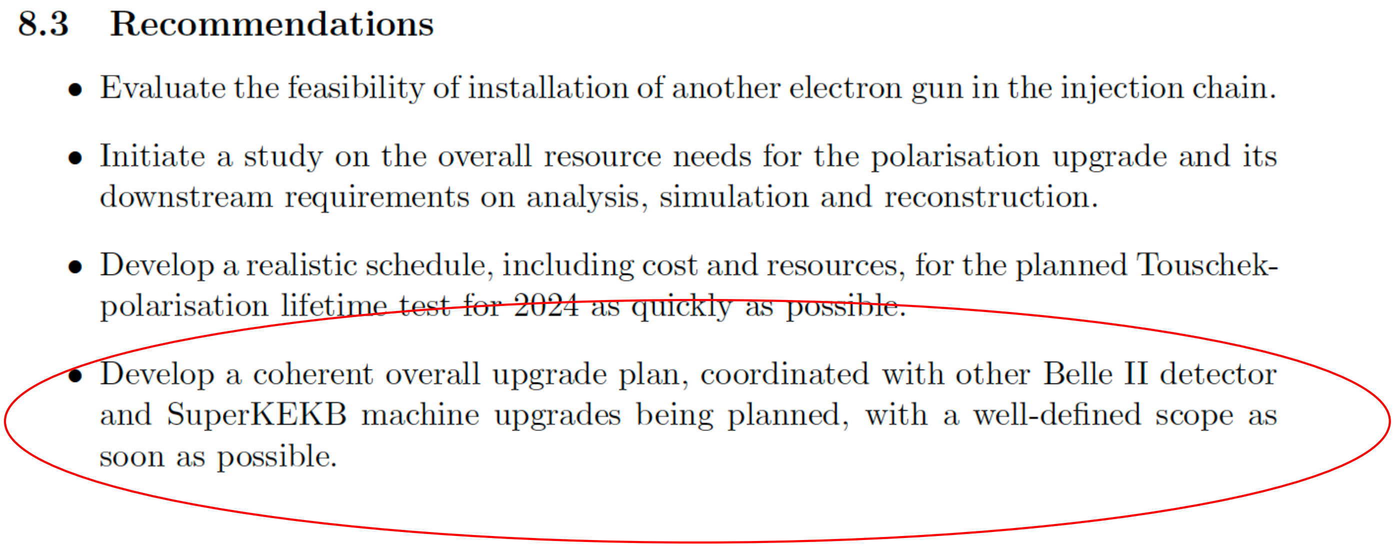

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Will take this into account in Chiral Belle CDR

Note that any changes to the HER lattice planned for LS2 must be incorporated into new polarization studies,
As these are not known at this time, the plan is to keep up with any changes as they occur in order to stay in sync.

Staging of Chiral Belle Precision electroweak measurements

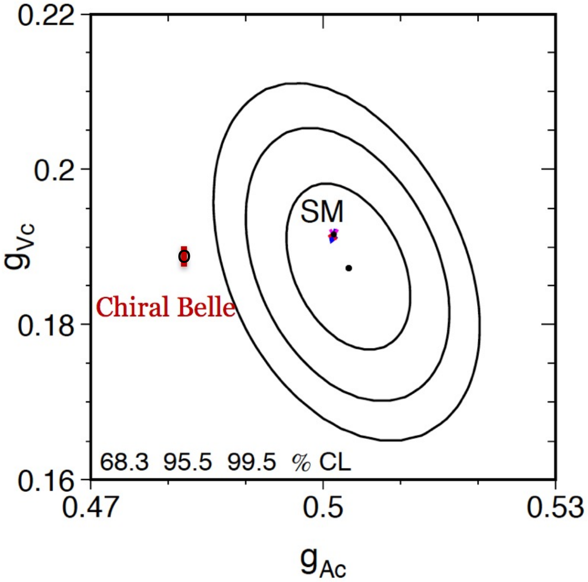
Fermion	g_V^f (SM)	g_V^f (WorldAve)	$\sigma(g_V^f)$ **Chiral Belle 0.5ab^{-1}**	$\sigma(g_V^f)$ **Chiral Belle 1ab^{-1}**	$\sigma(g_V^f)$ **Chiral Belle 5ab^{-1}**	$\sigma(g_V^f)$ **Chiral Belle 10ab^{-1}**
b-quark	-0.3437 ± 0.0001	-0.3220 ± 0.0077	0.0026 3x improvement over WA	0.0022	0.0018	0.0018 3x improvement over WA
c-quark	0.1920 ± 0.0002	0.1873 ± 0.0070	0.005	0.0036 2x improvement over WA	0.0018	0.0014 5x improvement over WA
Tau	-0.0371 ± 0.0003	-0.0366 ± 0.0010	0.0069	0.0049	0.0022	0.0015
Muon	-0.0371 ± 0.0003	-0.03667 ± 0.0023	0.0043	0.0031	0.0014	0.0010 2x improvement over WA
Electron	-0.0371 ± 0.0003	-0.03816 ± 0.00047	0.0055	0.0039	0.0017	0.0012

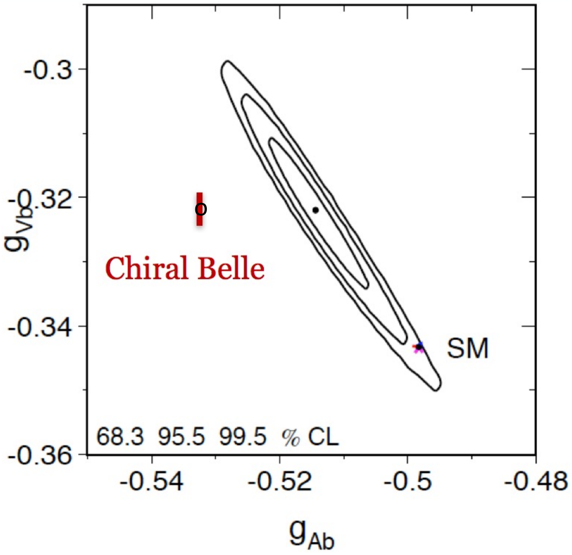
Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

c-quark:
Chiral Belle ~7 times more precise

b-quark:
Chiral Belle ~4 times more precise

with 20 ab^{-1}



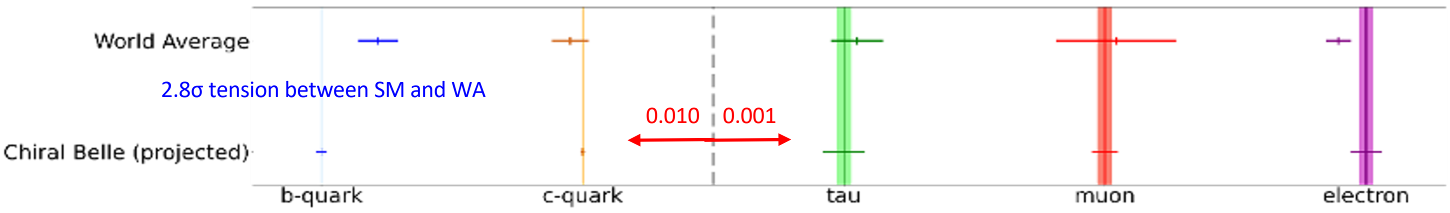


Chiral Belle probes both high and low energy scales

Chiral Belle Precision electroweak measurements

Fermion	g_V^f (Standard Model)	g_V^f (World Average)	$\sigma(g_V^f)$ **(Chiral Belle 40ab^{-1})**
b-quark	-0.3437 ± 0.0001	-0.3220 ± 0.0077	0.0020 (4 x improvement)
c-quark	0.1920 ± 0.0002	0.1873 ± 0.0070	0.0010 (7 x improvement)
Tau	-0.0371 ± 0.0003	-0.0366 ± 0.0010	0.0008
Muon	-0.0371 ± 0.0003	-0.03667 ± 0.0023	0.0005 (4 x improvement)
Electron	-0.0371 ± 0.0003	-0.03816 ± 0.00047	0.0006

Combined analysis (assuming universality) : $\sigma(g_V^f) = 0.00033_{stat} \pm 0.00018_{sys}$ [*cf.* SM error of ±0.0003]



2.8σ tension between SM and WA

0.010 | 0.001

More physics in Additional Material…

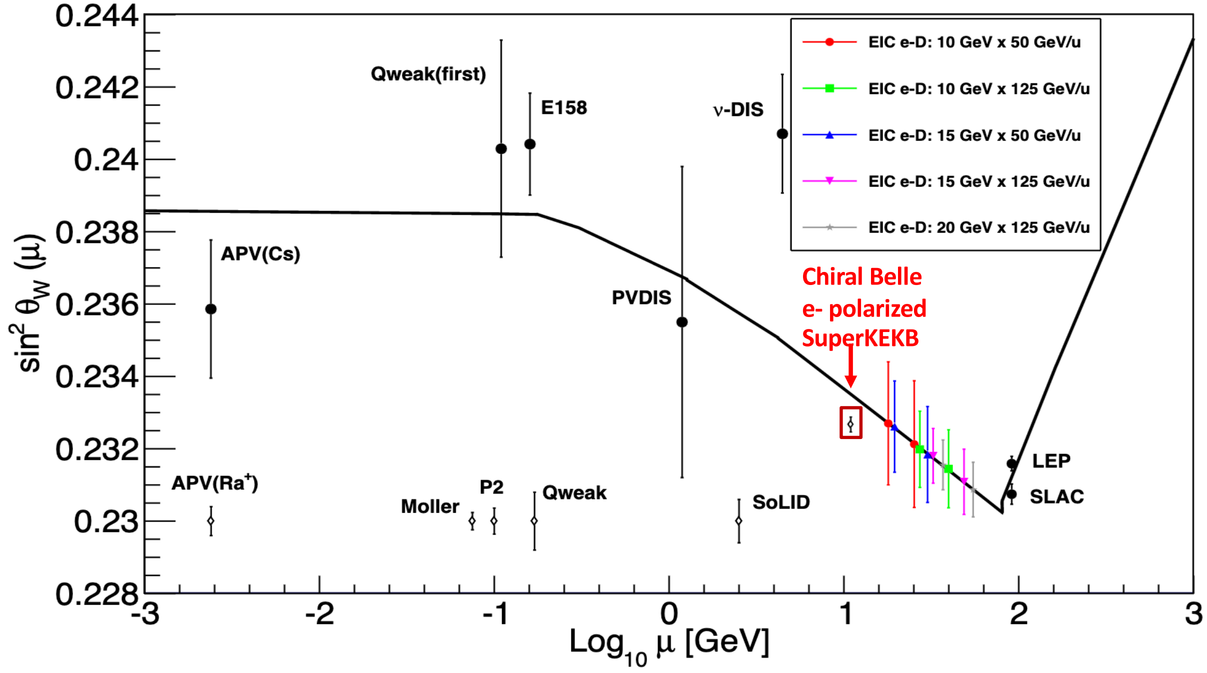
Precision weak mixing angle $\sin^2\theta_W$ to ±0.0002 with 40 ab^{-1} <P>=70%

using $A_{LR} = (\sigma_{Left} - \sigma_{Right})/(\sigma_{Left} + \sigma_{Right})$ and measured beam polarization to ± 0.005

same precision as at Z^0-pole measured at CERN (LEP) and SLAC (SLD)

But at 10GeV probes energy scaling of $\sin^2\theta_W$ making Chiral Belle a UNIQUE precision probe of New Physics in dark sector with e, μ, τ, c- and b-quarks

Adapted from Zhao et al., *"Neutral Weak Interactions at an EIC" Eur.Phys.J.A* 53 (2017) 3, 55



Measurements of scaling of $\sin^2\theta_W$ important part of new programs in U.S.

MOLLER at JLab complementary as they are at lower energy but MOLLER only probes electron couplings
cf Chiral Belle: e, μ, τ, c- & b-quarks

$\sin^2\theta_W$ 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

Beyond Touschek-Polarization Lifetime Experiment

Assuming Touschek-Polarization Lifetime Experiment validates the Long Term Tracking studies:

- Complete R&D on the spin rotators, Compton polarimeters and polarized source, including prototyping
- Schedule for installing one spin rotator to gain operational experience, including dipole mode only and demonstrate its transparency with solenoid+skew-quads
- Consider when to install around LS2 and operations after LS2 under requirement that luminosity is highest priority

Summary

- SuperKEKB's high luminosity fortuitously also enables an entirely new, high-impact and unique physics program when we polarize the electron beam
- 0.3% Beam polarization systematic uncertainty can be reached with both Tau Polarimetry and Compton Polarimetry
- Compact Spin Rotator provides solution to transparency with minimal changes to lattice AND ability to have SuperKEKB with no spin rotator (i.e. just use the dipole field) when we do not run with polarized beams – Long Term Tracking studies show minimal impact on beam lifetime and polarization lifetime
- Next step: **Progressing on putting LTT studies to the test with Touschek Polarization Experiment working with KEK source team**
- Conceptual Design Report, with schedule, is in preparation

Additional Material

B-factory Programme Advisory Committee

8 Upgrade plan with beam polarisation

8.1 Status

With Run 2 about to start with an expected running period from 2024 to 2028, reaching a peak instantaneous luminosity of $2 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, aiming for a total integrated luminosity up to 10 ab^{-1}, the collaboration is considering a major upgrade of the detector in parallel to the upgrade of the accelerator.

At this meeting, no update was provided on the upgrade of various detector components, but the implementation of longitudinal electron polarisation was discussed in more detail. Longitudinal polarisation of the electron beam, where the electron helicity can be flipped bunch-train by bunch-train, combined with the prospect of large integrated luminosity, opens up the possibility for an interesting and unique physics program. Precision electroweak studies via the measurement of $\sin^2 \vartheta_\mathrm{W}$ with a precision similar to that at the Z-pole but at a different centre-of-mass energy of 10 GeV would be possible.

The measurement would be very competitive with, and complementary to, a similar measurement from the MØLLER experiment at JLab and measurements at the EIC. It also opens the possibility of measuring $g - 2$ for the tau-lepton at the 10^{-5} level to be compared to the current level of precision of $\mathcal{O}(10^{-2})$. The physics program with polarisation requires high statistics, with integrated luminosities of 20–50 ab^{-1} assumed for the quoted goals. The proposal is to run with polarised beams while also accumulating high statistics for the approved Belle II program of flavor physics.

There are three key elements that are required for running with polarised beams: a low-emittance polarised electron source with about 80% polarisation, spin rotators in the High Energy Ring (HER) that do not reduce the luminosity, and a high precision Compton polarimeter that can measure the polarisation to better than 1% precision. When running with a polarised electron beam, transversely polarised electrons would be injected into the HER and rotated to longitudinal right before the interaction point (IP). Tau-decays would be used to get the absolute average polarisation at the IP.

Simulation studies of the proposed spin rotation setup show minimal impact on beam and polarisation lifetime, but these simulations do not take into account collisions. It will be important to cross-check the simulation results with data. To that end, a two-day experiment with a transverse polarised beam in SuperKEKB is proposed to validate the Touschek-polarisation lifetime on the timescale of the end of 2024. The studies will initially be performed without collisions, then the impact of collisions on the lifetimes will be measured. This would require the installation of a source of transversely polarised electrons and a suitably adjusted transfer line for the HER injection, and a polarimeter. A formal proposal is being prepared with a realistic schedule in consultation with KEK source experts and the LINAC team, to be submitted to the Belle II executive board. It was noted that the original machine configuration could be recovered with the spin rotator design that is being considered by turning off various beamline elements and retuning the machine.

8.2 Concerns

- The physics goals of running with polarised beams require high statistics, with integrated luminosities of 20–50 ab^{-1}. This implies that the upgrade would need to be made in a timely manner to profit from the accumulation of such a large dataset. It will be crucial to validate that the complication of adding polarisation does not perturb the achievement of high integrated luminosity, both during the testing and setting up of a polarisation upgrade as well as its final operation.
- Having data with polarised beams is expected to lead to more demands on resources, in particular for the physics analyses, simulation and reconstruction. It will also require a significant amount of effort from the accelerator team.
- The installing of another gun in the injection chain is not trivial and is expected to require significant resources.
- To be ready for the polarisation tests by the end of 2024 without limiting the approved programme of integrating luminosity looks overly optimistic.
- The idea of a polarisation upgrade will be documented in a forthcoming CDR. How this upgrade interfaces with other proposed upgrades to the Belle II detector and SuperKEKB machine upgrades are very important and were not discussed at this review. There is a serious concern that the forthcoming CDR (and possibly multiple CDRs) will not yet be a well thought-out overall package of upgrades, supported by the full collaboration, but rather a collection of possible options, and none of the other machine changes that are being considered will be included there.
- The full scope of the upgrade remains ill-defined. The timeline for LS2, planned for 2028, is very short. There is a serious concern that the timescale and resources required for realising the overall upgrade are underestimated and that the process is not as coordinated across the collaboration and the machine team as should be.

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- The full scope of the upgrade remains ill-defined. The timeline for LS2, planned for 2028, is very short. There is a serious concern that the timescale and resources required for realising the overall upgrade are underestimated and that the process is not as coordinated across the collaboration and the machine team as should be.

8.3 Recommendations

- Evaluate the feasibility of installation of another electron gun in the injection chain.
- Initiate a study on the overall resource needs for the polarisation upgrade and its downstream requirements on analysis, simulation and reconstruction.
- Develop a realistic schedule, including cost and resources, for the planned Touschek-polarisation lifetime test for 2024 as quickly as possible.
- Develop a coherent overall upgrade plan, coordinated with other Belle II detector and SuperKEKB machine upgrades being planned, with a well-defined scope as soon as possible.

Chiral Belle:
A Unique Opportunity for New Physics Discoveries

Snowmass 2021 White Paper
Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation
arXiv:2205.12847 (Sept. 2022)

From **KEK Roadmap 2021** (May 31, 2021)
*“Other proposals for future research, such as measurements using the Belle II detector and polarized electrons requiring **a modest upgrade to SuperKEKB**, have been made. R&D will continue to examine the technical feasibility of such projects while confirming their physics impact.”*

The Conceptual Design Report (CDR) for the polarization upgrade is being drafted

Chiral Belle's *unique* program of discovery-driven precision physics – an opportunity that comes once in a generation

With $A_{LR} = (\sigma_{Left} - \sigma_{Right})/(\sigma_{Left} + \sigma_{Right})$ and beam polarization measured to ± 0.005:

- Precision $\sin^2\theta_W$ ($\sigma_{\sin 2\theta W} = 0.0002$) : same precision as at Z^0-pole – but at 10GeV

  Probes energy scaling of $\sin^2\theta_W$ & unique probe of dark sector with **e, μ, τ, c, and 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 ($\sigma_{\sin 2\theta W}$ (EIC) = 0.0012 *cf* 0.0002 @ Chiral Belle) and only for couplings involving 1st generation fermions
- 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 World Average at Z^0)
- Highest precision neutral-current universality measurements by many factors (e.g. b:c universality 14x more precise with 40ab^{-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 parts of physics program reported in Snowmass Whitepaper

A New Path for Discovery in a Precision Neutral Current Electroweak Program

- Left-Right Asymmetries (A_{LR}) yield high precision measurements of the neutral current vector couplings (g_V) to each of five fermion flavours, *f* :
  - beauty (D-type)
  - charm (U-type)
  - tau
  - muon
  - electron

$$\text{Recall: } g_V^f \text{ gives } \theta_W \text{ in SM} \begin{cases} g_A^f = T_3^f \\ g_V^f = T_3^f - 2Q_f \sin^2\theta_W \end{cases}$$

as well as light quarks

T_3 = -0.5 for charged leptons and D-type quarks
+05 for neutrinos and U-type quarks

‘Chiral Belle’ Left-Right Asymmetries

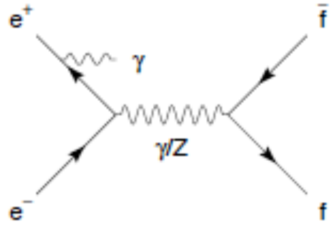
Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}}\left(\frac{G_F s}{4\pi\alpha Q_f}\right) g_A^e g_V^f \langle Pol \rangle$$

$$\propto T_3^f - 2Q_f \sin^2\theta_W$$

$$\langle Pol \rangle = 0.5\left\{\left(\frac{N_R^{e-} - N_L^{e-}}{N_R^{e-} + N_L^{e-}}\right)_R - \left(\frac{N_R^{e-} - N_L^{e-}}{N_R^{e-} + N_L^{e-}}\right)_L\right\}$$

(for s-channel Born)



Source generates mainly right-handed electrons

Source generates mainly left-handed electrons

For A_{LR} calculation with NLO corrections for mu-pair final state, see:
Aleksejevs, Barkanova, Roney, Zykunov “NLO radiative corrections for Forward-Backward and Left-Right Asymmetries at a B Factory”, arXiv:1801.08510

Magnetic Moment of τ lepton

No effect seen in the 0.511 MeV electron.

If effect is caused by New Physics related to
mass of μ, a MUCH bigger effect would exist for the τ

Current bound in tau ~ $\mathcal{O}(10^{-2})$

Chiral Belle reach ~ $\mathcal{O}(10^{-5})$ with $50ab^{-1}$

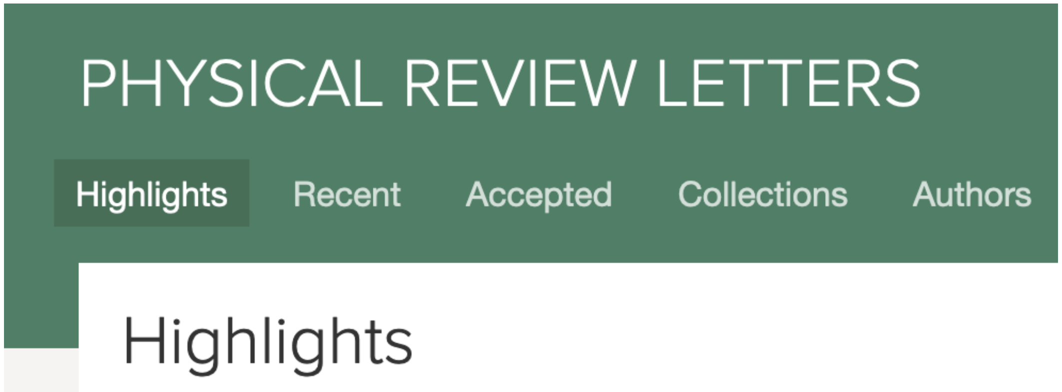
(*Phys.Rev.D* 106 (2022) 9, 093007)

1000 times more precise and is only experiment that can do this

Approaches precision regime in τ sensitive to Minimal Flavour Violation equivalent of $(g\text{-}2)_\mu$ anomaly and is in regime of other new physics scenarios

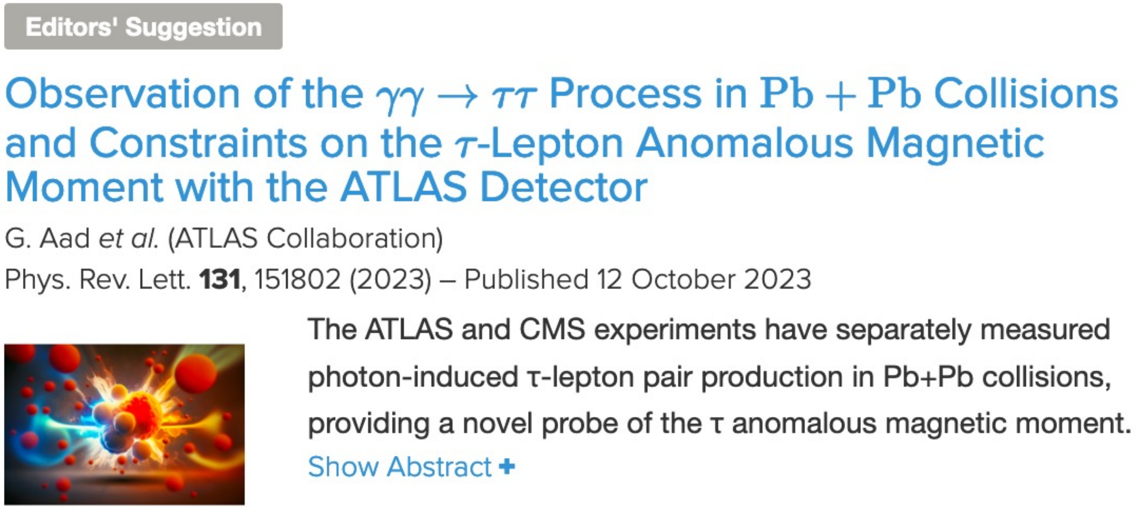
How? Detector level systematic uncertainties cancel in asymmetries between left (right) beams

τ−lepton g-2 is
VERY HOT Topic in Physics



PHYSICAL REVIEW LETTERS

Highlights



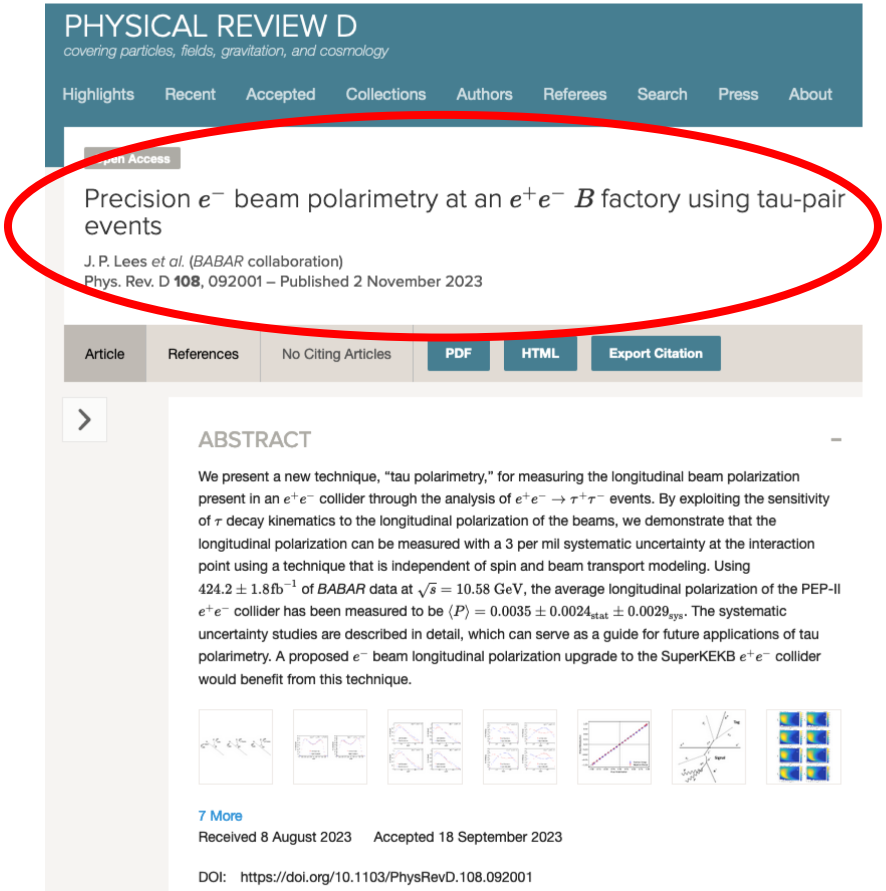
Observation of the $\gamma\gamma \to \tau\tau$ Process in Pb + Pb Collisions and Constraints on the τ-Lepton Anomalous Magnetic Moment with the ATLAS Detector

G. Aad *et al.* (ATLAS Collaboration)

Phys. Rev. Lett. **131**, 151802 (2023) – Published 12 October 2023

The ATLAS and CMS experiments have separately measured photon-induced τ-lepton pair production in Pb+Pb collisions, providing a novel probe of the τ anomalous magnetic moment.

Beam Polarization: Can be measured to < 0.005



PHYSICAL REVIEW D

covering particles, fields, gravitation, and cosmology

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Precision e^- beam polarimetry at an e^+e^- B factory using tau-pair events

J. P. Lees *et al.* (*BABAR* collaboration)
Phys. Rev. D **108**, 092001 – Published 2 November 2023

Article References No Citing Articles PDF HTML Export Citation

ABSTRACT

We present a new technique, "tau polarimetry," for measuring the longitudinal beam polarization present in an e^+e^- collider through the analysis of $e^+e^- \to \tau^+\tau^-$ events. By exploiting the sensitivity of τ decay kinematics to the longitudinal polarization of the beams, we demonstrate that the longitudinal polarization can be measured with a 3 per mil systematic uncertainty at the interaction point using a technique that is independent of spin and beam transport modeling. Using $424.2 \pm 1.8 \mathrm{fb}^{-1}$ of *BABAR* data at $\sqrt{s} = 10.58$ GeV, the average longitudinal polarization of the PEP-II e^+e^- collider has been measured to be $\langle P \rangle = 0.0035 \pm 0.0024_{\mathrm{stat}} \pm 0.0029_{\mathrm{sys}}$. The systematic uncertainty studies are described in detail, which can serve as a guide for future applications of tau polarimetry. A proposed e^- beam longitudinal polarization upgrade to the SuperKEKB e^+e^- collider would benefit from this technique.

7 More

Received 8 August 2023 Accepted 18 September 2023

DOI: https://doi.org/10.1103/PhysRevD.108.092001

J inst Published by IOP Publishing for Sissa Medialab

Received: *September 28, 2023*
Accepted: *October 12, 2023*
Published: *October 16, 2023*

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

D. Charlet,[a] T. Ishibashi,[b] A. Martens,[a,*] M. Masuzawa,[b] F. Mawas,[a] Y. Peinaud,[a] D. Zhou[b] and F. Zomer[a]

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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)

2023 JINST 18 P10014

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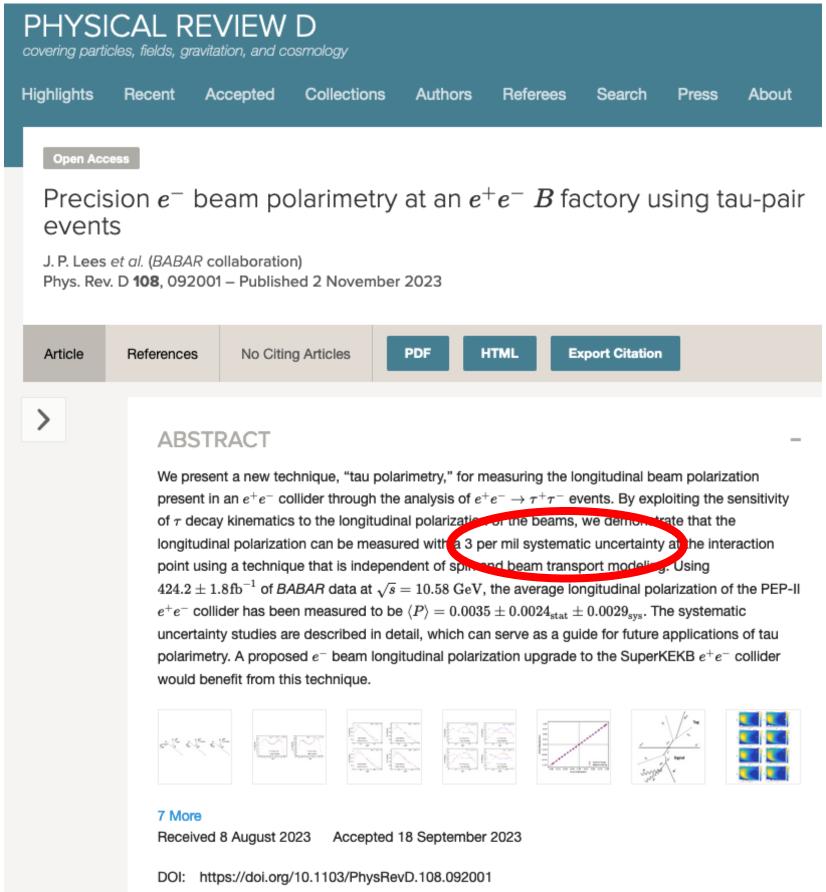
Beam Polarization: Can be measured to < 0.005



PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology

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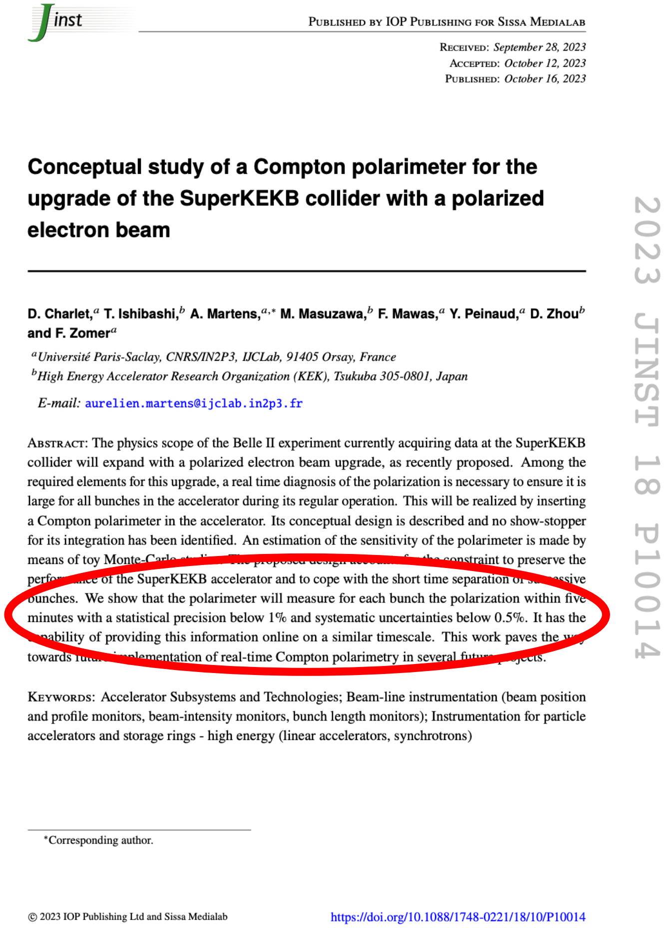

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https://doi.org/10.1088/1748-0221/18/10/P10014

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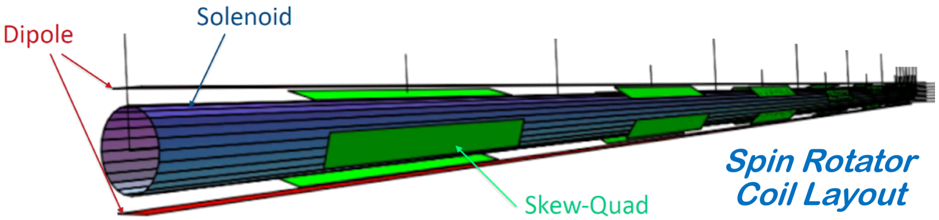
Consider
Compact spin rotator



Spin Rotator Coil Layout

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

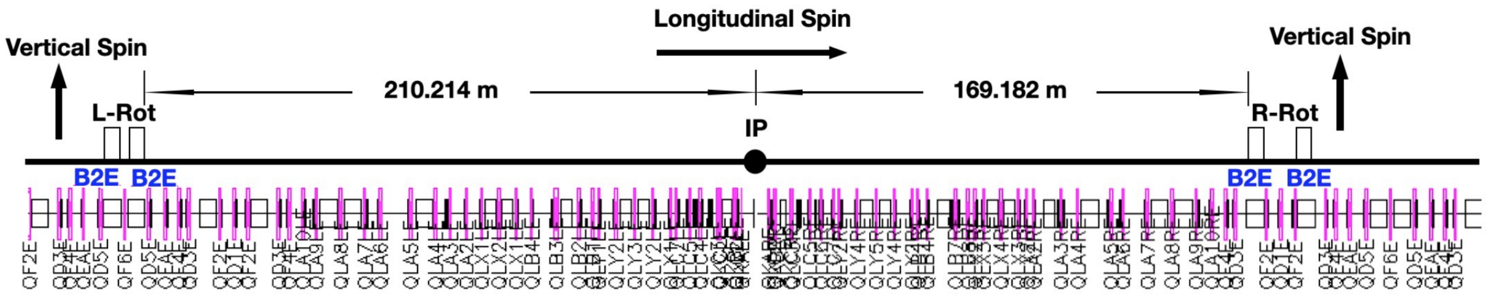
- Replace some existing ring dipoles on both sides of the IP with the dipole-solenoid combined function magnets and keep the original dipole strength to preserve the machine geometry
- Avoids repositioning of other magnets in the ring
- Install 6 skew-quadruple on top of each rotator section to compensate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

Y. Peng (UVic) with Uli Wienands (ANL)



- 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

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

BMAD LTT studies [N. Tessema (UVic) + U. Wienands (ANL)] of Peng-Wienand spin rotator solution after improving the dipole model in BMAD deployed for these compact magnets

Conclusion:

- Beam is stable with compact spin rotators (5 million turns with 20 particles – no lost particles)

- Good polarization lifetime of ~25 minutes (~10 top-up times) with HER energy of 7.035 GeV (0.4% [i.e.+28MeV] higher than default energy) – currently using LTT to map lifetime vs energy to maximize polarization lifetime & for resonant depolarization considerations

History of Touschek lifetime being used to measure transverse polarization

- Touschek described the lifetime of electrons in AdA ('accumulation ring') in 1963 (Bernardini et al., Phys. Rev. Lett 10 (1963) 407)
- Baier & Khoze, pointed out that Touschek lifetime is sensitive to polarization (At. Energ. 25 (1968) 440)
- It was then use in the VEPP-2M ring to measure depolarization (and thus beam energy): Derbenev Part. Acc. 8 (1978) 115
  - Measuring the counting rate of scattered electrons
- Ex: Allowed first precision mass measurement of J/Psi (3096.93+-0.09 MeV) then superseded in 1993 (E760)
- Continously improved at VEPP-4M (KEDR at VEPP-4M: 3096.900 ± 0.002 ± 0.006 MeV): Phys. Lett 96B (1980) 214; Blinov et al., proc. of EPAC (2002) 1954

- More recently used at :
  - HIgS (DUKE): NIMA 614 (2010) 339
  - SOLEIL, NIMA 697 (2013) 1
  - Diamond Light Source, PRAB22 (2019) 122801
  - Based on expressions given in NIMA 554 (2005) 85
  - Also proposed for FCCee: arXiv1909.12245

Touschek-Polarization Lifetime Experiment Draft Proposal

Dedicate 2 days at the **end** of the 2025 running period (December 2025) if possible, to inject transversely polarized beam into HER (**this timing puts priority on getting luminosity**)

Run the machine and measure Touschek Lifetime in the HER with and without polarization

Explore different polarization conditions (>3 Touschek lifetimes).

One Option to be considered:

Inject bunch trains into HER with

1/8 of the HER fill with ZERO polarization

Followed by bunch train of 1/8 of HER with UP transverse polarization

Followed by bunch train of 1/8 of HER with ZERO transverse polarization

Followed by bunch train of 1/8 of HER with DOWN transverse polarization

Followed by bunch train of 1/8 of HER with ZERO transverse polarization

Followed by bunch train of 1/8 of HER with UP transverse polarization

Followed by bunch train of 1/8 of HER with ZERO transverse polarization

Followed by bunch train of 1/8 of HER with DOWN transverse polarization

Perform these studies initially without collisions,
then study the impact of collisions on polarization lifetime: measure the magnitude of beam-beam depolarizing effects

Touschek-Polarization Lifetime Experiment Draft Proposal

Option 2:

Run the machine for two days and measure Touschek Lifetime in the HER

In a series of polarization conditions (>3 Toushek lifetimes).

PolRun 1: HER with ZERO polarization

PolRun 2: UP transverse polarization

PolRun 3: ZERO polarization

PolRun 4: DOWN polarization

PolRun 5: ZERO polarization

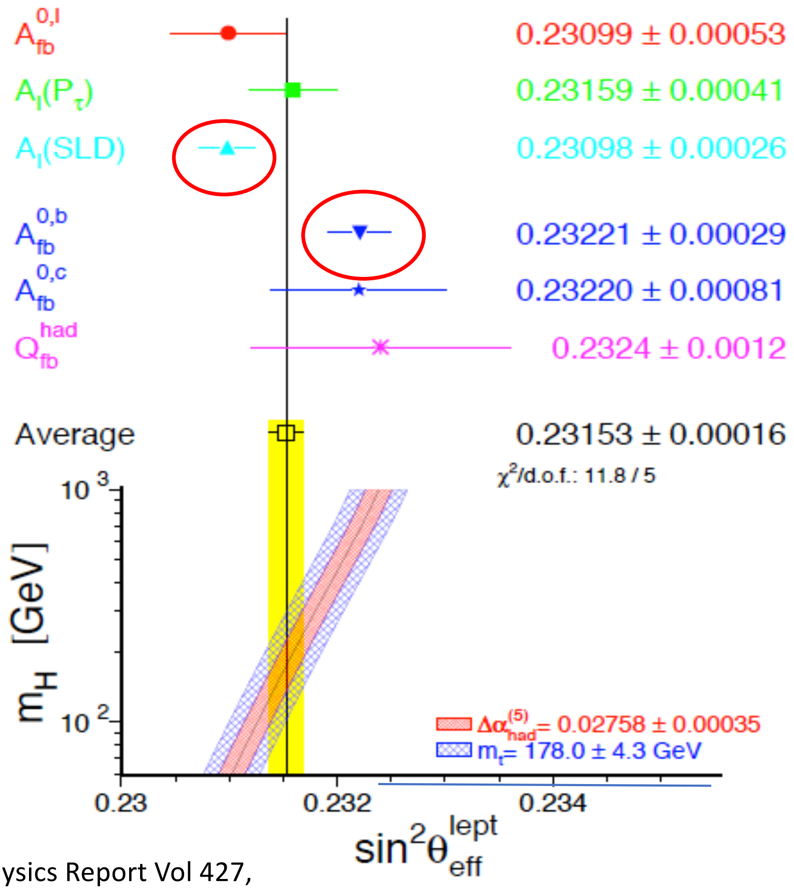
PolRun 6: UP transverse polarization

PolRun 7: ZERO polarization

PolRun 8: DOWN polarization

Perform these studies with single HER beam and then with HER and LER in collision (or after collisions) to measure the magnitude of beam-beam depolarizing effects

Existing tension in data on the Z-Pole



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

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

LHC precision electroweak program limited by strong interaction hadronization effects in Z → b-quark pairs (Physics Report 2006)
But Chiral Belle is at B-meson pair production threshold, so not limited by this

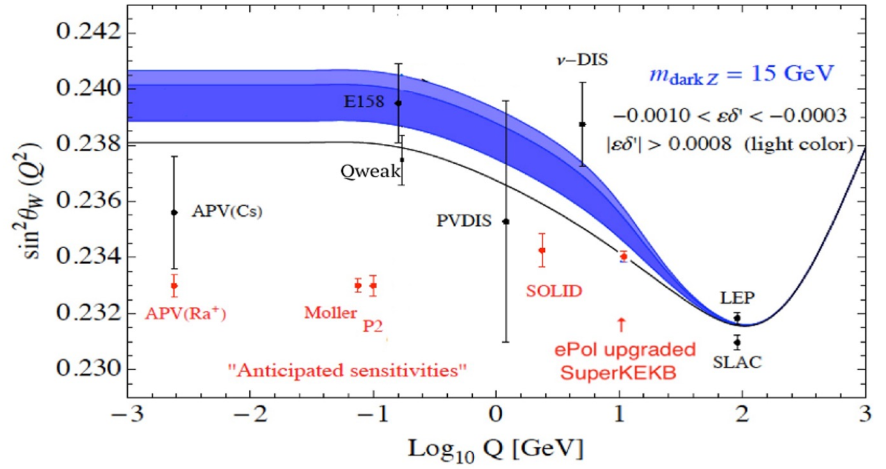
Chiral Belle unique position to resolve whether this tension is early sign of e:b universality violation signally New Physics or a fluctuation

40ab^{-1} @ Chiral Belle gives Highest precision neutral-current universality measurements by many factors (e.g. Chiral Belle b-quark to c-quark universality measurement is 14x more precise than combined World Average)

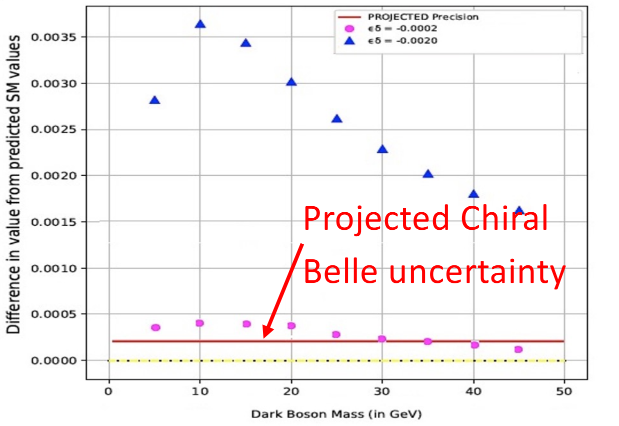
Upgrading SuperKEKB with e- Polarized Beams: Chiral Belle → unique probe of Dark Sector

Running of $\sin^2 \theta_W (Q^2)$:window to the Dark Sector

Dark blue band shows Q^2-dependent shift in $\sin^2 \theta_W$ due to 15 GeV parity-violating dark Z



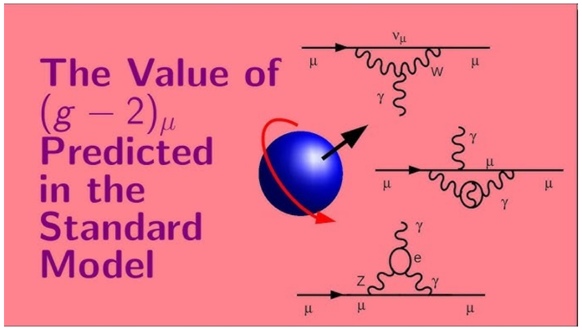
Differences between SM and two benchmark scenarios of dark Z



Projected Chiral Belle uncertainty

- Adapted from Fig. 3 of H. Davoudiasl, H.S. Lee and W.J. Marciano, Phys.Rev.D 92(5),2015.
- Red bars shows expected ±1 sigma uncertainty = 0.0002 with 40 ab^{-1} at Chiral Belle [placed at arbitrary positions].
- Also sensitive to parity violation induced by exchange of heavy particles e.g. a hypothetical TeV-scale Z' boson, which if couples only to lepton will be uniquely produced @ Belle II and not in pp collisions.

Magnetic Moment of τ lepton



$$a_\ell = (g_\ell - 2)/2$$

Large deviation in anomalous magnetic moment of muon:

$$a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (251 \pm 59)\times 10^{-11} [4.2\sigma]$$

(Older BNL and New FERMILAB measurements)

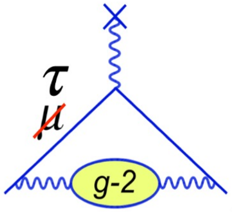
No effect seen in the electron.

If effect is caused by New Physics related to the mass of muon (106MeV >> 0.511MeV)

A MUCH bigger effect would exist for 1777 MeV tau lepton

Expectation from Minimal flavor violation for more massive tau lepton is:

$$a_\tau^{\mathrm{BSM}} \sim a_\mu^{\mathrm{BSM}} \left(\frac{m_\tau}{m_\mu}\right)^2 \sim 10^{-6}$$

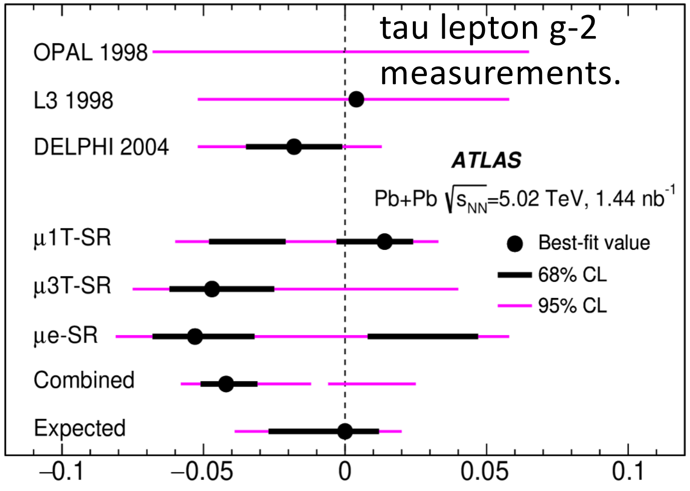


and larger under other new physics scenarios

Current bound in tau ~ $\mathcal{O}(10^{-2})$

Chiral Belle reach ~ $\mathcal{O}(10^{-5})$ with 50ab^{-1}

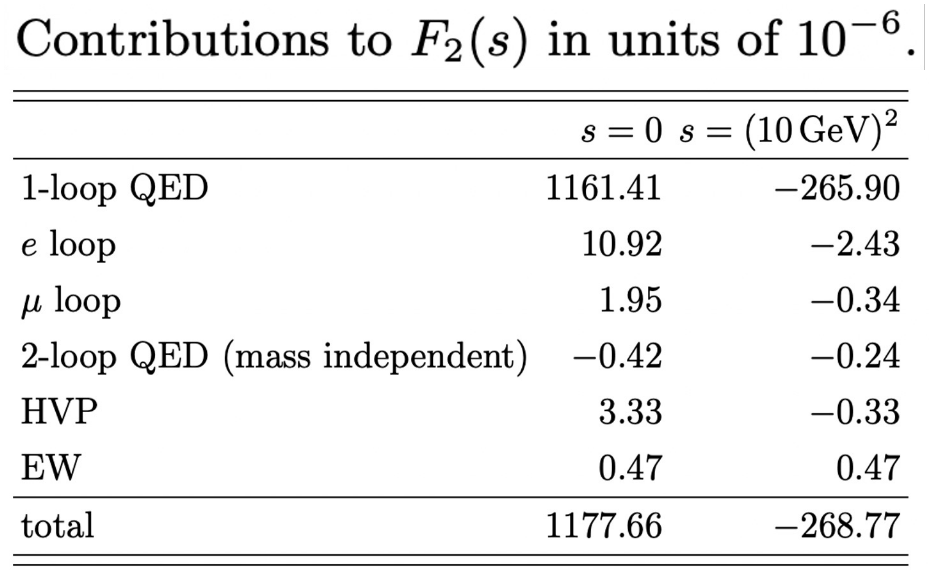
How? Small systematic uncertainties with polarization method



e-Print: 2204.13478 [hep-ex]

ATLAS Collaboration

Magnetic dipole moments of τ lepton



Contributions to $F_2(s)$ in units of 10^{-6}.

	$s=0$	$s=(10\,\mathrm{GeV})^2$
1-loop QED	1161.41	−265.90
e loop	10.92	−2.43
μ loop	1.95	−0.34
2-loop QED (mass independent)	−0.42	−0.24
HVP	3.33	−0.33
EW	0.47	0.47
total	1177.66	−268.77

(Crivellin, Hofericher, Roney, *Phys.Rev.D* 106 (2022) 9, 093007)

- Detector level systematics cancels in asymmetries between left (right) beams.
- Precision ≃ $\mathcal{O}(10^{-5})$ or better expected with 50 ab^{-1} of data with polarized beam.
- **1000 x more precise than current limits**
- **Approaches the precision regime in tau that would be sensitive to Minimal Flavour Violation equivalent of muon g-2 anomaly**

Chiral Belle physics broader program includes:

- τ electric dipole moment (EDM)
- Improved precision measurements of τ Michel Parameters
- e^- beam polarization can be used to reduce backgrounds in $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$ – leading to improved sensitivities; also electron beam polarization and can be used to distinguish Left and Right handed New Physics currents.
- Polarized e+e- annihilation into a polarized Λ or a hadron pair experimentally probes dynamical mass generation in QCD

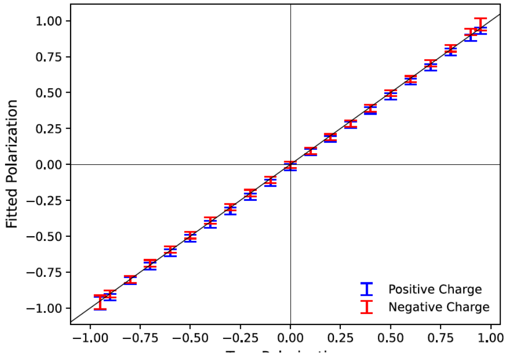
Precision measurement of polarization: Tau Polarimetry

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

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



MC sensitivity validation

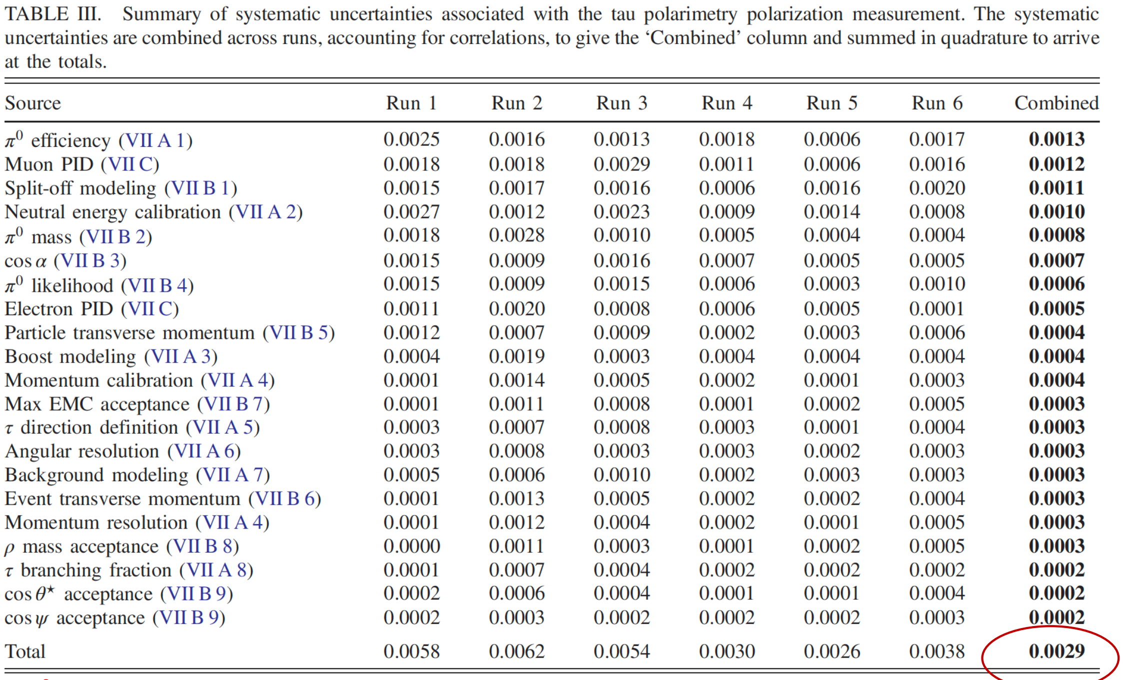


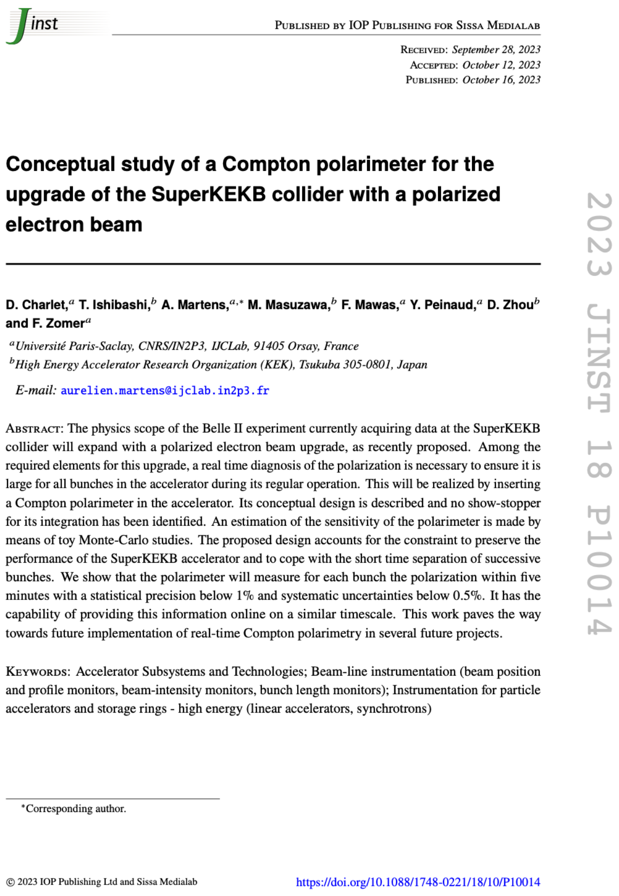
TABLE III. Summary of systematic uncertainties associated with the tau polarimetry polarization measurement. The systematic uncertainties are combined across runs, accounting for correlations, to give the 'Combined' column and summed in quadrature to arrive at the totals.

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**

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

(Caleb Miller Oct 2023 B2GM)

Precision measurement of polarization: Compton Polarimetry



JINST — Published by IOP Publishing for Sissa Medialab

Received: *September 28, 2023*
Accepted: *October 12, 2023*
Published: *October 16, 2023*

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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https://doi.org/10.1088/1748-0221/18/10/P10014

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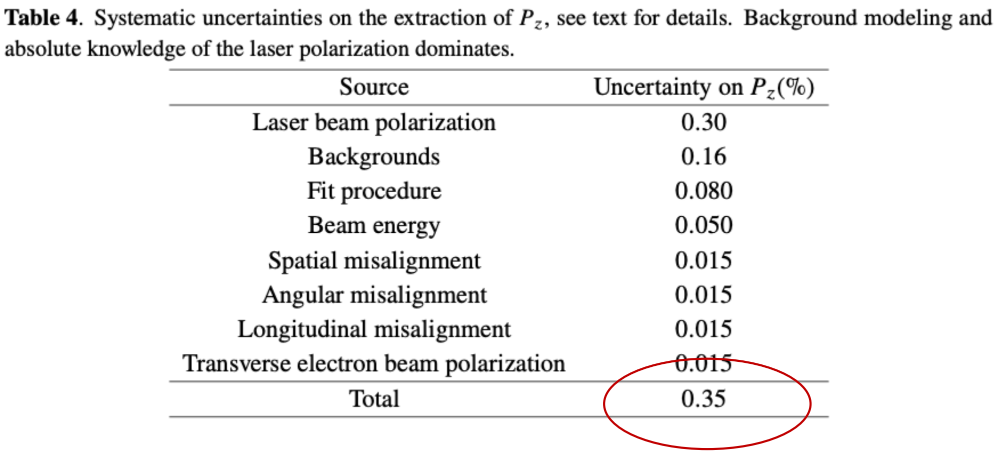


Table 4. Systematic uncertainties on the extraction of P_z, see text for details. Background modeling and absolute knowledge of the laser polarization dominates.

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

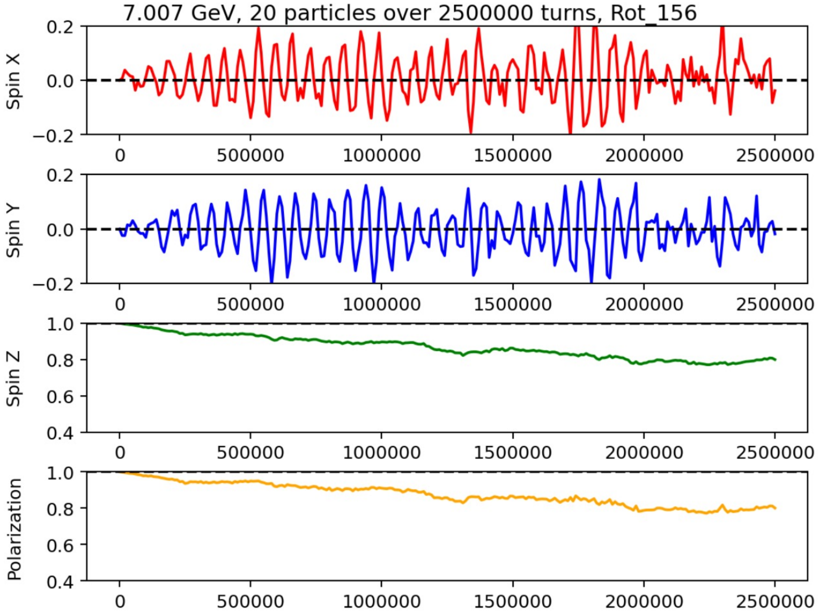
- Systematic uncertainty related to beam transport from Compton IP to Belle 2 IP
- Prototype photon detector → French National Research Agency call for funding, answer in Spring.
- Laser synchronization → possible solution found with relevant KEKB expert, relevant tests may be performed in the coming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

(Aurélien Martens presentation in Oct 2023 B2GM)

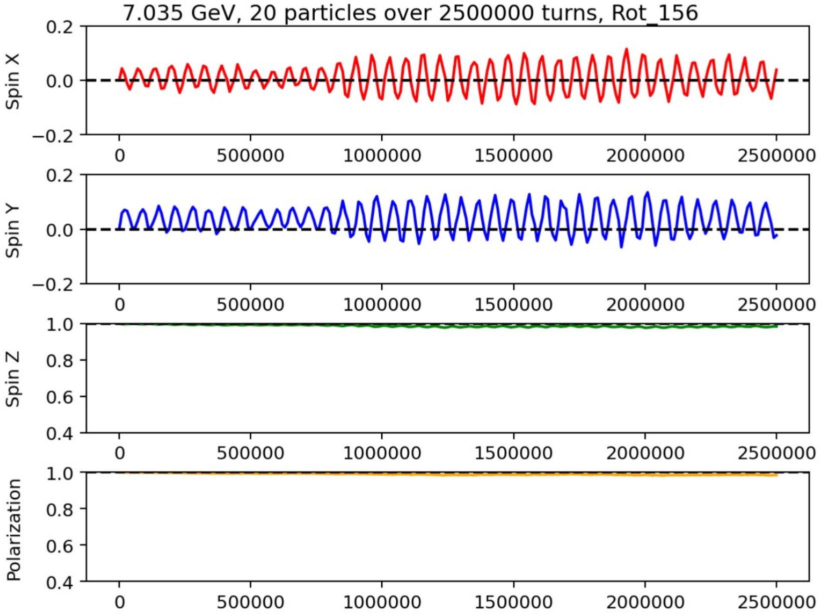
Compact spin rotator

Alternative Energies and LTT

University of Victoria



Nominal Energy

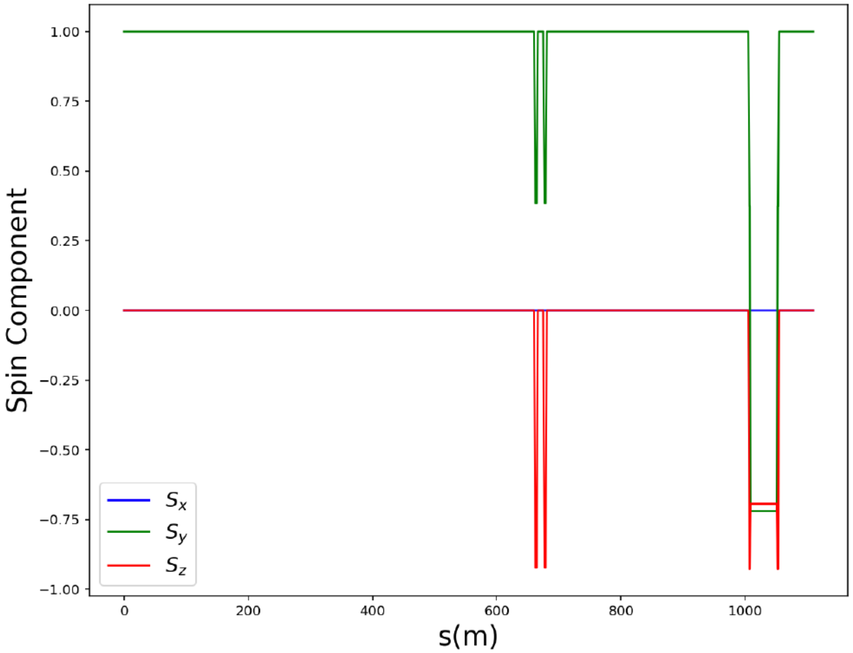


Nominal +28 MeV

(Plotted are averages)

Spin motion in the KEK Injection Linac

Y. Peng's (UVictoria)

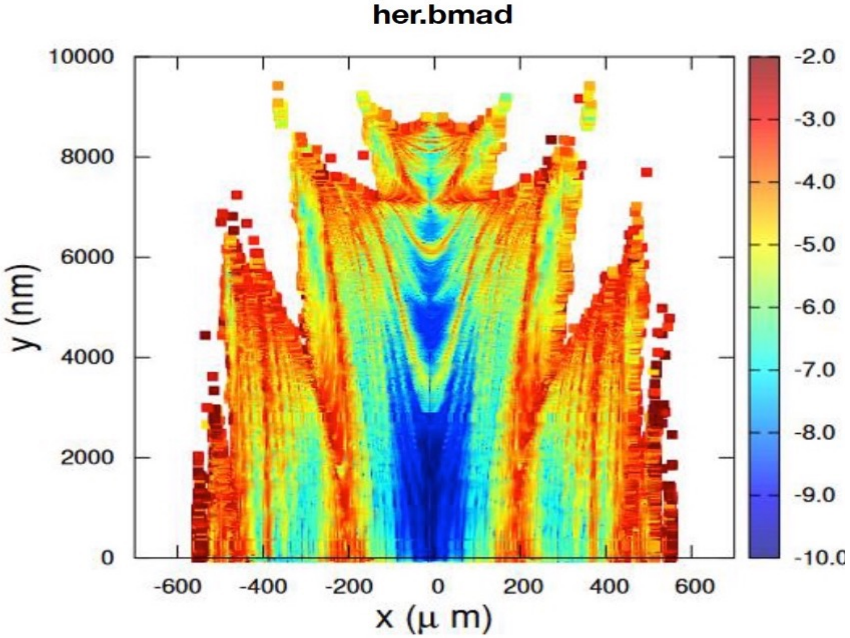


These spin tracking using BMAD show if the electron starts with vertical spin (0,1,0) at the source, after all the vertical beam motion,
it will end up with a vertical spin at the injection point, as desired.

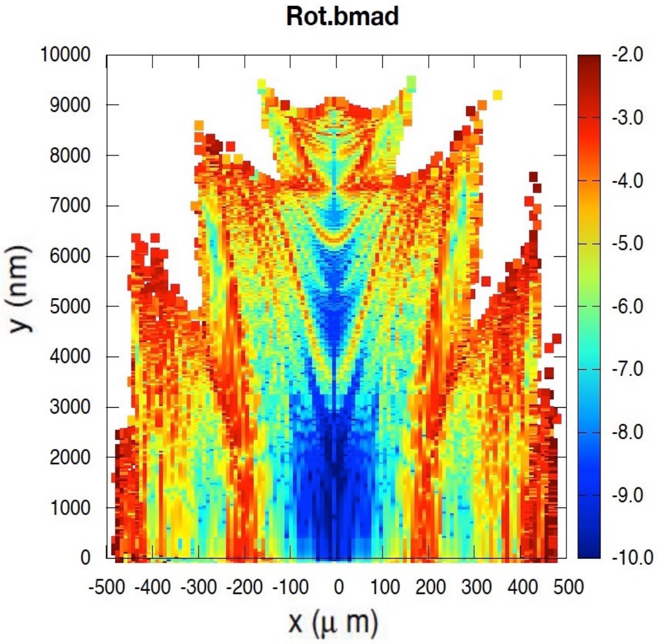
Compact spin rotator

Initial Frequency Map Analysis (FMA)
dynamic aperture studies using BMAD – show no large changes
work by Noah Tessema (UVic) advised by D. Zhou (KEK), U. Wienands (ANL)

Original HER Lattice



HER Lattice with spin rotator



Compact spin rotator

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

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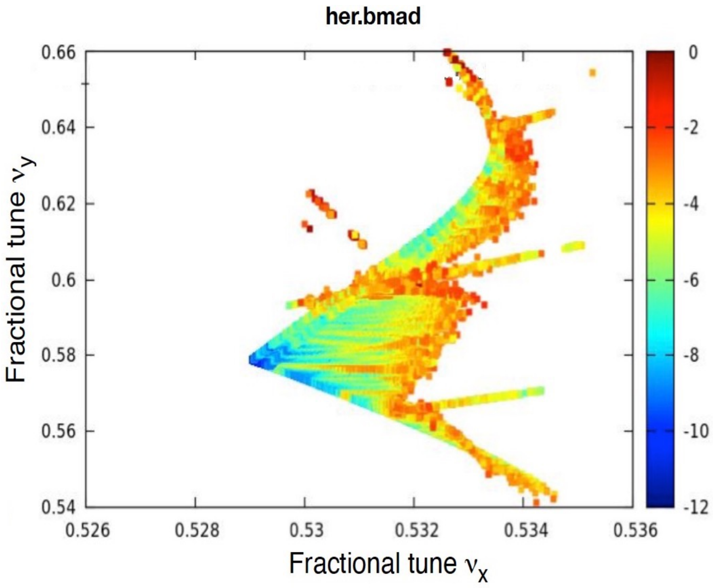
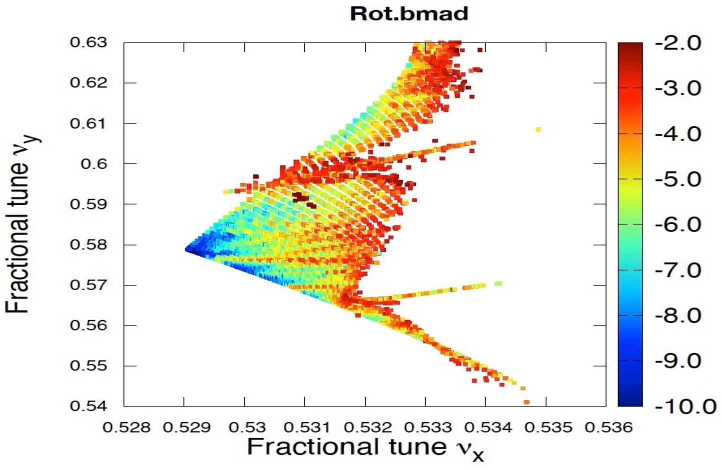


HER Lattice with spin rotator



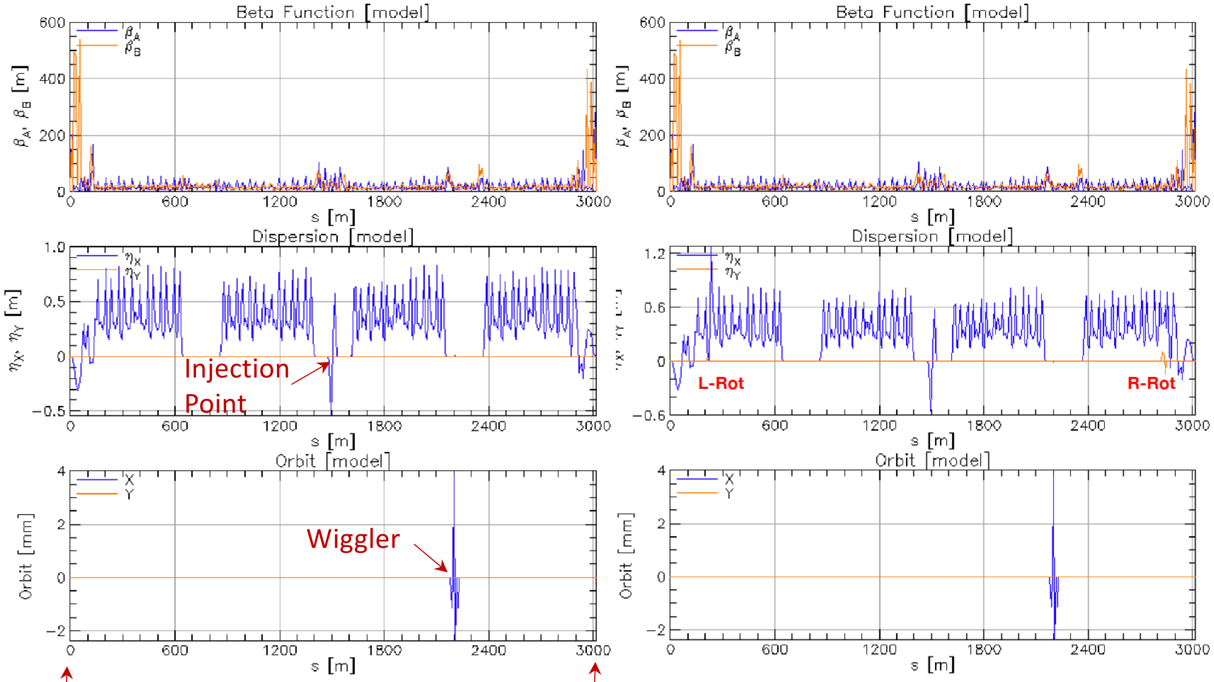
Compact spin rotator

Full lattice Comparison with L/R-Rot installed & matched in the HER ring

Beta
x & y

Diffusion
x & y

Orbit



Interaction Point

Original Ring

Interaction Point

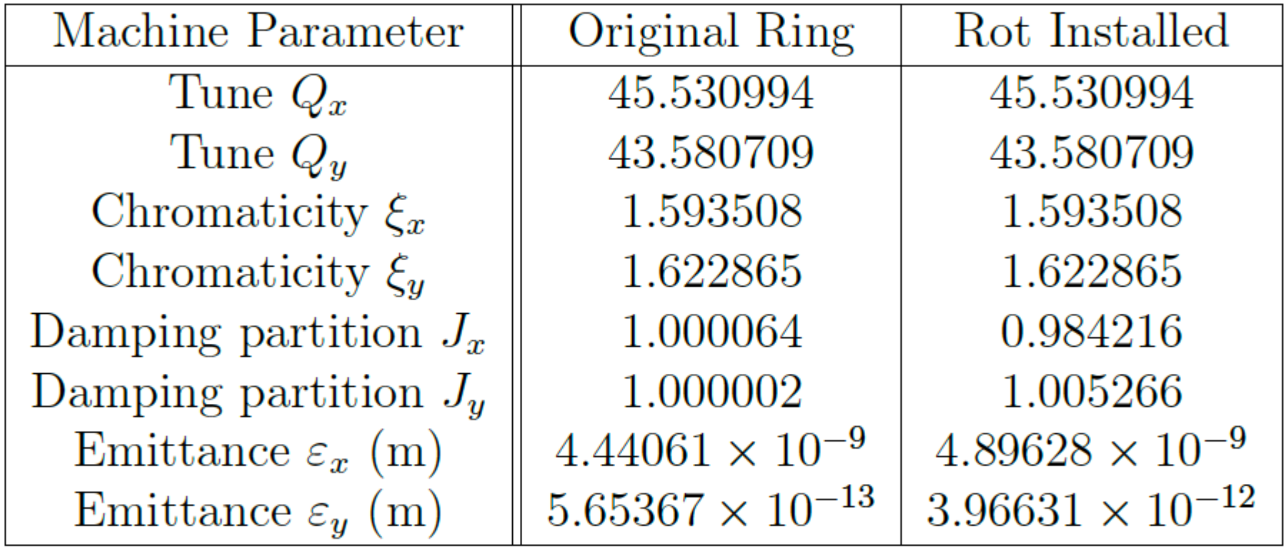
Rotator Ring

Yuhaou Peng

Compact spin rotator

Yuhao Peng

Ring parameter comparisons with BMAD following closed-geometry optimization and after matching tune and chromaticity to the original HER



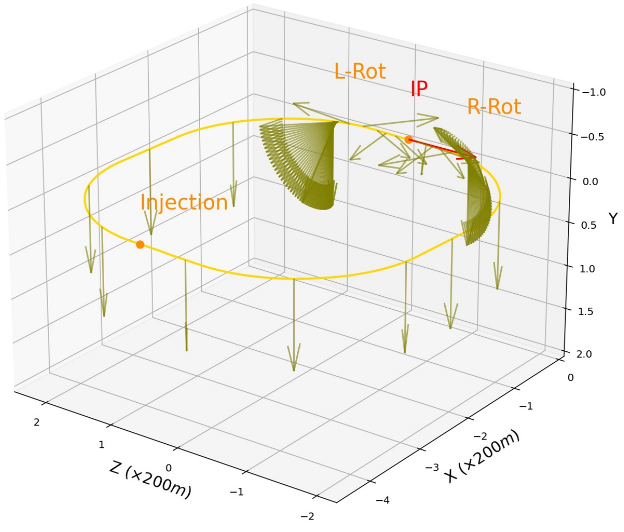
Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}
Emittance ε_y (m)	5.65367×10^{-13}	3.96631×10^{-12}

Compact spin rotator

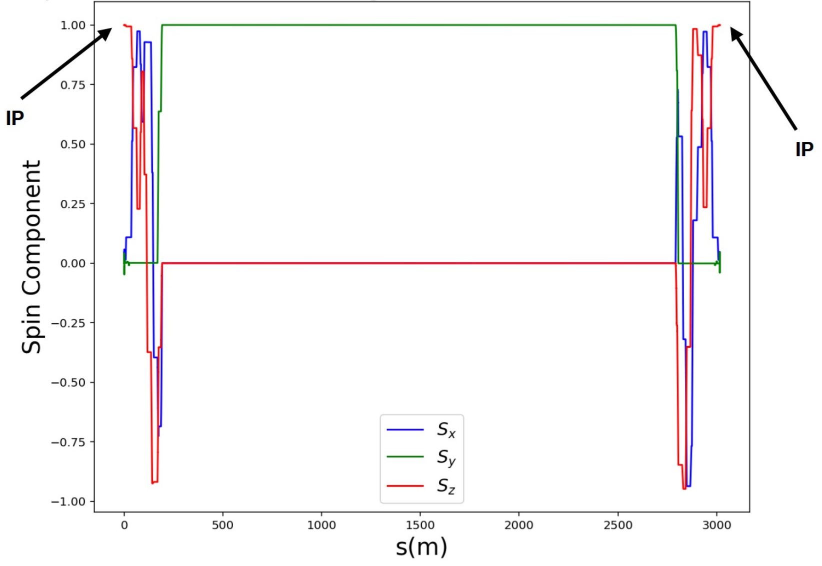
Yuhao Peng

Single Particle Spin Tracking Result

Spin Component	Entrance of the L-Rot	IP	Exit of the R-Rot
X	-0.0000450734	0.0000066698	0.0000538792
Y	0.9999999959	0.0000926945	0.9999999959
Z	-0.0000788085	0.9999999957	-0.0000728110

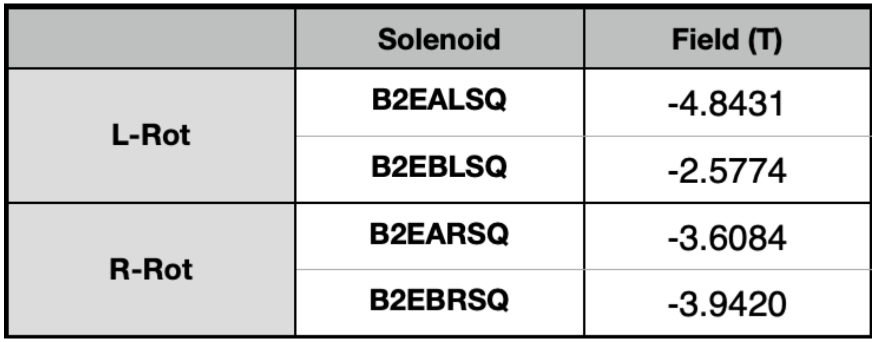


Spin Motion of e^- (Co-Moving Frame) in the HER with Rot installed



Compact spin rotator

Yuhao Peng



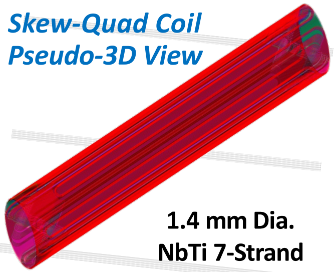
	Solenoid	Field (T)
L-Rot	**B2EALSQ**	-4.8431
	B2EBLSQ	-2.5774
R-Rot	**B2EARSQ**	-3.6084
	B2EBRSQ	-3.9420

- Solenoid fields below 5 T limit
- Maximum skew-quad strength is ~20 T/m, below 30T/m limit
- Maximum Ring quad is ~ 14 T/m, which is achievable

Compact Spin Rotator – Coil Feasibility

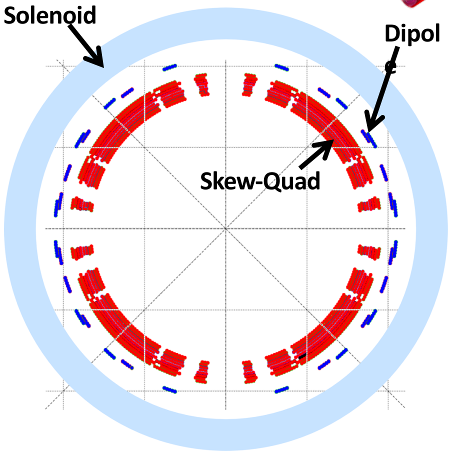
Brett Parker (BNL)

BNL Direct Wind Coil Production



Skew-Quad Coil Pseudo-3D View

1.4 mm Dia. NbTi 7-Strand Cable



Coil Cross Section at Skew-Quad Center

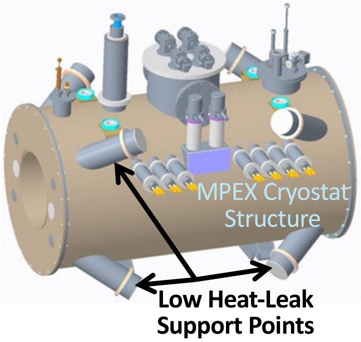
Solenoid Field 4.85 T
Skew Gradient 24 T/m
Dipole Field 0.2 T

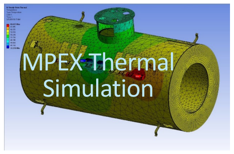
Combined Field @ Skew-Quad is 6.15 T
I_{op} = 729 A
I_q = 1050 A
for 69% Short Sample

- **We plan to use BNL Direct Wind coil production technique to fabricate the nested coil structure.**
- **Results from first pass NbTi coil structure shown here yield desired operating margin at 4.22 K.**
- **Final coil layout requires careful optimization balancing warm-bore, intermediate heat shield, support structure and current lead designs to allow standalone cryocooler operation in tunnel.**
- **Resources needed to carry out this optimization**
- **Our R&D results will then be used as a basis for a formal request to appropriate funding agency(ies) for the spin rotator component of a future Belle II based Spin Physics upgrade of SuperKEKB.**

Compact Spin Rotator – Cryostat System Feasibility

Brett Parker (BNL)





BNL Design Work: Snake magnet in AGS tunnel and conceptual Oak Ridge MPEX cryostat showing warm bore, low heat-leak support structure, current leads and integrated cooling via cryocoolers.

- **Basic consideration: enough warm bore to accommodate HER beam pipe with water cooling and vacuum features.**
- **Also need some radial space for inner cryostat heat shield.**
- **But skew-quad inner radius should be as small as possible in order to limit peak field (we want to use NbTi cable!).**
- **We are far from any cryogenic supply; so, use cryocoolers.**
- **Cryocooler capacity depends upon heat leak: e.g., the heat shield, support structure and current lead requirements.**
- **For redundancy/rapid maintenance use closed "wet system."**
- **We need a self-consistent pre-conceptual design to find out basic info' such as helium structure (cryogenic safety input).**
- **Feedback from mechanical design used to adjust coil design and ultimately validate magnetic strengths for HER optics.**