2026 CAP Congress
June 21-26 Juin
Ottawa
Congrès de l’ACP 2026

W2-1 SYMPOSIUM: Future Particle Physics Energy Frontier Facilities | Installations futures à la pointe de la physique des particules

Chiral Belle Status:
R&D on SuperKEKB Upgrade with Polarized Electron Beams

J. Michael Roney
University of Victoria

24 June 2026

On behalf of the Belle II/ SuperKEKB Polarization Upgrade Working Group

University of Victoria

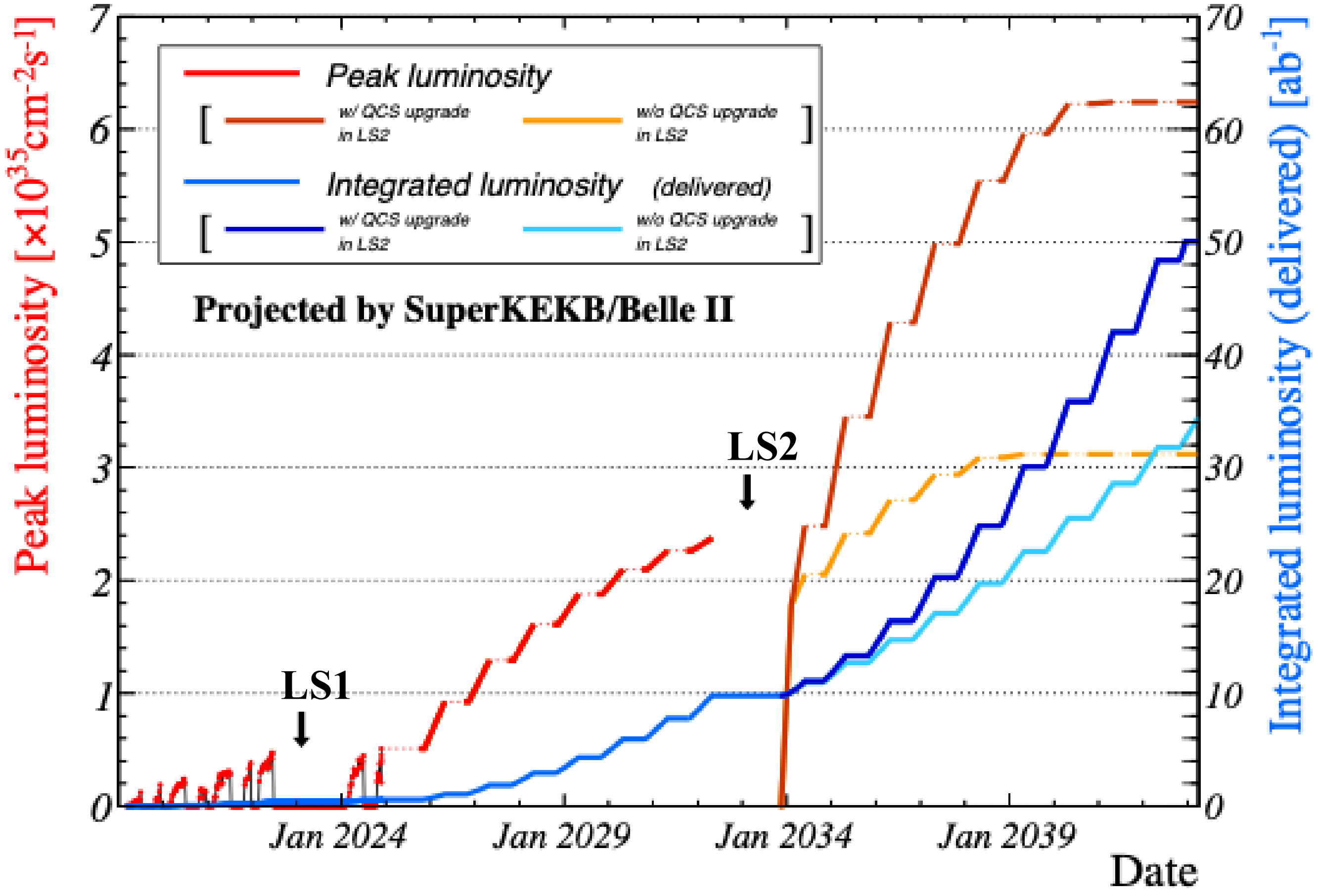
Introducing polarized electron beam in SuperKEKB

Outline

- Particle Physics Motivation for Chiral Belle program
- Requirements – high luminosity, polarized source, spin rotators, Compton polarimetry
- Status of R&D on the project
  - Polarimetry, Spin rotator, Polarized Source
  - Touschek-Polarization Lifetime Experiment Proposal in preparation
    - Motivation
    - Status of R&D work on polarized source

SuperKEKB's HIGH LUMINOSITY drives the rich research program of Belle II

Reaching the design luminosity is our highest priority



Adapted from https://www.belle2.org/research/luminosity/ downloaded October 2025

SuperKEKB's HIGH LUMINOSITY drives the rich research program of Belle II

Reaching the design luminosity is our highest priority

FORTUITOUSLY, SuperKEKB's HIGH LUMINOSITY also enables an

entirely new, rich and unique physics program when we

POLARIZE THE ELECTRON BEAM

SuperKEKB’s HIGH LUMINOSITY drives the rich research program of Belle II

Reaching the design luminosity is our highest priority

FORTUITOUSLY, SuperKEKB’s HIGH LUMINOSITY also enables an

entirely new, rich and unique physics program when we

POLARIZE THE ELECTRON BEAM

Goal is for Data with polarized e^- beam to be collected by Belle II

- **used simultaneously for conventional non-polarized beam physics program**
- **no negative impact on existing unpolarized beam program**

Particle Physics Motivation for Chiral Belle program

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

Left-Right Asymmetries ($A_{LR}=\frac{\boldsymbol{\sigma}_L-\boldsymbol{\sigma}_R}{\boldsymbol{\sigma}_L+\boldsymbol{\sigma}_R}$) yield high precision measurements of the neutral current vector couplings (g_V) to each of five fermion flavours, *f* , and so to $\sin^2\theta_W$

- **beauty (D-type)**
- **charm (U-type)**
- **tau**
- **muon**
- **electron**

g_V precisely predicted in SM (@Z^0±0.03% b,±0.1% c,±0.8% leptons)

Deviations from SM → Sensitive to Dark Sector
Parity Violating Mediators, e.g. Z_{dark}

Advantage of measurement away from Z^0 at lower energy with access to 2nd & 3rd generations with high precision

as well as light quarks

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

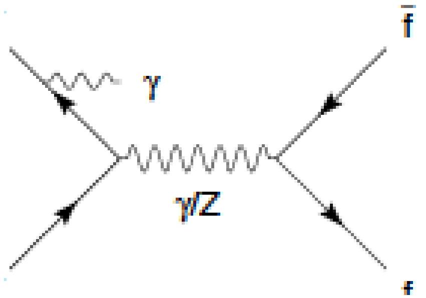
T_3 = -0.5 for charged leptons and Down-type quarks
+0.5 for neutrinos and Up-type quarks

‘Chiral Belle’ -> Left-Right Asymmetries

At 10.58 GeV - Z-γ interference for s-channel Born:

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

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

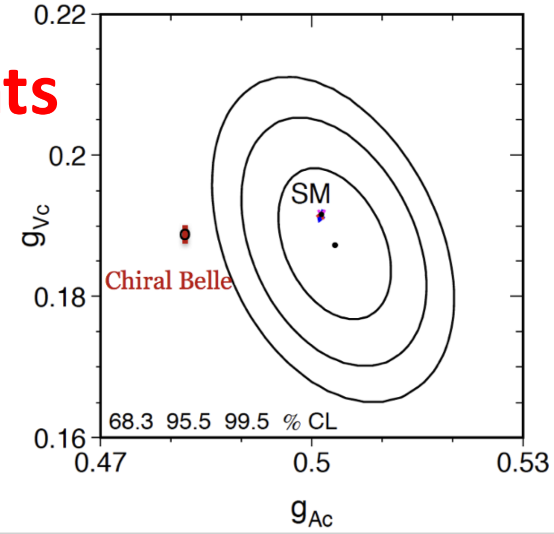


<Pol> is average beam polarization

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

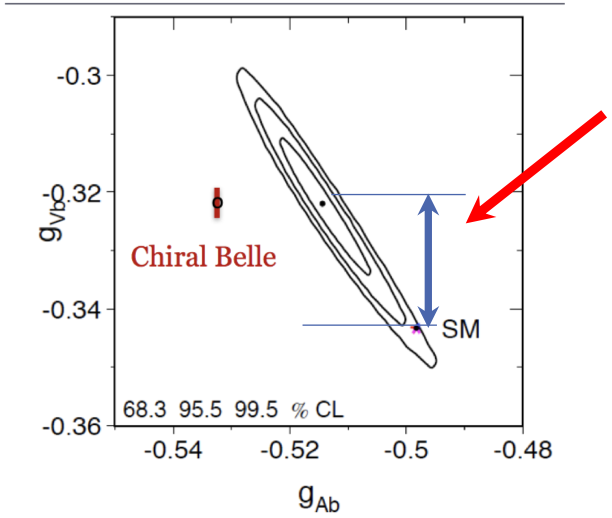
Large improvements over LEP for c-quark and b-quark couplings

c-quark:
Chiral Belle ~6 times more precise



b-quark:
Chiral Belle ~4 times more precise

with 20 ab^{-1}



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

Chiral Belle probes both high and low energy scales

Universality of Fermion Couplings to the Z^0

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

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

- With A_{LR} for all 3 charged leptons plus b-quark and c-quark
- Ratios of pairs of these cancels <Pol>, the dominant systematic uncertainty
- Produces VERY high precision evaluation of Standard Model predictions of the ratios
- The precision scales with square root of luminosity

The b-to-c ratio for example:

- With 40 ab^{-1} of data Chiral Belle achieves a 0.3% relative error for b-to-c ratio, *cf* 4.8% of the current World Average value, >14 fold improvement
- 20 ab^{-1} of data Chiral Belle achieves a 0.4% relative error for b-to-c ratio, >10 x improvement

With only 1 ab^{-1} of data: achieves more than twice the precision of the current World Average

With 70% polarized electron beam get unprecedented precision for neutral current vector couplings

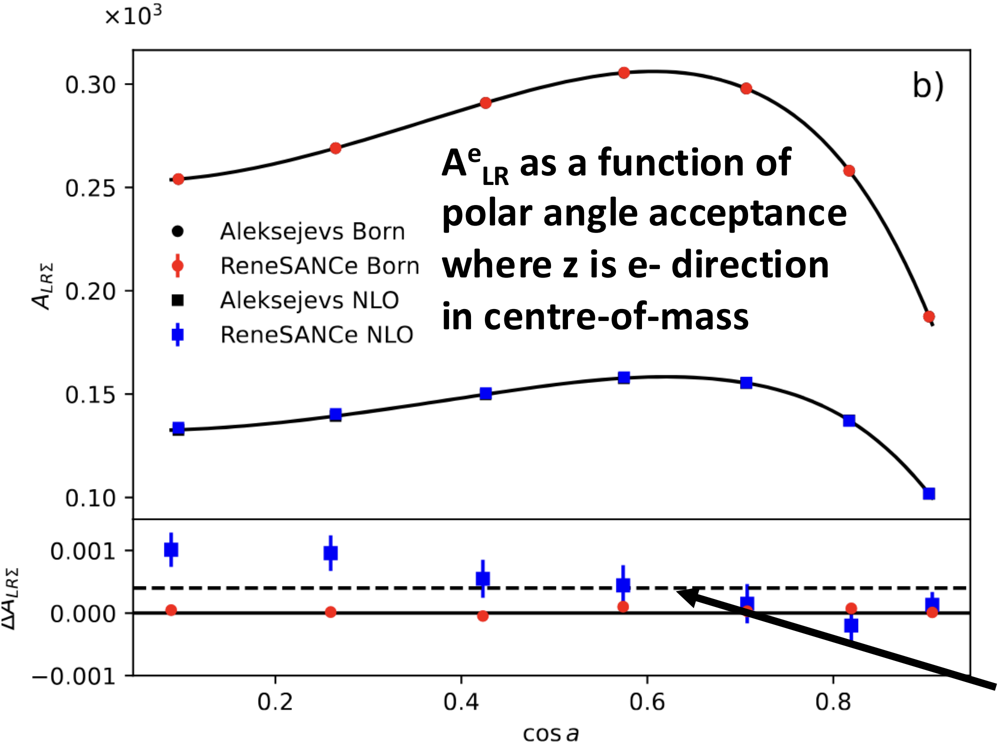
Final State Fermion	SM A_{LR} (statistical error & sys from 0.5% P_e) for 40 ab^{-1}	Relative Error
b-quark (selection eff.=0.3)	-0.0200 ±0.0001	0.5%
c-quark (eff. = 0.3)	+0.00546 ±0.00003	0.5%
tau (eff. = 0.25)	-0.00064 ±0.000015	2.4%
muon (eff. = 0.5)	-0.00064 ±0.000009	1.5%
Electron (barrel) (eff. = 0.36)	+0.00015 ±.000003	2.0%

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

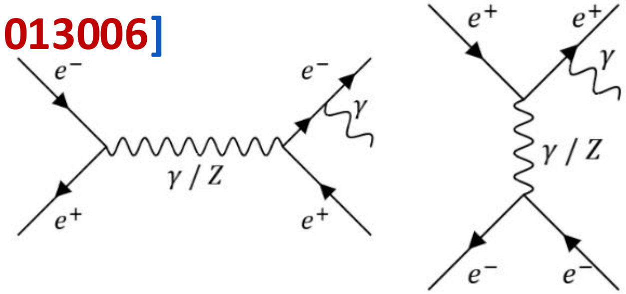
$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

Comparing Two Bhabha NLO Theory Calculations of A_{LR}

***Left-right asymmetry calculation comparisons and projected sensitivity to the weak mixing angle in polarized Bhabha scattering at 10.58GeV*, [Miller&Roney, Phys.Rev.D 112 (2025) 1, 013006]**



A^e_{LR} as a function of polar angle acceptance where z is e- direction in centre-of-mass



Study compares calculations of ReneSANCe Monte Carlo generator

[R. Sadykov and V. Yermolchyk, Computer Physics Communications 256, 107445 (2020)]

with those of an independent NLO calculation

[A. G. Aleksejevs, S. G. Barkanova, Y. M. Bystritskiy, and V. A. Zykunov, Physics of Atomic Nuclei 83, 463 (2020)]

The average absolute difference between the calculations is $4.4\text{x}10^{-7}$ equivalent to a **relative difference of 0.3%**

Difference is much smaller than projected experimental uncertainty using Bhabha acceptance in central part of Belle II (| cos θ | < 0.819)

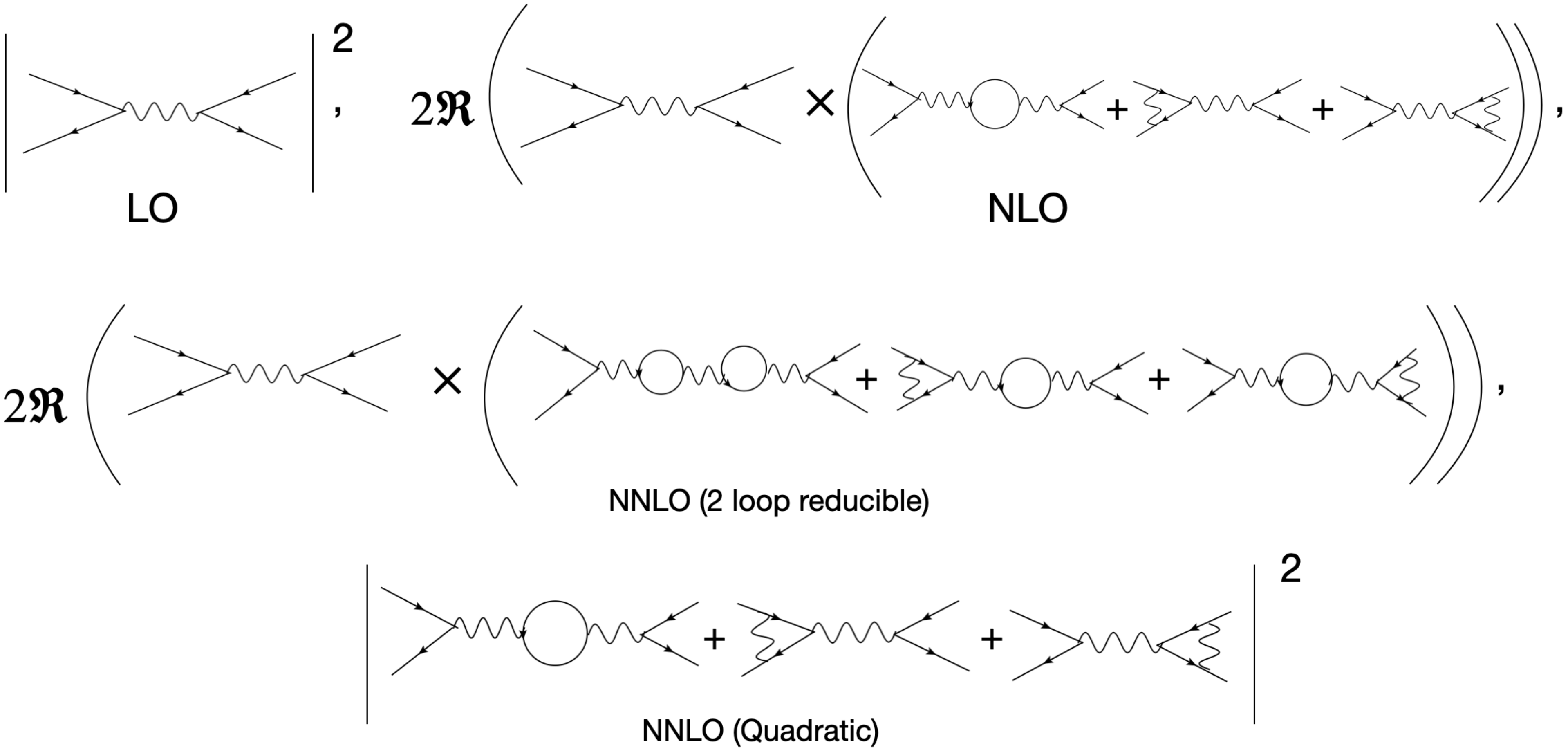
[F. Abudinén et al, Belle II Collaboration, Chin.Phys.C 44 (2020) 2, 021001
Reports: Cross-section = 17.4nb, efficiency=36%]

With 40ab^{-1} and 70% polarization at the IP:
For | cos θ | < 0.819, project a Chiral Belle uncertainty on A^e_{LR} of ±2.3%(stat) ±1%(sys) → $\sigma_{\sin 2\theta W}$ = ±0.00032
For | cos θ | < 0.9 → $\sigma_{\sin 2\theta W}$ = ±0.00028. **Motivates calculation of NNLO contributions, which are not negligible at this level**

Next steps… work on getting to NNLO

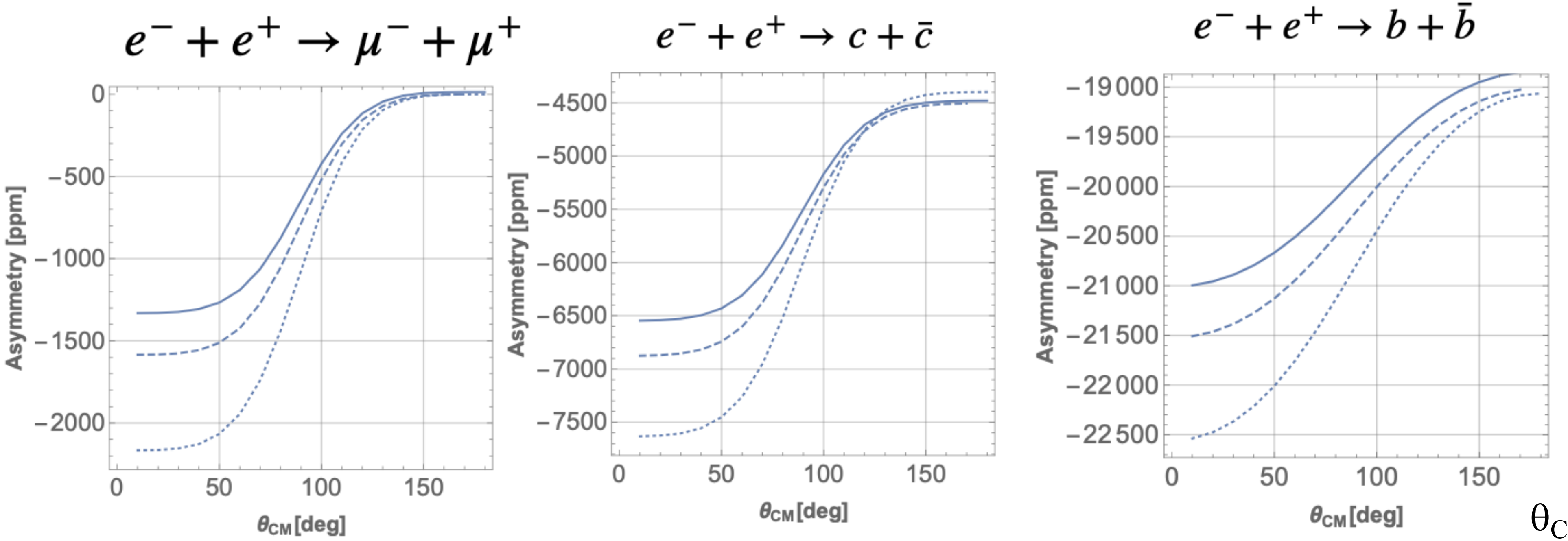
*A. Aleksejevs, S. Barkanova, **M. Ghaffar**, Reefat* (Memorial University of Newfoundland)

Topology Graphs up to NNLO



Next steps… work on getting to NNLO

A. Aleksejevs, S. Barkanova, ***M. Ghaffar****, Reefat* (Memorial University of Newfoundland)



STAY TUNED!

θ_{CM} is Polar angle of the final state fermion in e+e- rest frame

A_{LR} obtained using covariant approach

- Box diagrams and bremsstrahlung not included
- Results are UV and IR finite

……. Tree A_{LR}

- - - - Tree+NLO A_{LR}

—— Tree+NLO+Qud+2Loop-red A_{LR}

With 70% polarized electron beam get unprecedented precision for neutral current vector couplings

Final State Fermion	**SM** $g_V^f(M_Z)$	**World Average**[1] g_V^f	**Chiral Belle** $\sigma(g_V^f)$ **1** $\mathbf{ab^{-1}}$	**Chiral Belle** $\sigma(g_V^f)$ **20** $\mathbf{ab^{-1}}$	**Chiral Belle** $\sigma(g_V^f)$ **40** $\mathbf{ab^{-1}}$	**Chiral Belle** $\sigma\ \sin^2\Theta_W$ **40** $\mathbf{ab^{-1}}$
b-quark (eff.=0.3)	-0.3437±.0001	-0.3220±0.0077 (high by 2.8σ)	0.0022 Improve x3	0.002 Improve x4	0.002	0.003
c-quark (eff. = 0.3)	+0.1920±.0002	+0.1873 ± 0.0070	0.0036 Improve x2	0.001 Improve x6	0.001	0.0008
Tau (eff. = 0.25)	-0.0371 ±.0003	-0.0366 ± 0.0010	0.0049	0.001 (similar)	0.0008 Improve	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667±0.0023	0.0031	0.0007 Improve x 3	0.0005 Improve x 4	0.0003
Electron (17nb, eff=0.36)	-0.0371 ±.0003	-0.03816±0.00047	0.0039	0.0009	0.0006 (similar)	0.0003

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

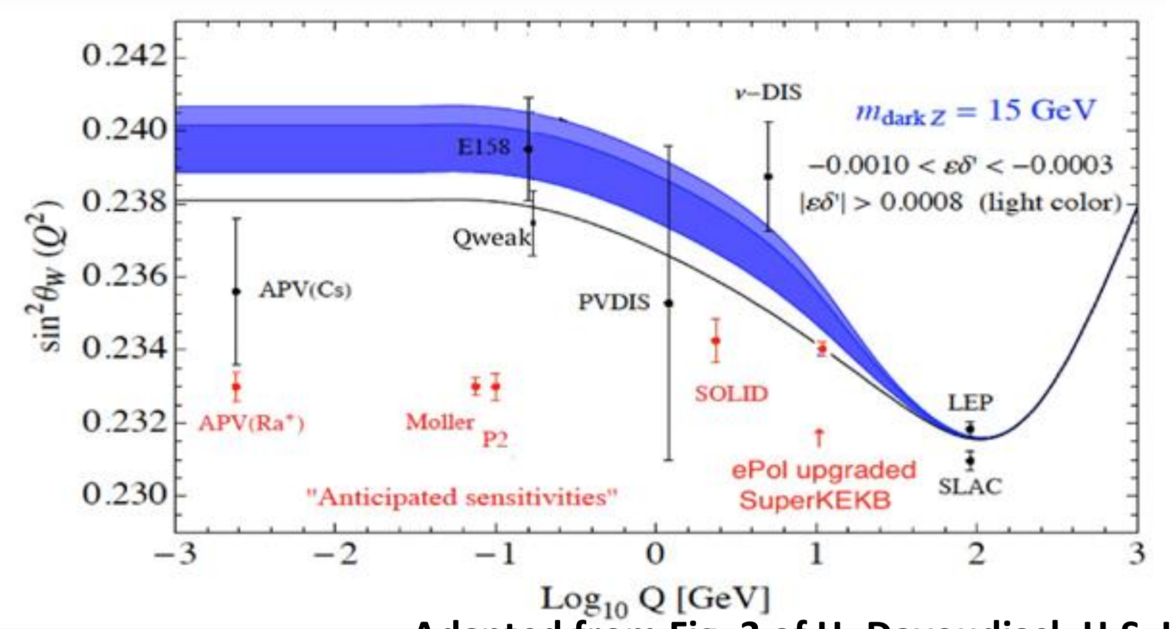
$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

$\sin^2\Theta_W$ - Chiral Belle combined leptons with 40 ab^{-1} have error ~current WA but at 10GeV

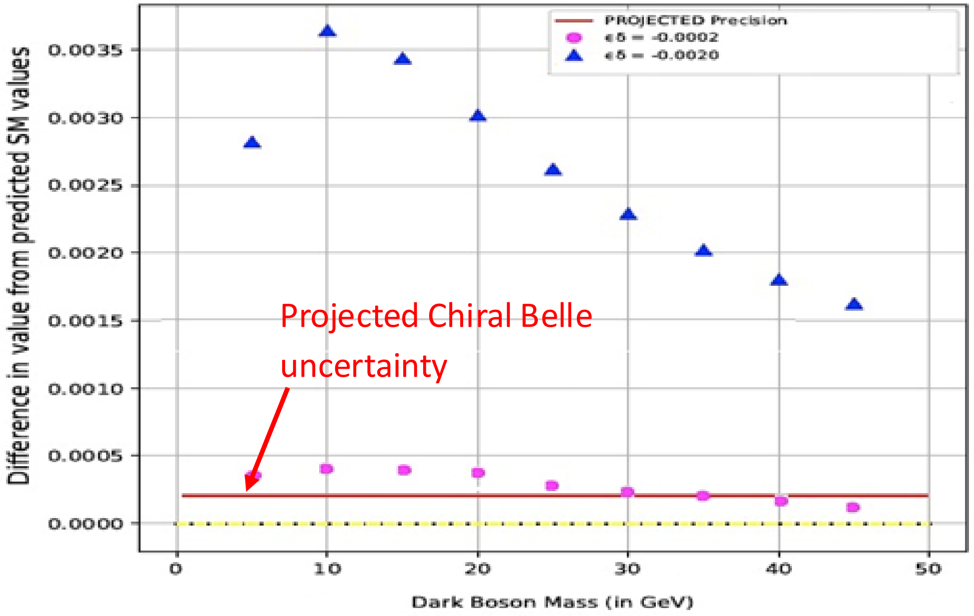
Upgrading SuperKEKB with e- Polarized Beams:
Chiral Belle → unique probe of Dark Sector

Running of $\sin^2\Theta_W$: Parity Violation 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



- **Adapted from Fig. 3 of H. Davoudiasl, H.S. Lee and W.J. Marciano, Phys.Rev.D 92(5),2015** "Low Q^2 weak mixing angle measurements and rare Higgs decays"
- **Red bar shows expected ±1 sigma uncertainty 0.00018 with 40 ab^{-1} at Chiral Belle**
- **Also sensitive to parity violation induced by exchange of heavy particles e.g. a hypothetical TeV-scale Z' boson, which if couples only to leptons will be produced @ Belle II but not in pp collisions**
- **Separately sensitive to e, μ, τ, c, b**

Precision weak mixing angle $\sin^2\theta_W$

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

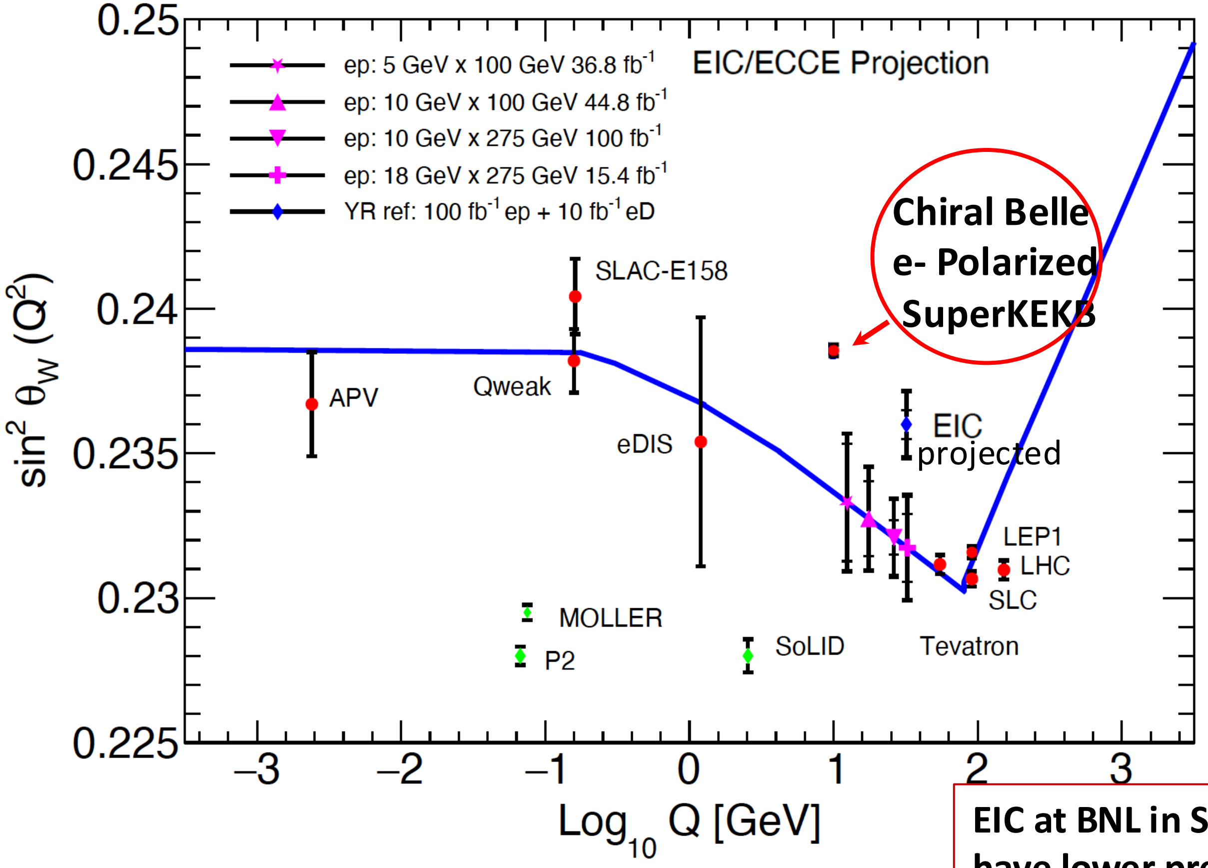


Figure Adapted from *Phys Rev D 106, 016006 (2022)*
(used in EIC Snowmass Whitepaper *arXiv:2203.13199v2)*
using data from PDG 2022 EW review (Erler&Freitas)

Chiral Belle:
σ = 0.00018 with 40ab^{-1}
Using only clean leptonic states (common <Pol> systematic included)

- **Precision probe of running of $\sin^2\theta_W$**
- **Being away from Z-pole opens NP sensitivities not available at the pole**

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

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**

New Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

A. Aleksejevs, S. Barkanova, M. Ghaffar, ***Reefat*** (Memorial University of Newfoundland)

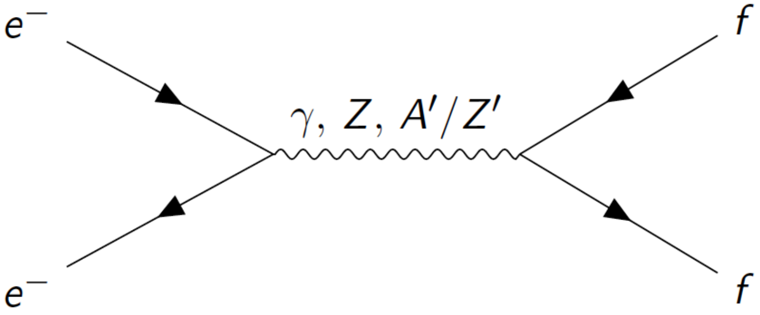
Motivation

Why Light Dark Vectors?

- SM tested at per-mil level; dark matter and matter–antimatter asymmetry remain unexplained.
- Minimal $U(1)'$ extensions introduce a dark vector communicating via kinetic mixing.
- Suppressed coupling $|\epsilon| \ll 1$ makes mediators elusive but testable at e^+e^-.

This Work

- Full NLO electroweak calculation of A_{LR} for $e^+e^- \to f\bar{f}$ ($f = \mu, \tau, b, c$).
- Exclusion contours for dark photon and dark Z' over 1–16 GeV.



Key observable:

$$A_{\mathrm{LR}} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

Isolates parity-violating interference.

STAY TUNED!

Chiral Belle physics broader program includes:

- Tau Lepton Magnetic Form factor $F_2(10GeV) \rightarrow \tau$ g-2
  - Detector level systematics cancels in asymmetries between left (right) beams.
  - Precision $\simeq 10^{-5}$ expected with 40 ab^{-1} of data with polarized beam with 60% selection efficiency of semileptonic tau decays
  - 1000 x more precise than current limits (with only 1 ab^{-1} ~100x more precise than current limits)

- Greater than Order of Magnitude Improved precision measurements of τ Michel Parameters

- τ electric dipole moment (EDM)

- 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

Some 2025 papers on measuring magnetic dipole moment of τ at Chiral Belle

Towards Testing $(g-2)_\tau$ *in* $e^+e^- \rightarrow \tau^+\tau^-$*: radiative corrections and projections for Belle II*
J. Gogniat, M. Hoferichter and Y. Ulrich, JHEP 07(2025) 172, arXiv:2505.09678 **(July 2025)**

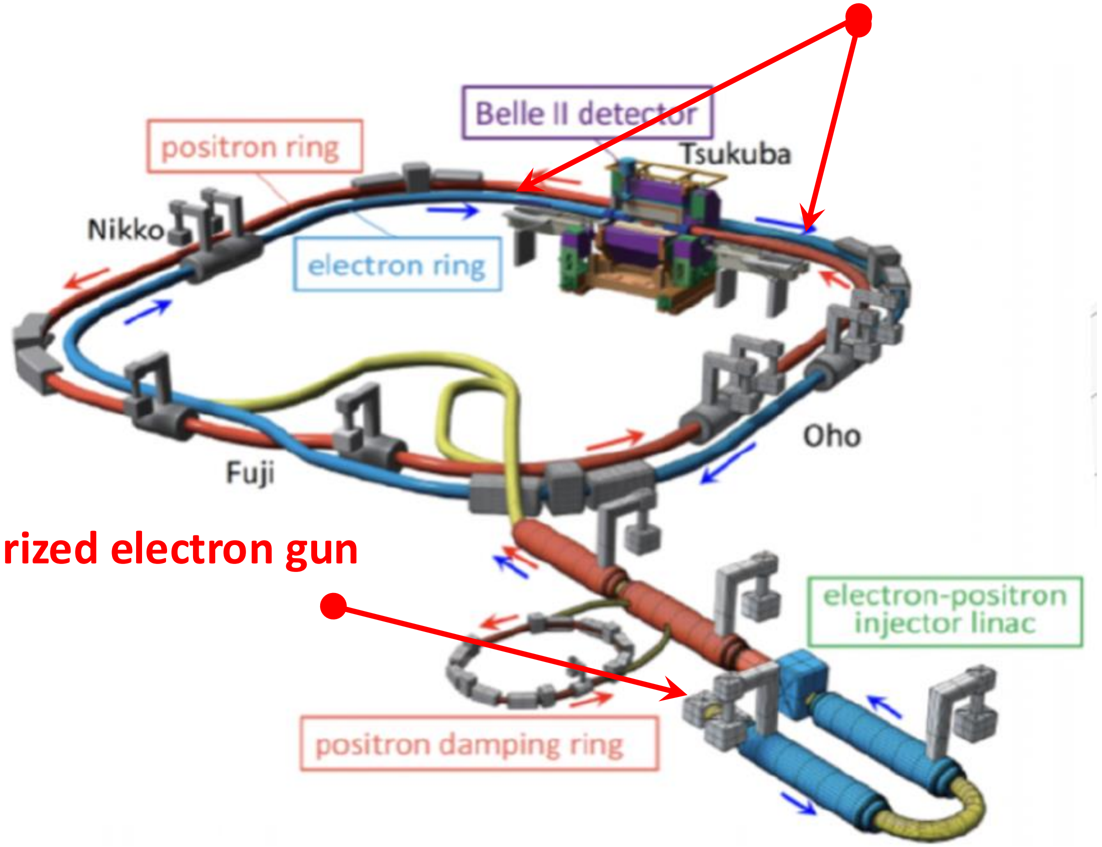
Light new physics and the τ *lepton dipole moments: prospects at Belle II*
M. Hoferichter and Gabriele Levati (2510.13966 [hep-ph], **Oct 15, 2025)**

Complete one-loop result for the fully polarized $e^+e^- \rightarrow \tau^+\tau^-$ *process and its implementation in the Monte-Carlo integrator McMule* **[Joël Gogniat, M. Hoferichter and Y. Ulrich, JHEP 07(2025) 172**

e- beam polarization in SuperKEKB

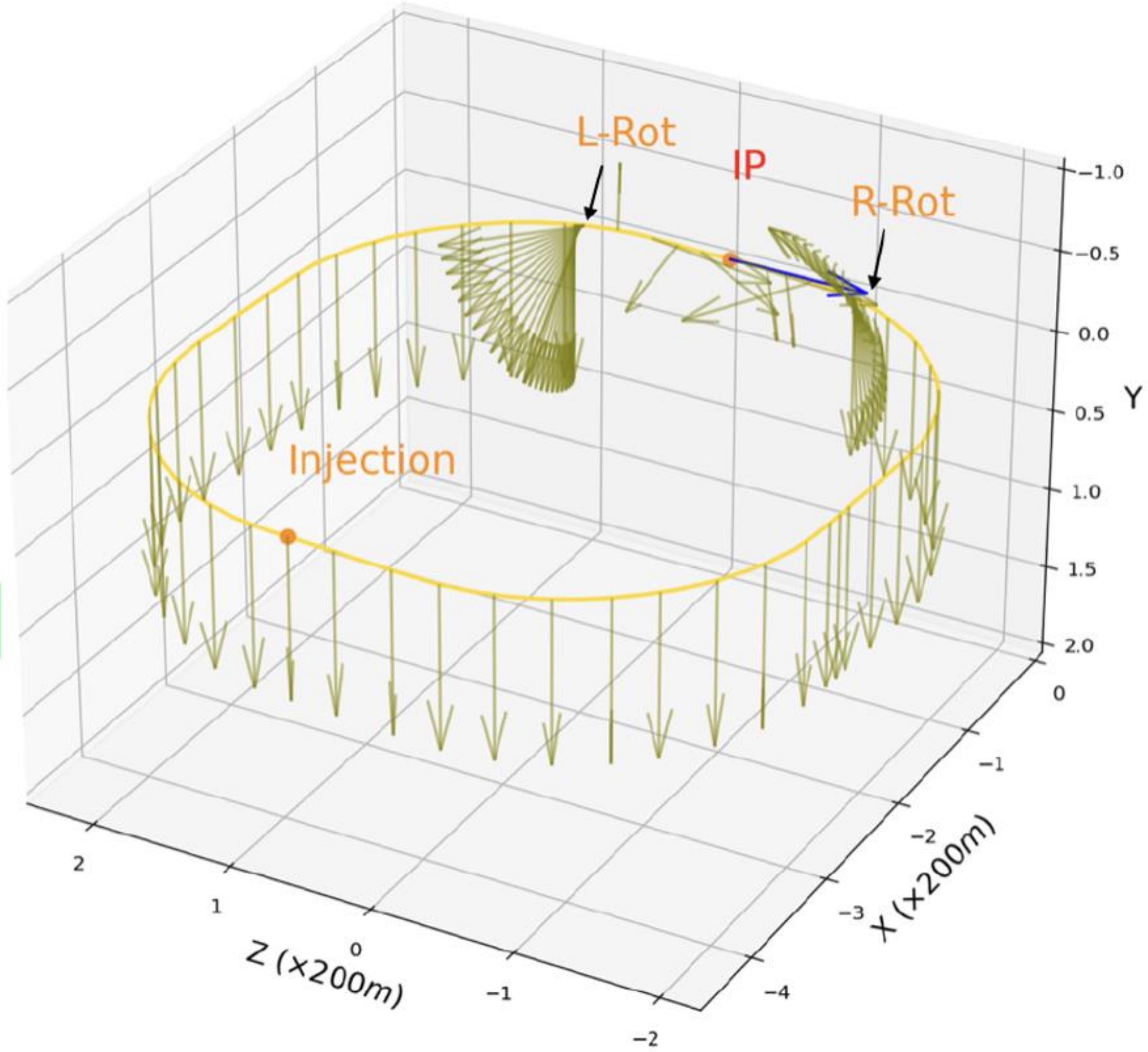
- **Goal is 70% polarization with 80% polarized source producing longitudinal electron spins at source**
- **Electron helicity changed by controlling the circular polarization of the source laser illuminating a GaAs photocathode**
- **Inject transversely (vertically) polarized electrons into the High 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 at <0.5%**

e- beam polarization in SuperKEKB



Spin rotators

Polarized electron gun



e- beam polarization in SuperKEKB

Requires both: high SuperKEKB luminosity and e- beam polarization

- **Polarized Source R&D highly synergistic with other international efforts, e.g. EIC – work is progressing to improve photocathode lifetimes**

e- beam polarization in SuperKEKB

Requires both: high SuperKEKB luminosity and e- beam polarization

- **Polarized Source R&D highly synergistic with other international efforts, e.g. EIC – work is progressing to improve photocathode lifetimes**
- **Precise polarization measurement (require 0.5% precision)**

e- beam polarization in SuperKEKB

Requires both: high SuperKEKB luminosity and e- beam polarization

- **Polarized Source R&D highly synergistic with other international efforts, e.g. EIC – work is progressing to improve photocathode lifetimes**
- **Precise polarization measurement (require 0.5% precision)**

Compton Polarimetry Publication:

2023 JINST 18 P10014

"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]*

*[a]IJCLab, [b]KEK , *corresponding author*

Precision: 1% (stat) in 5min, <0.5% (syst)

Polarimeter between spin rotator and IP

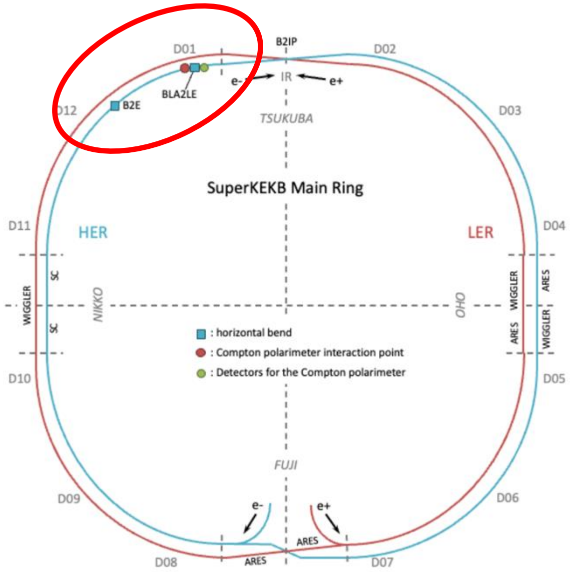


Figure 1. Schematic drawing of the main SuperKEKB ring, where the current B2E dipole to be replaced by spin rotators is identified. The location of the Compton polarimeter is also shown as well as Belle II interaction point.

e- beam polarization in SuperKEKB

Requires both: high SuperKEKB luminosity and e- beam polarization

- **Polarized Source R&D highly synergistic with other international efforts, e.g. EIC – work is progressing to improve photocathode lifetimes**
- **Precise polarization measurement (require 0.5% precision)**

Compton Polarimetry Publication:

JINST **_2023 JINST 18 P10014_**

"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]*

*[a]IJCLab, [b]KEK , *corresponding author*

Precision: 1% (stat) in 5min, <0.5% (syst)

Polarimeter between spin rotator and IP

Tau Polarimetry Publication:

PHYSICAL REVIEW D ***Phys.Rev.D*** **108 (2023) 9, 092001**

arXiv:2308.00774 (C. Miller corresponding author)

"Precision e^- Beam Polarimetry at an e^+e^- B-Factory using Tau-Pair Events"

BABAR Collaboration, J.P. Lees et al

New technique: uses sensitivity of τ decay kinematics to polarization of beams

Precision: 0.34% (stat) in 424fb^{-1}, 0.29% (syst)

Polarization measured at IP

e- beam polarization in SuperKEKB

Requires both: high SuperKEKB luminosity and e- beam polarization

- **Polarized Source R&D highly synergistic with other international efforts, e.g. EIC – work is progressing to improve photocathode lifetimes**
- **Precise polarization measurement (require 0.5% precision)**

Compton Polarimetry Publication:

Jinst ***2023 JINST 18 P10014***

"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]*
*[a]IJCLab, [b]KEK , *corresponding author*

Precision: 1% (stat) in 5min, <0.5% (syst)
Polarimeter between spin rotator and IP

Tau Polarimetry Publication:

PHYSICAL REVIEW D ***Phys.Rev.D* 108 (2023) 9, 092001**
arXiv:2308.00774 (C. Miller corresponding author)

"Precision e^- Beam Polarimetry at an e^+e^- B-Factory using Tau-Pair Events"

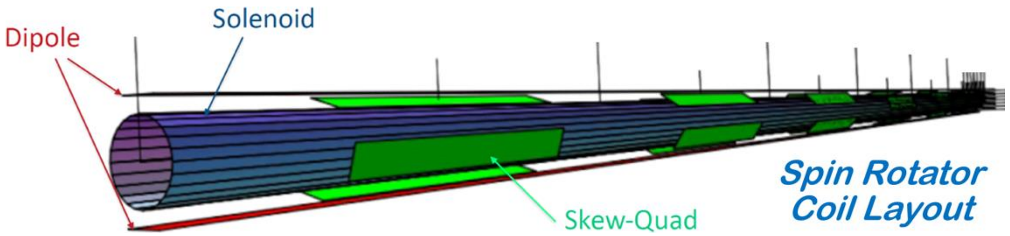
BABAR Collaboration, J.P. Lees et al

New technique: uses sensitivity of τ decay kinematics to polarization of beams

Precision: 0.34% (stat) in 424fb^{-1}, 0.29% (syst)
Polarization measured at IP

- **Requires spin rotators in HER that do not reduce the luminosity (i.e. "transparent" to the lattice) – high luminosity is required for Chiral Belle**

Compact spin rotator



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

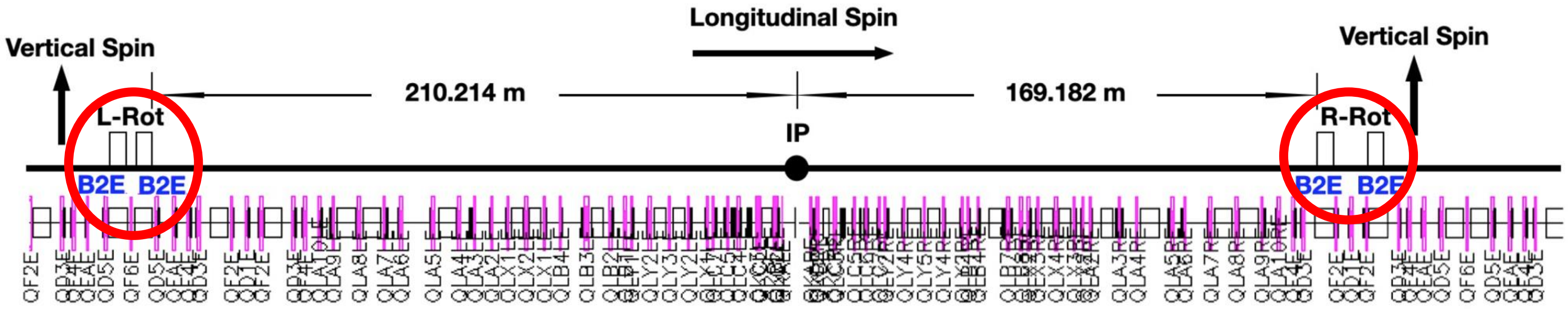
- **Replace 2 existing ring dipoles on each side of the IP with the dipole-solenoid combined function magnets and keep the original dipole strength to preserve the machine geometry**
- **Avoids repositioning of other magnets in the ring**
- **Install 6 skew-quadruple on top of each rotator section to 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)

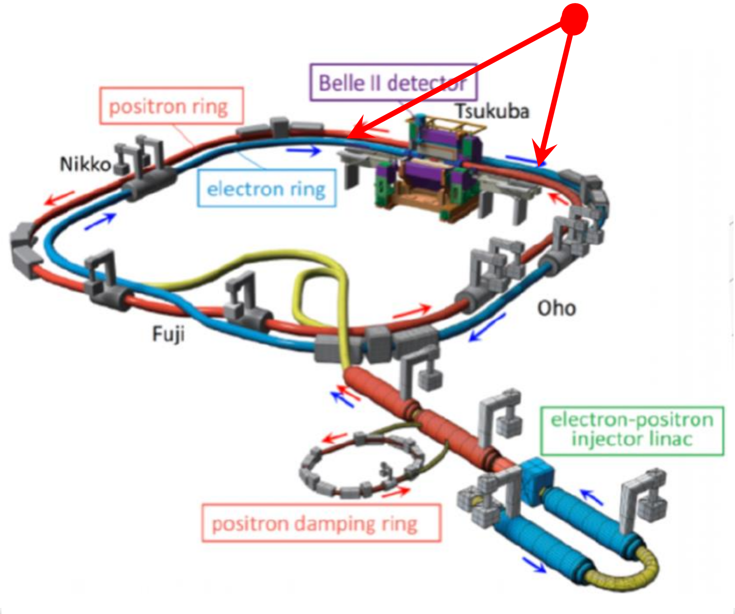
Compact spin rotator

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



Existing HER Lattice elements →

Spin rotators



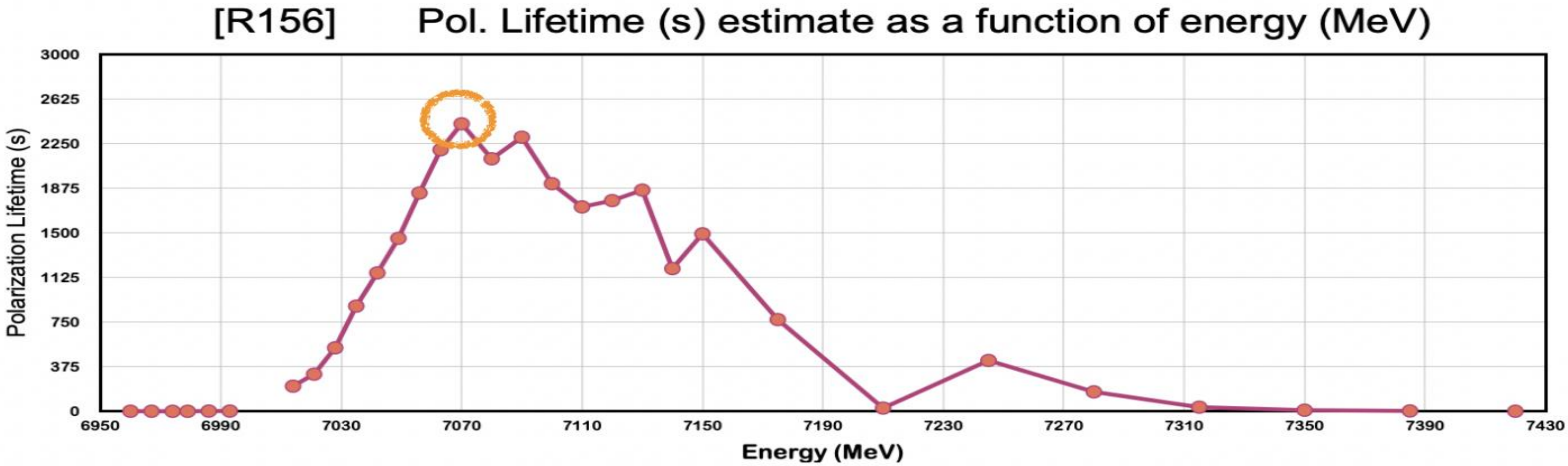
- Left Rotator (L-Rot) rotates the spin from the vertical to the horizontal plane
- Right Rotator (R-Rot) rotates the spin back to the vertical direction
- 4 **B2E** dipoles in existing High Energy Ring shown above to be replaced with the spin rotator magnets

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

[R156]



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:

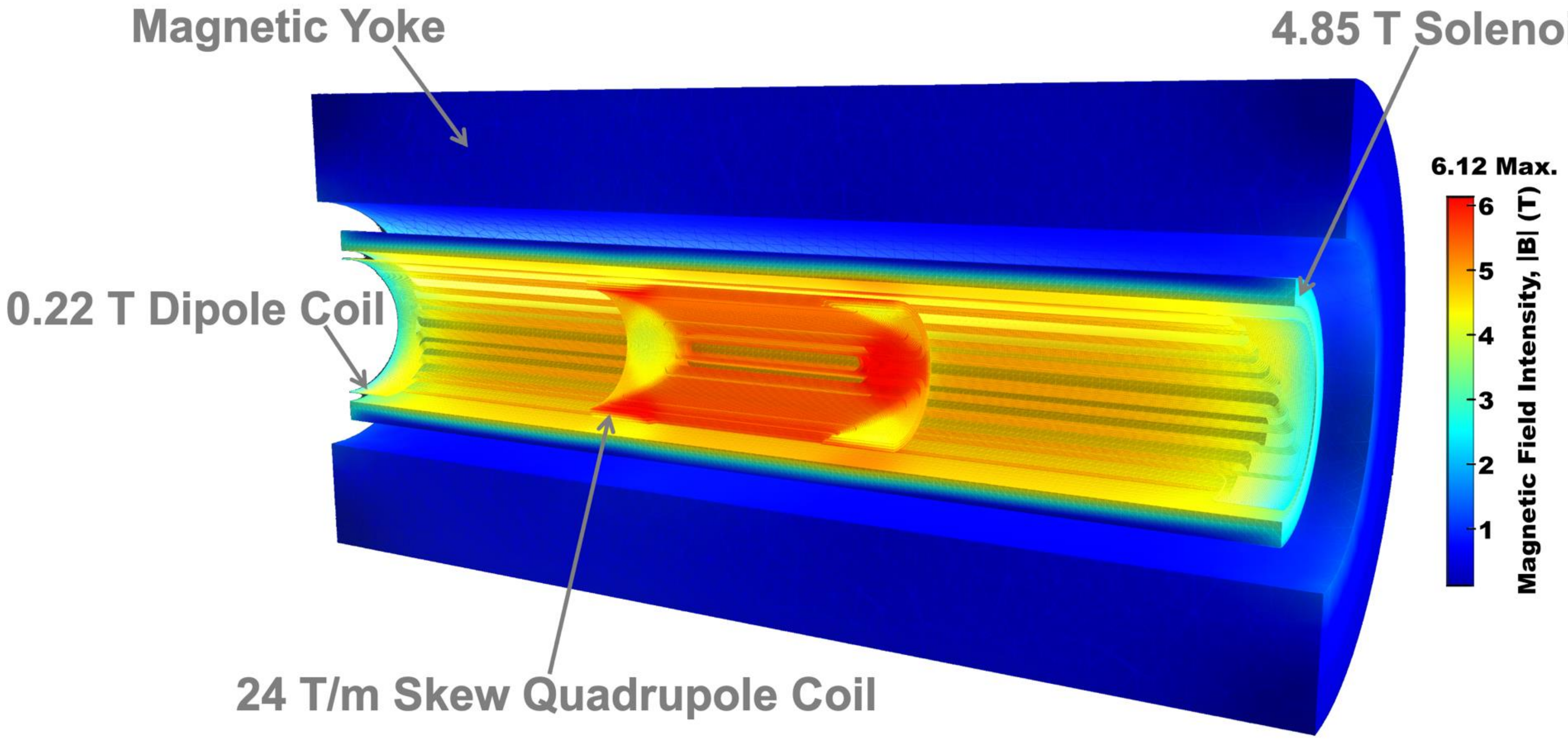
Beam is stable with compact spin rotators (5x10^6 turns with 20 particles – no lost particles)

Good polarization lifetime (25 minutes ~10 top-up times) with HER energy of 7.05GeV (~0.7% [i.e.+50MeV] higher than default energy) – currently using LTT to map lifetime vs energy to maximize polarization lifetime & for resonant depolarization considerations

Compact Spin Rotator provides solution to transparency with minimal changes to lattice AND ability to have SuperKEKB with no spin rotator when we do not run with polarized beams – LTT studies show minimal impact on beam & polarization lifetimes

from Brett Parker (BNL) presentation eeFACT2025
“A novel spin rotator concept for longitudinally polarized beam for Chiral Belle at SuperKEKB”

¼-Length Chiral Belle Spin Rotator Demonstration Prototype



Brookhaven National Laboratory

Discovery Technologies Directorate

7

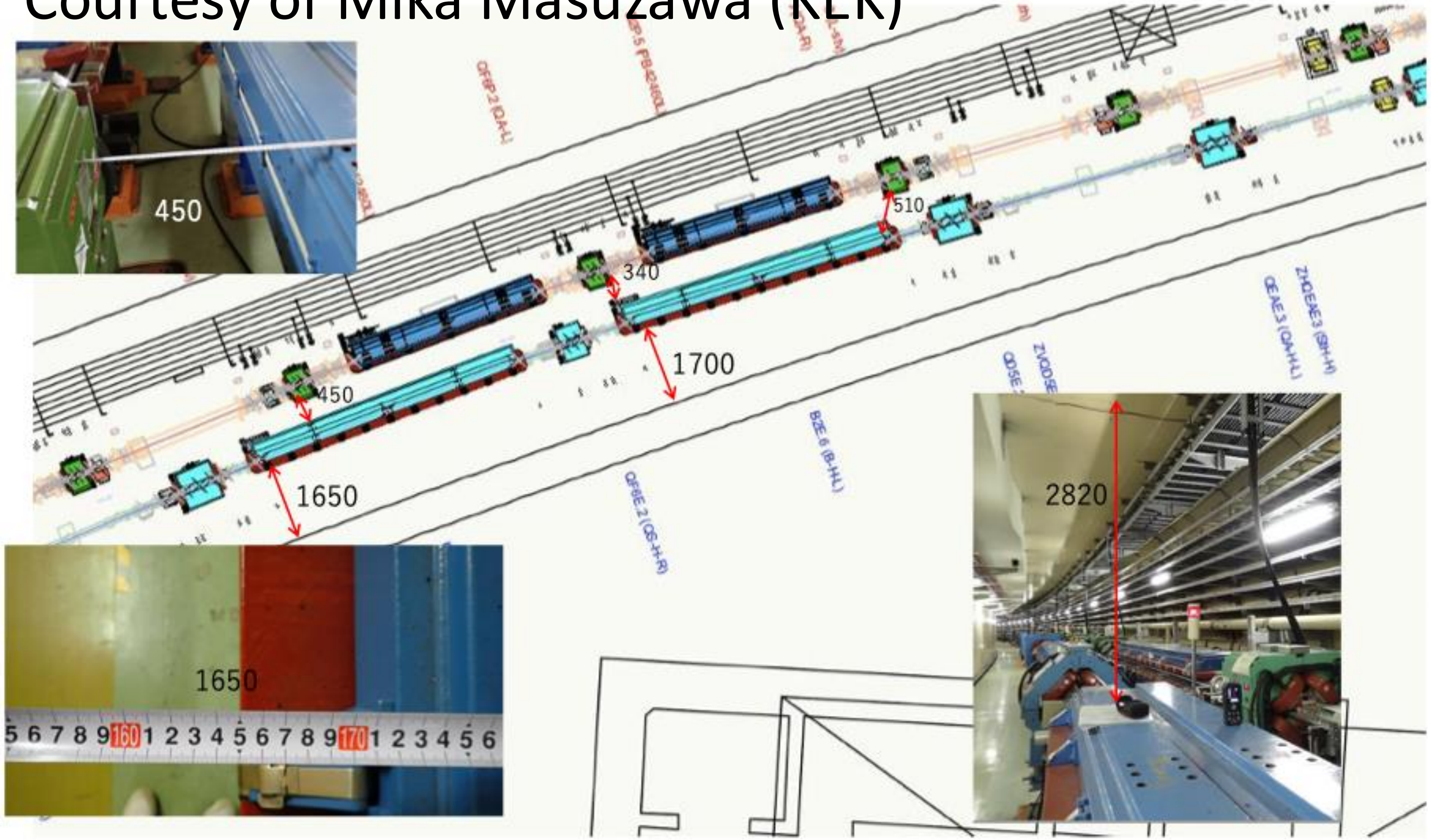
R&D Work on Compact Spin Rotator and Compton Polarimeter

- Funding for this compact spin rotator prototype magnet approved by Canadian Foundation for Innovation grant (CFI component: $4.17M)
- Includes request for funds in Canada for Compton polarimeter R&D work at University of Manitoba
- Matching funds from Japan to develop source in parallel with work at KEK to improve SuperKEKB luminosity and funds in France for Compton polarimeter R&D work

- Now setting up the contract with BNL to start engineering design of prototype
- Work on the Compton polarimeter electron detector system continues - currently validating initial proposal for its location in the HER using an existing lattice dipole to bend the trajectory of the scattered Compton electron

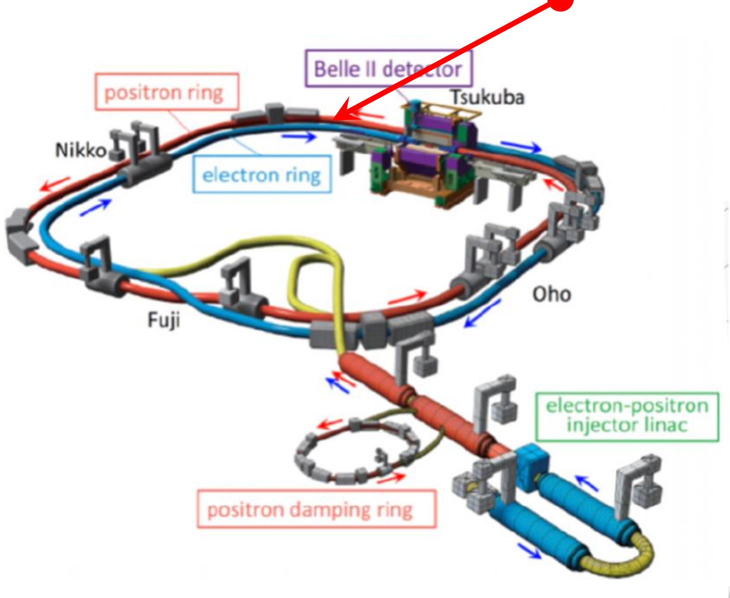
15 June 2026 Survey of HER Tunnel on left side of IP

Courtesy of Mika Masuzawa (KEK)



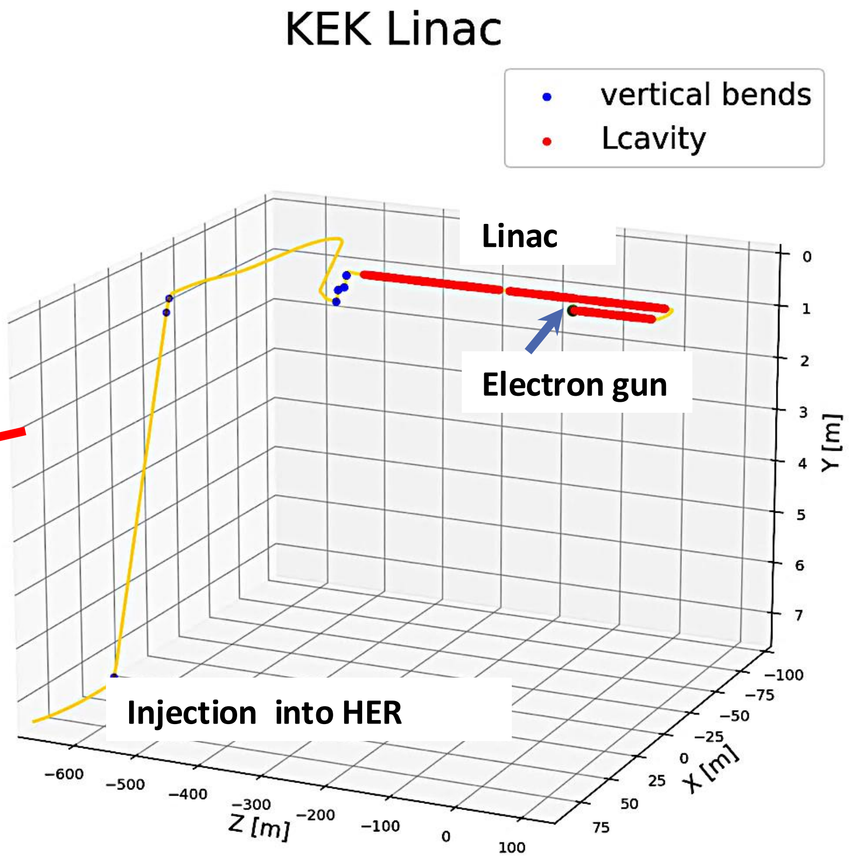
Study of space constraints
- important for cryocoolers
- initial indications: these constraints are not a problem

Left Spin Rotator survey location



Proposing to put LTT studies to the test with data in a dedicated ~ 1 - 2 week experiment with TRANSVERSE polarized beam to validate polarization lifetime

Inject transversely polarized beam at the HER injection point

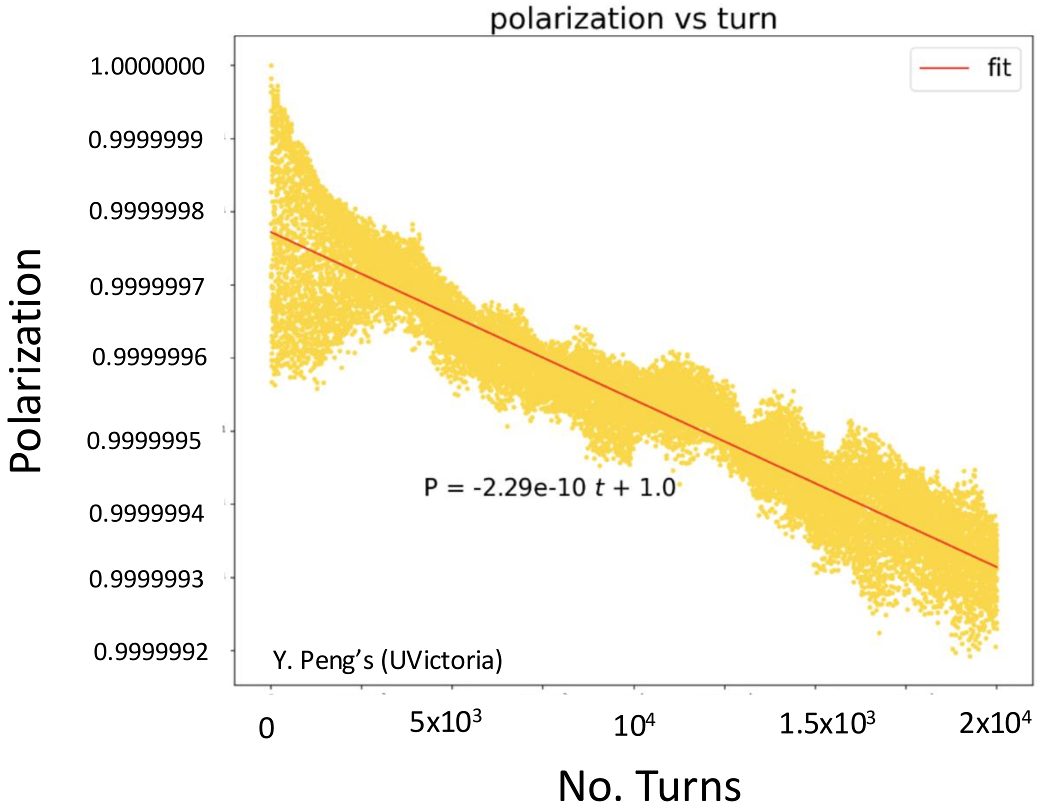


KEK Injection Linac polarization Bmad studies

KEK Injection Linac polarization Bmad studies

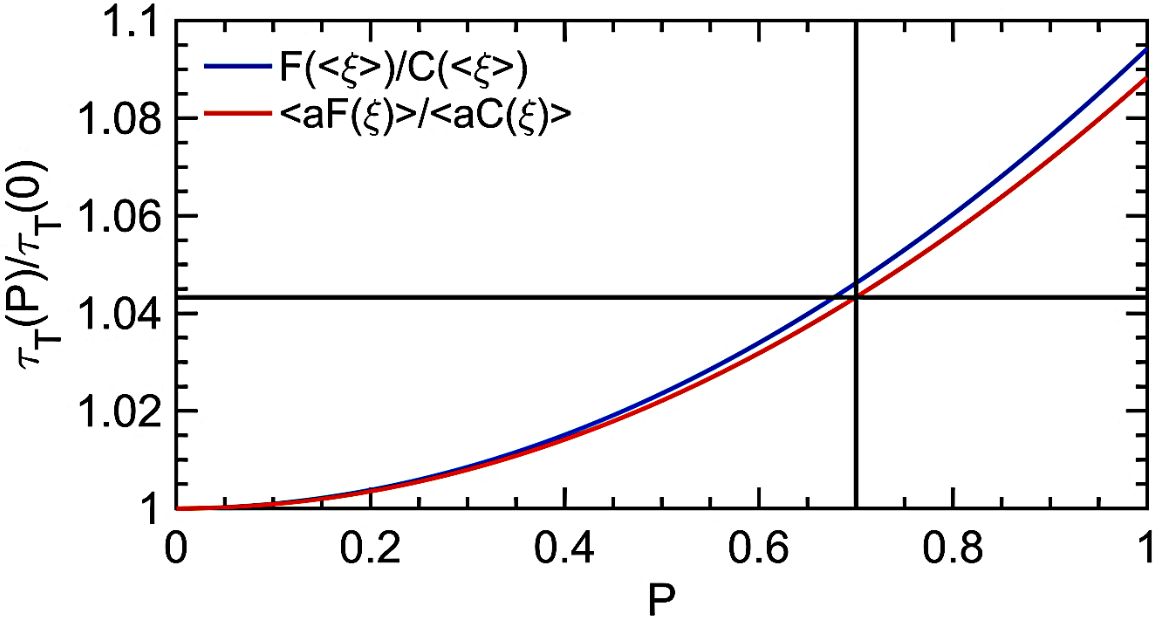
Inject transversely polarized beam at the HER injection point

Transverse polarization survival rate in HER



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

Touschek Lifetime Dependence on e- polarization



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

Belle II Background Group: measured Touschek Lifetime to ±0.2% in 2020 and 2021

Touschek lifetime measurements already performed in HER with required precision

Goals of Touschek Polarization Lifetime Experiment

- Implement transversely polarized e^- source
- Confirm large transverse polarization is transferred to HER
- Measure transverse polarization lifetime using Touschek lifetime studies to validate calculations of long spin lifetime
- Consider possible beam energy calibration for additional physics:
  - Energy calibration of HER e^- beam at the $\Upsilon(4S)$ with resonant depolarization
  - In future consider performing calibration at the narrow $\Upsilon(1S)$ resonance where CM is precisely known to also calibrate LER e+ energy - would provide precision CM energies potentially useful for tau mass and for studies above the $\Upsilon(4S)$

Preparations for Touschek Polarization Lifetime Experiment

- Polarized source including merge line of new source:
  - source designed (M. Yoshida (KEK) & A. Beaubien, UVic) now in hand and is being commissioned at KEK.
  - Work converging on solution for minimal-impact merge line in Linac source room

- Will repeat Touschek lifetime measurements in 2027 (SuperKEKB shutting down soon for 6 months maintenance and will resume operations Jan 2027)

Final approval for experiment to be requested once R&D is completed

Considering overall Chiral Belle Project Staging Options

One scenario under consideration:

Stage 1: Complete R&D on spin rotators, polarized source & Compton polarimeter - move towards final designs (R&D funding for prototypes secured)

- In parallel, prepare for and execute Touschek Polarization Lifetime experiment

Stage 2: Build & install source, spin rotators and Compton polarimeters in LS2

- Will request CFI-IF funding in 2029 competition for Stage 2

- Commission with only dipoles on
- Initial running with dedicated polarization runs and start Chiral Belle physics program
- Propose to accumulate ~ few ab^{-1} of polarized beam data in mid-2030s

Stage 3: Collect higher integrated luminosity polarization data set

- Full Chiral Belle physics program – including highest precision EW physics and high precision tau g-2 approaching 10^{-6}.

Summary

- e^- polarization upgrade at SuperKEKB coupled to high luminosity opens unique discovery windows with precision electroweak physics and broader program
- New ideas from theory community on further exploitation of polarized beam at SuperKEKB VERY WELCOME!
- Feasible Technical Realization
  - Polarized source – synergies with e.g. EIC
  - Polarimetry at <0.5%
  - Spin Rotators transparent to rest of HER lattice
- R&D on Chiral Belle spin rotators, polarization source and Compton Polarimetry is progressing
- Funded to build and test prototype of spin rotator magnet at BNL in 2027-28
- Preparing for Touschek-Polarization lifetime experiment to validate existing studies

Additional Information

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

Conceptual Design Report for polarization upgrade to be completed this year

Feasible to plan for installation and have collisions with polarization data starting while SuperKEKB completes its program of delivering 50ab^{-1} of data and to continue beyond that program

‘Chiral Belle’ Left-Right Asymmetries

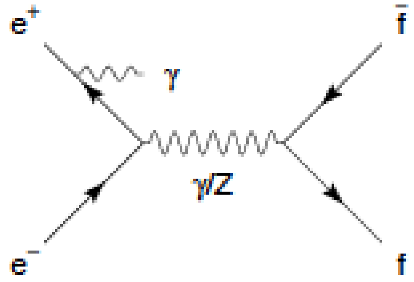
Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.

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

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

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

(for s-channel Born)



Source generates mainly right-handed electrons

Source generates mainly left-handed electrons

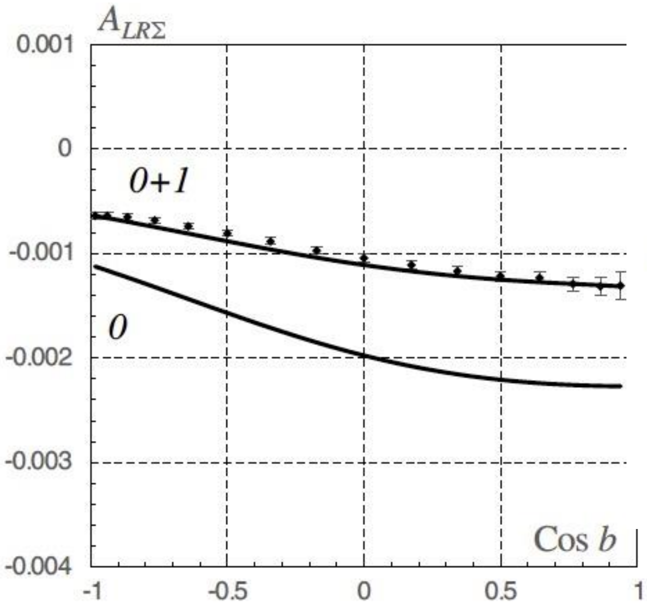
For A_{LR} calculation with NLO corrections for mu-pair final state, see:
Aleksejevs, Barkanova, Roney, Zykunov “NLO radiative corrections for Forward-Backward and Left-Right Asymmetries at a B Factory”, arXiv:1801.08510

Leptonic Left-Right Asymmetries

➤ SM Electroweak calculations at NLO:

Aleks Aleksejevs & Svetlana Barkanova, (Memorial U Newfoundland), Vladimir Zykunov & Yu.M.Bystritskiy (DUBNA)

$e^+e^- \to \mu^+\mu^-$

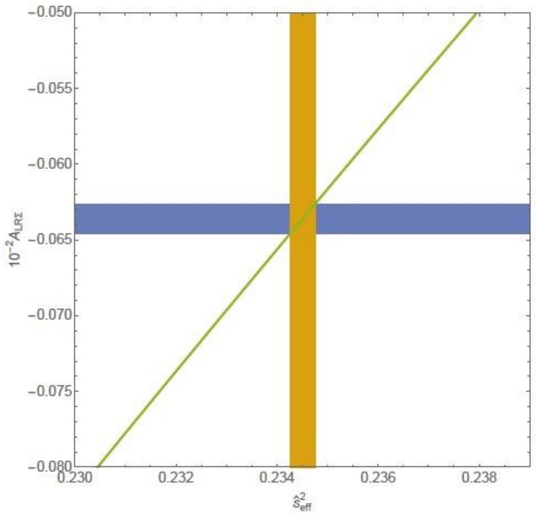


$$\Sigma_L^C = \int_{\cos b}^{\cos a} \sigma_L^C \cdot d(\cos\theta), \quad \Sigma_R^C = \int_{\cos b}^{\cos a} \sigma_R^C \cdot d(\cos\theta)$$

a=10° & energy of photons < 2GeV

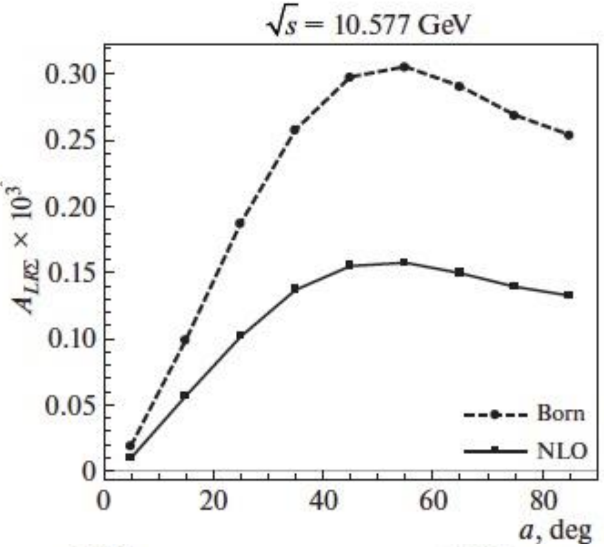
Phys.Rev. D101 (2020) no.5, 053003

$A_{LR}^{\mu\mu}$ vs $\sin^2\theta_W^{eff}$



$$A^C_{LR\Sigma} = A^C_{LR\Sigma}(a) = \frac{\Sigma_L^C - \Sigma_R^C}{\Sigma_L^C + \Sigma_R^C}$$

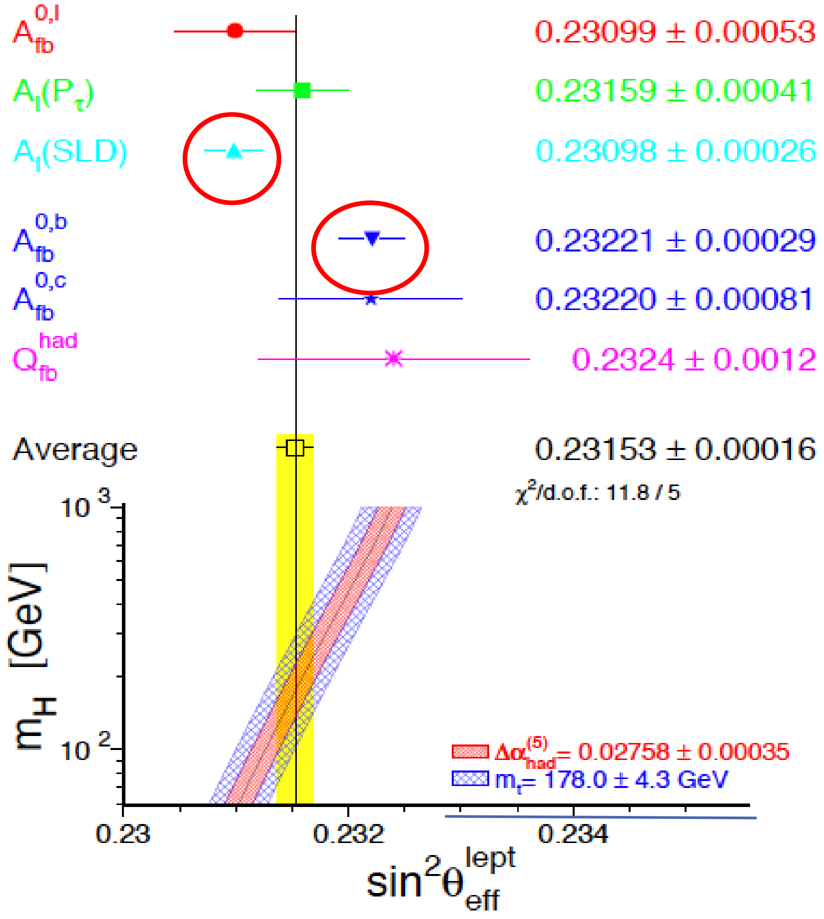
$e^+e^- \to e^+e^-$



$$\Sigma_L^C = \int_{-\cos a}^{\cos a} \frac{d\sigma^C_{L0}}{dc} \cdot dc, \quad \Sigma_R^C = \int_{-\cos a}^{\cos a} \frac{d\sigma^C_{R0}}{dc} \cdot dc.$$

PHYSICS OF ATOMIC NUCLEI Vol. 83 No. 3 2020

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)

Chiral Belle is at B-meson pair production threshold, so not limited by this

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

Dark Photon, A' Exclusion Contours

A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat

Scan Parameters

$1\ \mathrm{GeV} \leq m_{A'} \leq 16\ \mathrm{GeV}$; $\varepsilon_{Z'} = 0$ (dark photon limit);

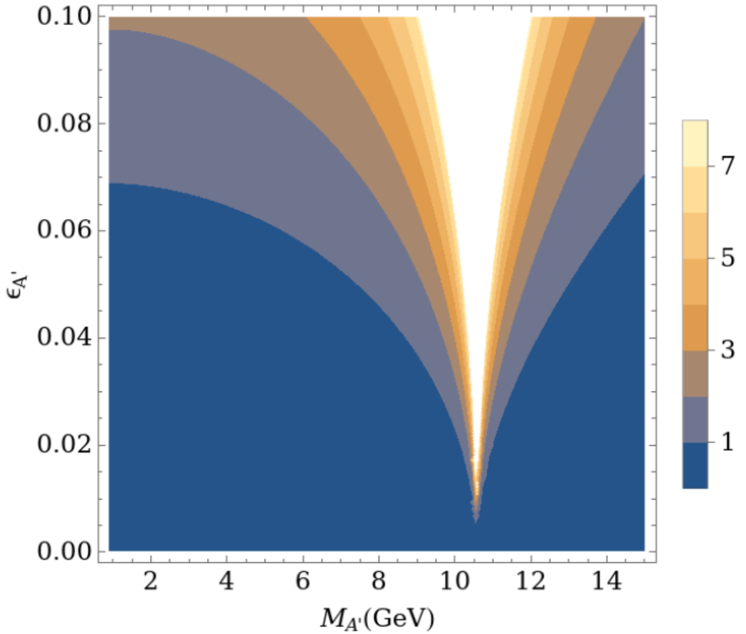


Figure: Process: $e^+e^- \to \mu^+\mu^-$. On the attached scale, the color contours at $|\Delta A_{LR}| = 1\%, 2\%$, and 3%

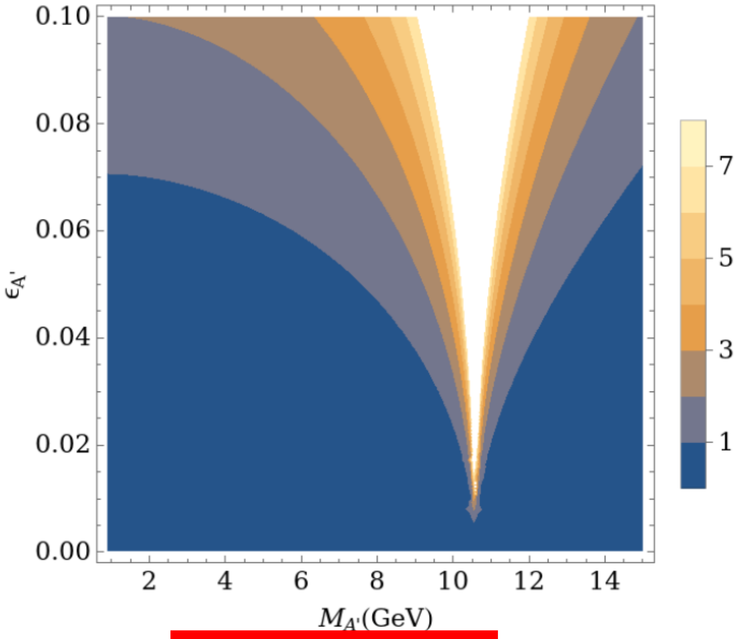


Figure: Process: $e^+e^- \to \tau^+\tau^-$. On the attached scale, the color contours at $|\Delta A_{LR}| = 1\%, 2\%$, and 3%

Dark Photon, A' Exclusion Contours

A.Aleksejevs, S. Barkanova, M. Ghaffar, Reefat

Scan Parameters

$1\ \text{GeV} \leq m_{A'} \leq 16\ \text{GeV}; \quad \varepsilon_{Z'} = 0$ (dark photon limit);

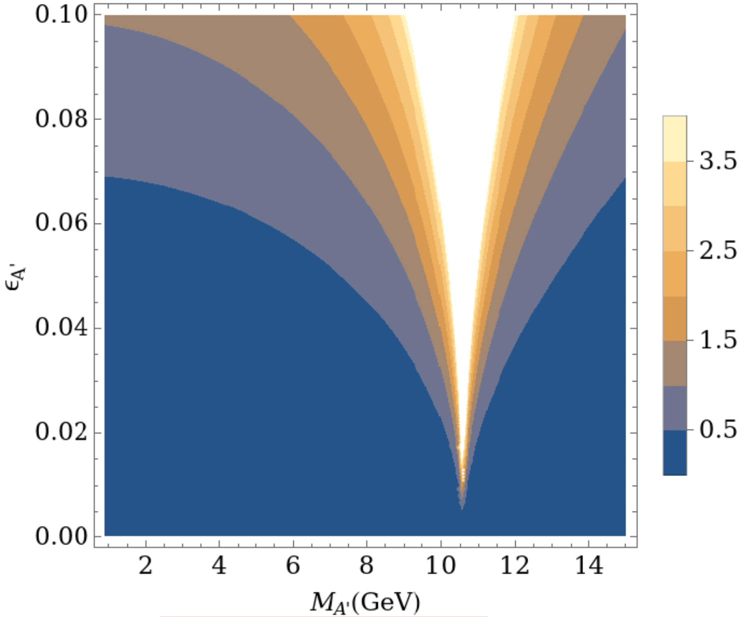


Figure: Process: $e^+e^- \to c^+c^-$. On the attached scale, the color contours at $|\Delta A_{LR}| = 1\%, 2\%$, and 3%

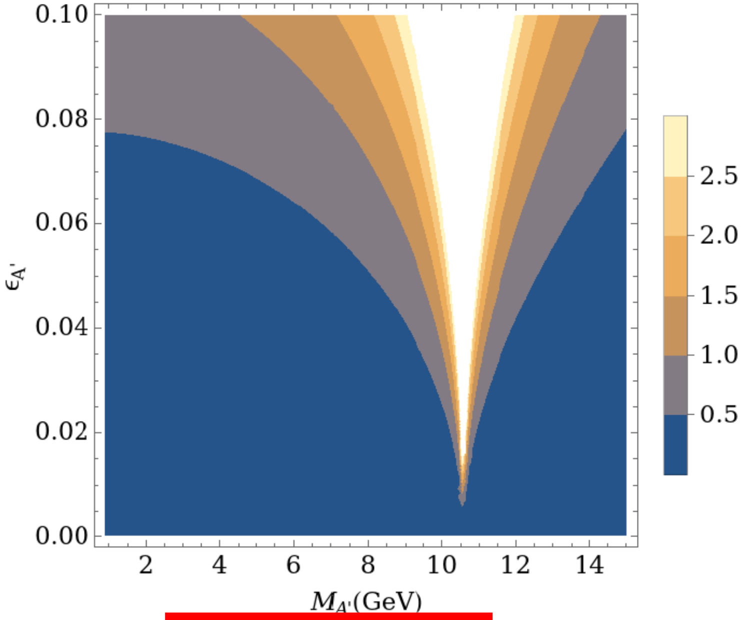
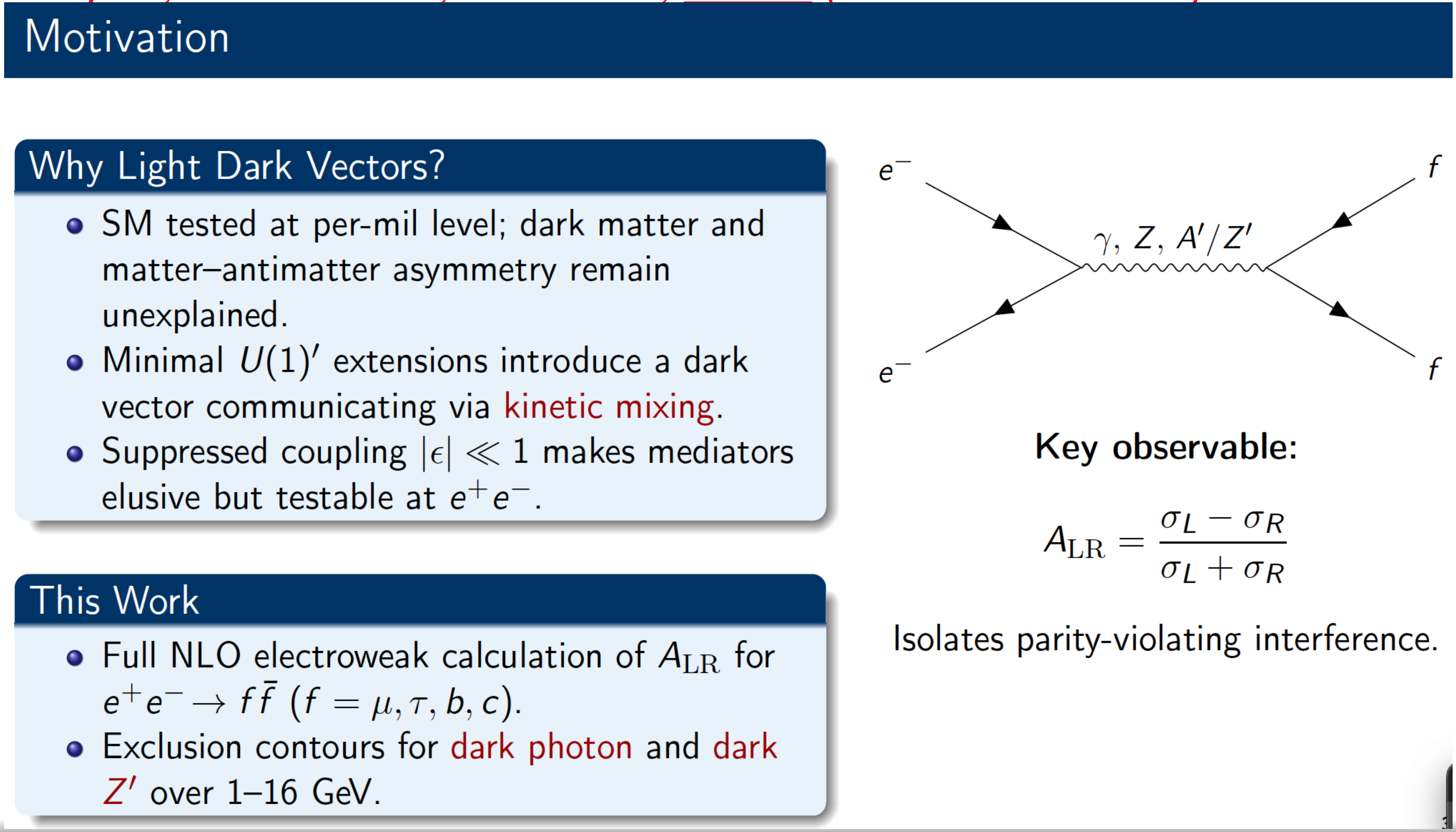


Figure: Process: $e^+e^- \to b^+b^-$. On the attached scale, the color contours at $|\Delta A_{LR}| = 1\%, 2\%$, and 3%

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

A. Aleksejevs, S. Barkanova, M. Ghaffar, ***Reefat*** (Memorial University of Newfoundland)



Motivation

Why Light Dark Vectors?

- SM tested at per-mil level; dark matter and matter–antimatter asymmetry remain unexplained.
- Minimal $U(1)'$ extensions introduce a dark vector communicating via kinetic mixing.
- Suppressed coupling $|\epsilon| \ll 1$ makes mediators elusive but testable at e^+e^-.

This Work

- Full NLO electroweak calculation of A_{LR} for $e^+e^- \to f\bar{f}$ $(f = \mu, \tau, b, c)$.
- Exclusion contours for dark photon and dark Z' over 1–16 GeV.

Key observable:

$$A_{\mathrm{LR}} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

Isolates parity-violating interference.

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat

Minimal $U(1)'$ Extension

Gauge Kinetic Lagrangian (before EWSB)

$$\mathcal{L}_{\mathrm{kin}} = -\tfrac{1}{4}B_{\mu\nu}B^{\mu\nu} - \tfrac{1}{4}W^a_{\mu\nu}W^{a,\mu\nu} - \tfrac{1}{4}A'_{\mu\nu}A'^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W}B_{\mu\nu}A'^{\mu\nu}$$

After EWSB: Interaction Lagrangian

$$\begin{aligned}\mathcal{L}_{\mathrm{int}} = &-e\,\bar{f}\gamma^\mu f\left[Q_f(A_\mu + \varepsilon_{A'}A'_\mu)\right]\\ &- \frac{e}{s_W c_W}\,\bar{f}\gamma^\mu(g_V^f - g_A^f\gamma_5)f\left[Z_\mu + \varepsilon_{Z'}Z'_\mu\right]\end{aligned}$$

with $g_V^f = T_3^f - Q_f s_W^2, \;\; g_A^f = T_3^f$.

Two Physical Limits

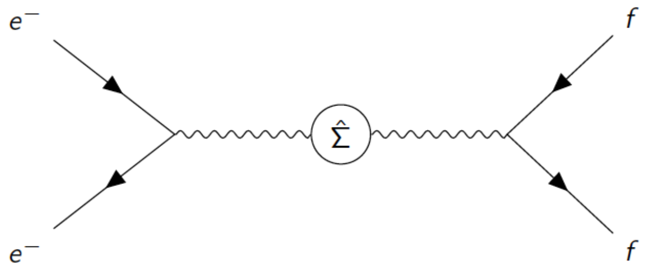
1. **Dark photon** $(\varepsilon_{Z'} = 0 \;\&\; \varepsilon_{A'} \neq 0)$: pure vector coupling $\propto \varepsilon_{A'}\, e\, Q_f$; *no parity violation.*
2. **Dark** Z' $(\varepsilon_{Z'} \neq 0 \;\&\; \varepsilon_{A'} = 0)$:
$$\varepsilon_{Z'} = \frac{m_{Z'}}{m_Z}\,\delta$$
acquires axial-vector couplings; parity-violating interactions.

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

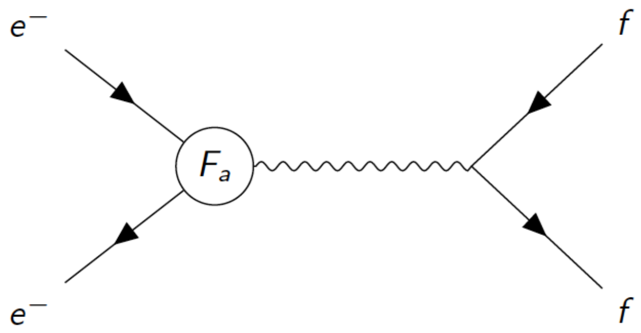
NLO Feynman Diagrams

A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat

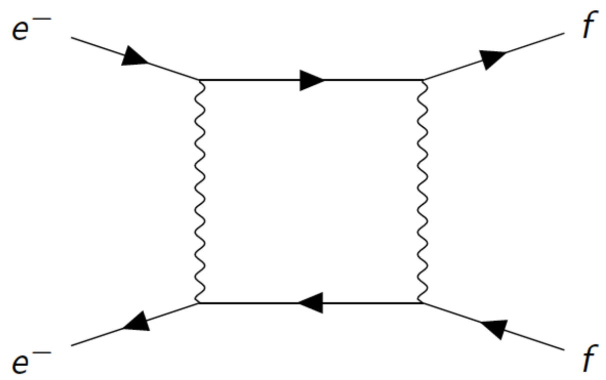
Self-Energy



Vertex Correction



Box Diagram



Sensitivity Metric

$$\Delta A_{\rm LR} \equiv \frac{A_{\rm LR}^{\rm SM+NP} - A_{\rm LR}^{\rm SM}}{A_{\rm LR}^{\rm SM}} \times 100\%$$

Contours drawn at $|\Delta A_{\rm LR}| = 1\%,\ 2\%,\ 3\%$.

One-Loop Decomposition

$$\mathcal{M}_{NLO} = \mathcal{M}_{NLO}^{\rm SE} + \mathcal{M}_{NLO}^{\rm Ver} + \mathcal{M}_{NLO}^{\rm Box}$$

Calculations are done using *on-shell renormalization* scheme.

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat

Processes and Electroweak Input Parameters

Four Final States

$$e^+e^- \to \mu^+\mu^-, \quad e^+e^- \to \tau^+\tau^-$$

$$e^+e^- \to b\bar{b}, \quad e^+e^- \to c\bar{c}$$

- **Leptons:** pure EW, theoretically clean.
- **Quarks:** complementary sensitivity via Q_f, g_V^f, g_A^f.
- All channels accessible at $\sqrt{s} = 10.579$ GeV.

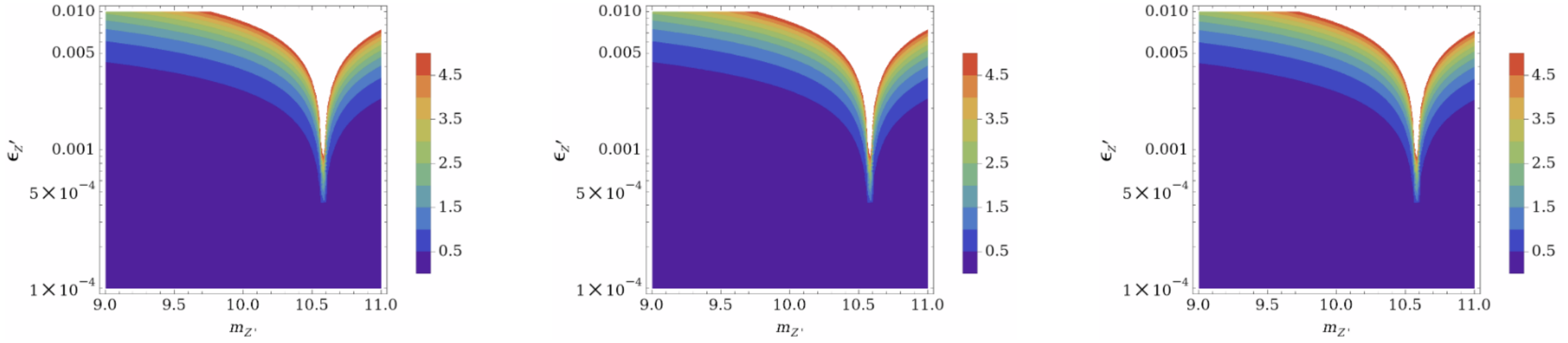
On-Shell Input Parameters

Parameter	Value	Parameter	Value
α	$1/137.036$	m_H	125.0 GeV
m_Z	91.1876 GeV	m_W	80.398 GeV
	Leptons		
m_e	0.511 MeV	m_μ	105.66 MeV
m_τ	1.7768 GeV		
	Quarks		
m_u	69.83 MeV	m_d	69.84 MeV
m_s	150 MeV	m_c	1.2 GeV
m_b	4.6 GeV	m_t	174.0 GeV

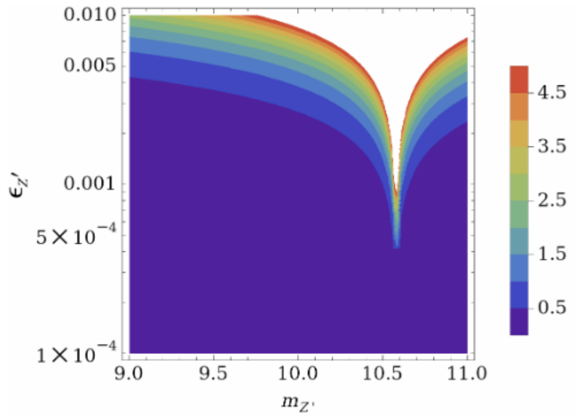
$$s_W^2 = 1 - \frac{m_W^2}{m_Z^2}$$

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

Log Exclusion Contours: Dark Z'



(a) $e^+e^- \to \mu^+\mu^-$ (b) $e^+e^- \to \tau^+\tau^-$ (c) $e^+e^- \to c^+c^-$



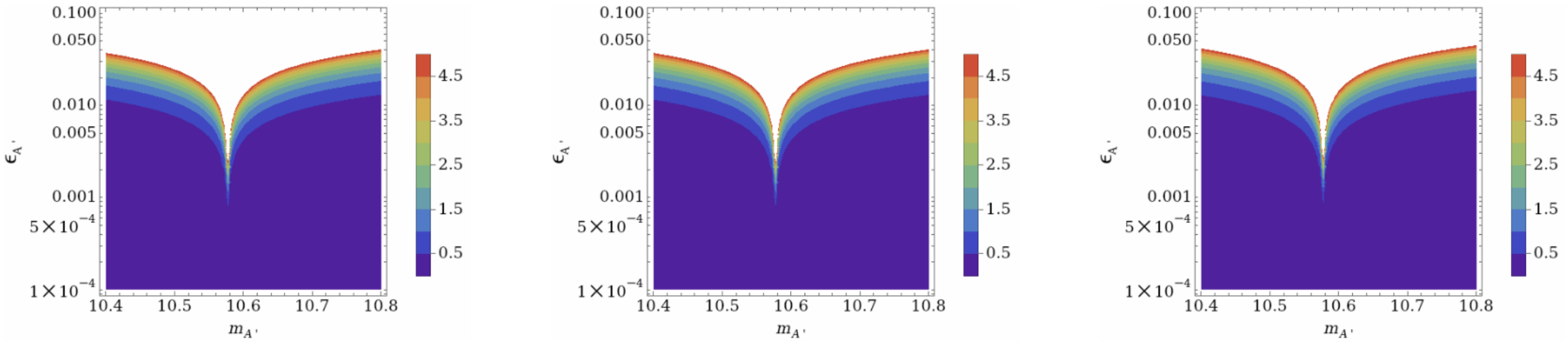
(d) $e^+e^- \to b^+b^-$

Figure: Primary regions of interest for $|\Delta A_{LR}| = 1\%, 2\%$, and 3%. The analysis focuses on the resonance region 10.4–10.8 GeV on a linear scale, mapping $\epsilon_{Z'}$ down to 1×10^{-4} on a log scale.

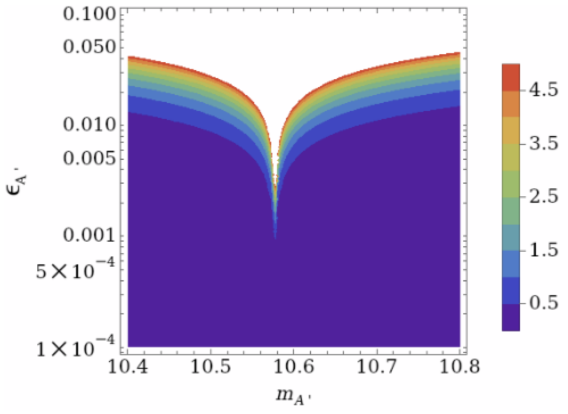
A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)’ SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

Log Exclusion Contours: Dark A'



(a) $e^+e^- \to \mu^+\mu^-$ (b) $e^+e^- \to \tau^+\tau^-$ (c) $e^+e^- \to c^+c^-$



(d) $e^+e^- \to b^+b^-$

Figure: Primary regions of interest for $|\Delta A_{LR}| = 1\%, 2\%$, and 3%. The analysis focuses on the resonance region 10.4–10.8 GeV on a linear scale, mapping $\epsilon_{A'}$ down to 1×10^{-4} on a log scale.

*A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat*

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)' SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

A.Aleksejevs,
S. Barkanova,
M. Ghaffar,
Reefat

Dark Photon vs. Dark Z'

Dark Photon ($\varepsilon_{A'} \neq 0 \quad \varepsilon_{Z'} = 0$)

- Purely vector coupling $\propto \varepsilon_{A'}\, e\, Q_f$.
- No intrinsic parity violation.
- ΔA_{LR} arises only via γ–Z mixing at loop level.

Dark Z' ($\varepsilon_{A'} = 0 \quad \varepsilon_{Z'} \neq 0$)

- Axial coupling $g_A^{f,Z'} = \varepsilon_{Z'}\, g_A^{f,Z} \neq 0$.
- Direct parity violation at **tree level**.
- ΔA_{LR} enhanced by Z-portal interference.

Universal Features (Both Models)

- **V-shaped** minimum at $m_{A'(Z')} \approx \sqrt{s} = 10.579$ GeV ($\Upsilon(4S)$ resonance propagator enhancement).
- Off-resonance smooth scaling: $\Delta A_{\mathrm{LR}} \propto \varepsilon^2/(m^2 - s)$.
- Leptonic and hadronic channels provide **complementary** coverage through differing Q_f and T_3^f.

Preliminary Studies into *Dark Sector Sensitivities in Minimal U(1)’ SM Extension of Parity-Violating Asymmetry Measurements with Chiral Belle (April 12, 2026)*

A. Aleksejevs, S. Barkanova, M. Ghaffar, ***Reefat*** (Memorial University of Newfoundland)

Summary

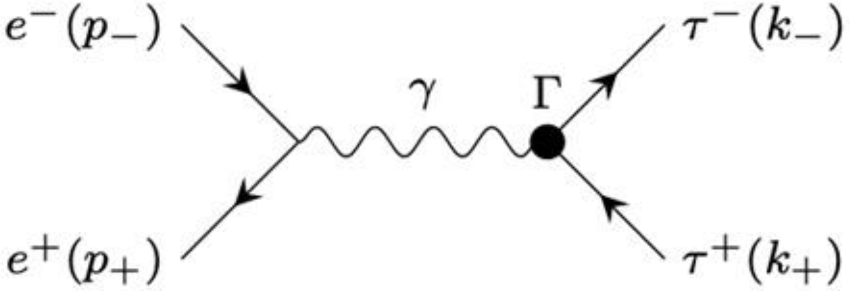
1. Computed **full NLO EW corrections** to A_{LR} for $e^+e^- \to \mu, \tau, b, c$ at Belle II energy $\sqrt{s} = 10.579$ GeV.
2. Included dark vector contributions (tree + 1-loop SE, vertex, box) for **dark photon** and **dark** Z'.
3. Generated exclusion contours in $(m_{A'}, \varepsilon_{A'})$ and $(m_{Z'}, \delta(\varepsilon_{Z'}))$ planes.
4. **V-shaped** resonance feature at $m \approx 10.58$ GeV is a distinctive signature.

Outlook

- Fold in Belle II acceptance and luminosity projections.
- Global fit combining all four channels.

Belle II A_{LR} measurements provide a unique precision window on dark-sector mediators in the 1–20 GeV mass range.

Effective field theory approach to τ-pair production



$$\Gamma^\mu = \underbrace{F_1\left(q^2\right)\gamma^\mu}_{\text{radiative corrections}} + \underbrace{F_2\left(q^2\right)\frac{1}{2m_\tau}\mathrm{i}\sigma^{\mu\nu}q_\nu}_{\text{MDM}} + \underbrace{F_3\left(q^2\right)\frac{1}{2m_\tau}\sigma^{\mu\nu}q_\nu\gamma_5}_{\text{EDM}}$$

- $F_1\left(q^2\right)$, $F_2\left(q^2\right)$ are called the Dirac and Pauli; $F_1(0) = 1$; $F_2(0) = a_\tau$
- $g = 2 \cdot [F_1(0) + F_2(0)] = 2 + 2F_2(0)$ $d_\tau^\gamma = \frac{e}{2m_\tau} \cdot F_3(0)$

$F_2(0)$ Leading term:

$$\frac{\alpha}{2\pi} \approx 0.001\,161\,4$$

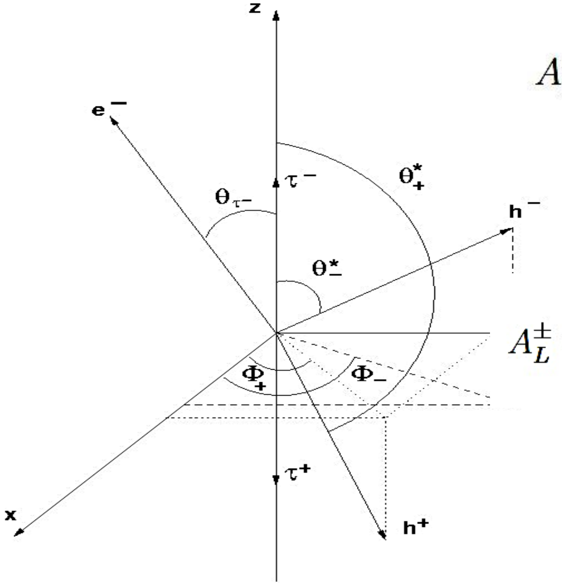
”Schwinger term”

Very active area of research at LHC and in theory community

A number of presentations on the tau g-2 during the 2025 Tau Workshop, including

Savannah Clawson- *Strategy to measure tau g −2 via photon fusion in LHC proton collisions*
Eslam Shokr - *Limits on the tau anomalous magnetic moment in CMS*
John Hallford -*Tau-lepton pair production via di-photon fusion in ultra-peripheral heavy-ion collisions at the ATLAS detector*
Luca Marzola - *Quantum state tomography with τ leptons*
Joël Gognia - *Advancing Precision Calculations of the Tau Lepton's Magnetic and Electric Dipole Moments*

Magnetic dipole moment of τ lepton at Belle II with SuperKEKB upgraded to have electron beam polarization



$$A_T^{\pm} = \frac{1}{2\sigma}\left[\int_{-\pi/2}^{\pi/2}\left(\left(\frac{d\sigma^{R_e}}{d\phi_\pm}\right)-\left(\frac{d\sigma^{L_e}}{d\phi_\pm}\right)\right)d\phi_\pm - \int_{\pi/2}^{3\pi/2}\left(\left(\frac{d\sigma^{R_e}}{d\phi_\pm}\right)-\left(\frac{d\sigma^{L_e}}{d\phi_\pm}\right)\right)d\phi_\pm\right]$$

$$A_L^{\pm} = \frac{1}{2\sigma}\left[\int_0^1 dz_\pm^*\left(\int_0^1 dz\,(A_{RL}) - \int_{-1}^0 dz\,(A_{RL})\right) - \int_{-1}^0 dz_\pm^*\left(\int_0^1 dz\,(A_{RL}) - \int_{-1}^0 dz\,(A_{RL})\right)\right]$$

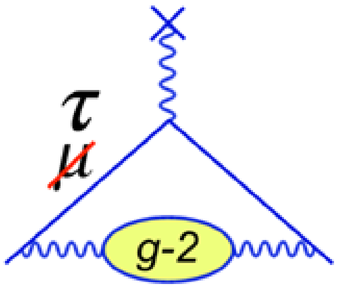
$$A_{RL} = \frac{d^2\sigma^{R_e}}{dz_\pm^* dz} - \frac{d^2\sigma^{L_e}}{dz_\pm^* dz}$$

$$\mathrm{Re}(F_2^{\mathrm{eff}}) = \mp\frac{8(3-\beta^2)}{3\pi\gamma\beta^2\alpha_\pm}\left(A_T^{\pm} - \frac{\pi}{2\gamma}A_L^{\pm}\right)$$

requires precision E_{cm} & $m_{\tau.}$ for F_1 cancellation

J. Bernabeu, G. A. Gonzalez-Sprinberg, J. Papavassiliou, and J. Vidal, Nucl. Phys. B 790, 160 (2008), arXiv:0707.2496
J. Bernabeu, G. A. Gonzalez-Sprinberg, and J. Vidal, JHEP 01, 062 (2009), arXiv:0807.2366

Magnetic dipole moment of τ lepton with Chiral Belle

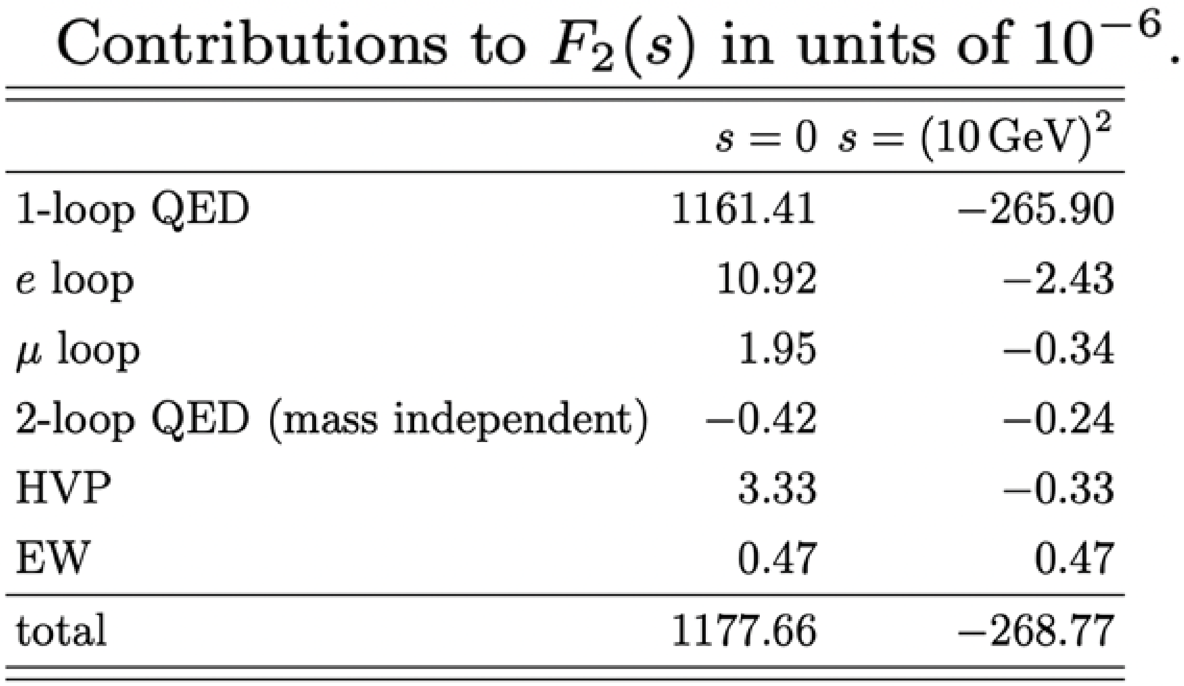


$$a_\tau^{\text{BSM}} \sim a_\mu^{\text{BSM}} \left(\frac{m_\tau}{m_\mu}\right)^2 \sim 10^{-6}$$

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

a_τ is focus of LHC ultraperipheral lead-lead collisions, Pb+Pb→Pb($\gamma\gamma \to \tau\tau$)Pb with ATLAS & CMS

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


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

	$s = 0$	$s = (10\,\text{GeV})^2$
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

- **Detector level systematics cancels in asymmetries between left (right) beams.**
- **Precision ≃ 10^{-5} expected with 40 ab^{-1} of data with polarized beam with 60% selection efficiency of semileptonic tau decays**
- **1000 x more precise than current limits (w/ 1 ab^{-1} ~100x more precise than current limits)**
- **Approaches the precision regime in tau that starts to be sensitive to Minimal Flavour Violation equivalent of muon g-2 anomaly**

New publication on magnetic dipole moment of τ lepton:

Complete one-loop result for the fully polarized $e^+e^- \rightarrow \tau^+\tau^-$ process and its implementation in the Monte-Carlo integrator McMule [Joël Gogniat, M. Hoferichter and Y. Ulrich, JHEP 07(2025) 172

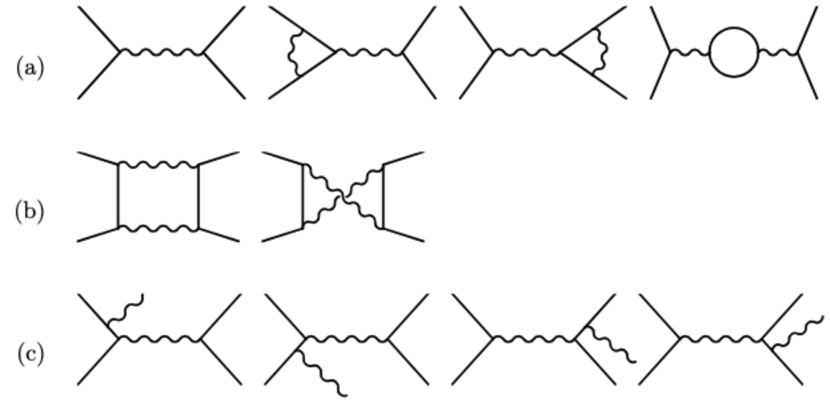
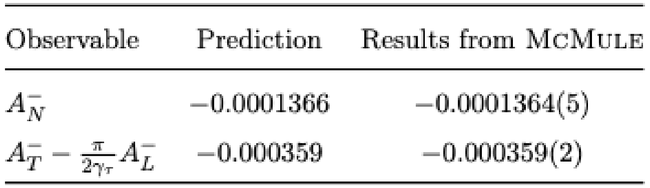
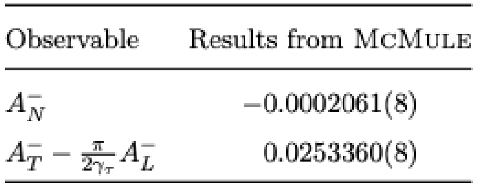


Figure 1: Leading-order (LO) and NLO Feynman diagrams for $e^+e^- \to \tau^+\tau^-$. (a) Direct s-channel diagrams; (b) box diagrams; (c) real emission.



Observable	Prediction	Results from McMule
A_N^-	-0.0001366	$-0.0001364(5)$
$A_T^- - \frac{\pi}{2\gamma_\tau} A_L^-$	-0.000359	$-0.000359(2)$

Table 1: Results obtained from McMule for the asymmetries without angular cuts compared to theoretical predictions.



Observable	Results from McMule
A_N^-	$-0.0002061(8)$
$A_T^- - \frac{\pi}{2\gamma_\tau} A_L^-$	$0.0253360(8)$

Table 2: Results obtained from McMule for the asymmetries with angular cuts at NLO including box diagrams.

$$17^\circ < \theta_{\tau^\pm}^{\text{lab}} < 150^\circ, \qquad E_\gamma < 50 \text{ MeV}.$$

`` A significant aspect of our study concerns the investigation of the impact of realistic kinematical cuts, specifically adapted to Belle II detector conditions, on these asymmetries.

We demonstrated that while the dominant $|F_1|^2$ contributions cancel in the ideal case, angular cuts introduce residual effects. To mitigate these, we proposed an alternative linear combination of $A^\pm_T$ and $A^\pm_L$ that uses a modified coefficient C(Θ) to effectively cancel both the dominant charge form factor corrections as well as the γ–Y–Z interference."

New publication on magnetic dipole moment of τ lepton:

Complete one-loop result for the fully polarized $e^+e^- \to \tau^+\tau^-$ process and its implementation in the Monte-Carlo integrator McMule [Joël Gogniat, M. Hoferichter and Y. Ulrich, JHEP 07(2025) 172

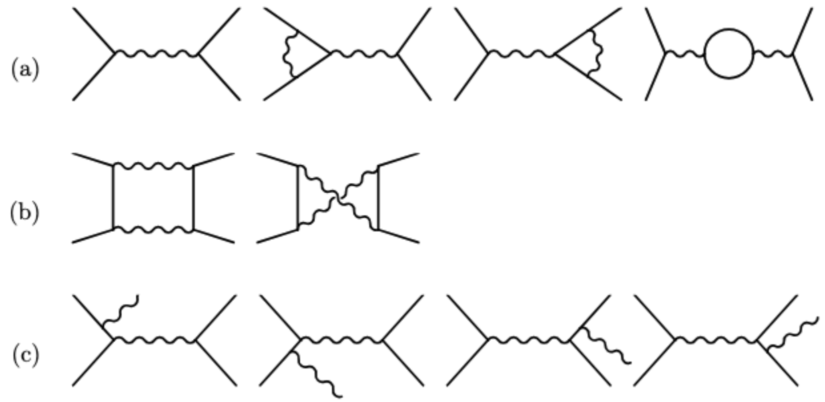
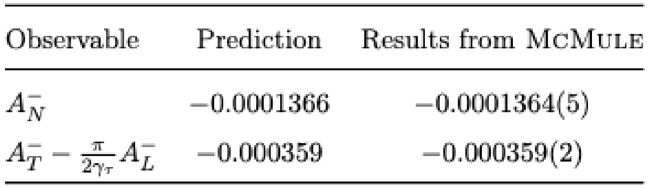
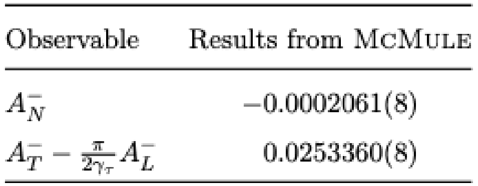


Figure 1: Leading-order (LO) and NLO Feynman diagrams for $e^+e^- \to \tau^+\tau^-$. (a) Direct s-channel diagrams; (b) box diagrams; (c) real emission.



Observable	Prediction	Results from McMule
A_N^-	-0.0001366	$-0.0001364(5)$
$A_T^- - \frac{\pi}{2\gamma_\tau} A_L^-$	-0.000359	$-0.000359(2)$

Table 1: Results obtained from McMule for the asymmetries without angular cuts compared to theoretical predictions.



Observable	Results from McMule
A_N^-	$-0.0002061(8)$
$A_T^- - \frac{\pi}{2\gamma_\tau} A_L^-$	$0.0253360(8)$

Table 2: Results obtained from McMule for the asymmetries with angular cuts at NLO including box diagrams.

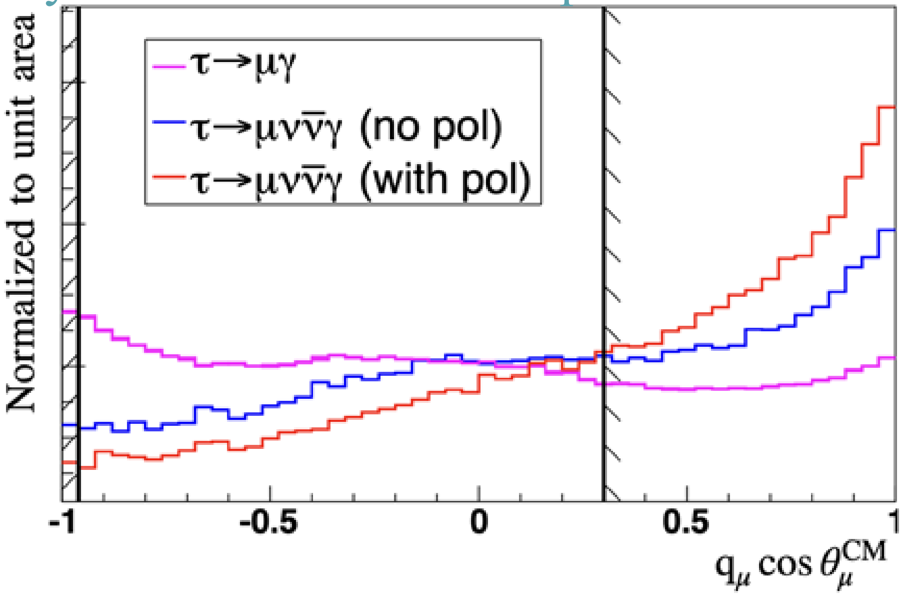
$$17^\circ < \theta_{\tau^\pm}^{\text{lab}} < 150^\circ, \qquad E_\gamma < 50\ \text{MeV}.$$

“From these studies, we see no fundamental issues in reaching a precision of 10^{-5} and beyond, essential for establishing relevant bounds on potential BSM contributions.

However, to reach this goal, the calculation should be extended to NNLO, to ensure that the theoretical precision does not become the limiting factor."

Search for lepton flavor violation in τ decays

- Belle II to probe LFV in several channels $\simeq \mathcal{O}(10^{-10})$ to $\mathcal{O}(10^{-9})$ with 50 ab^{-1}
- With beam polarization, helicity distributions can suppress backgrounds
- Optimization study shows at least 10% improvement in $\tau\rightarrow\ell\gamma$ sensitivity



- Possible to disentangle helicity structure of LFV in $\tau\rightarrow\ell\ell\ell$ from Dalitz plots

τ Michel Parameter with polarized e- beam

($\tau \rightarrow e\,\nu\,\bar{\nu}$ and $\tau \rightarrow \mu\,\nu\,\bar{\nu}$ decay parameters – details in Additional Slides)

Tau Michel Parameter (Standard Model V-A theory given)	Current World Average (PDG)	Projected Chiral Belle statistical uncertainty with 20% efficiency for (ℓ,ρ) events with 70% polarization and 50 ab^{-1} *	Projected Chiral Belle statistical uncertainty with 70% polarization and 1 ab^{-1} *
ρ (e or μ) = 0.75	0.745 ± 0.008 (1.1%)	± 0.4×10^{-4} (±0.005% of SM value)	±0.00028 (29x better than WA)
η (e or μ) = 0	0.013 ± 0.020	±1.8×10^{-4}	±0.0013 (16x better than WA)
ξ (e or μ) = 1	0.985 ± 0.030 (3.0%)	±1.3×10^{-4} (±0.013% of SM)	±0.0009 (33x better than WA)
$(\delta\xi)$ (e or μ) = 0.75	0.746 ± 0.021 (2.8%)	±0.8×10^{-4} (±0.01% of SM value)	±0.0006 (35x better than WA)

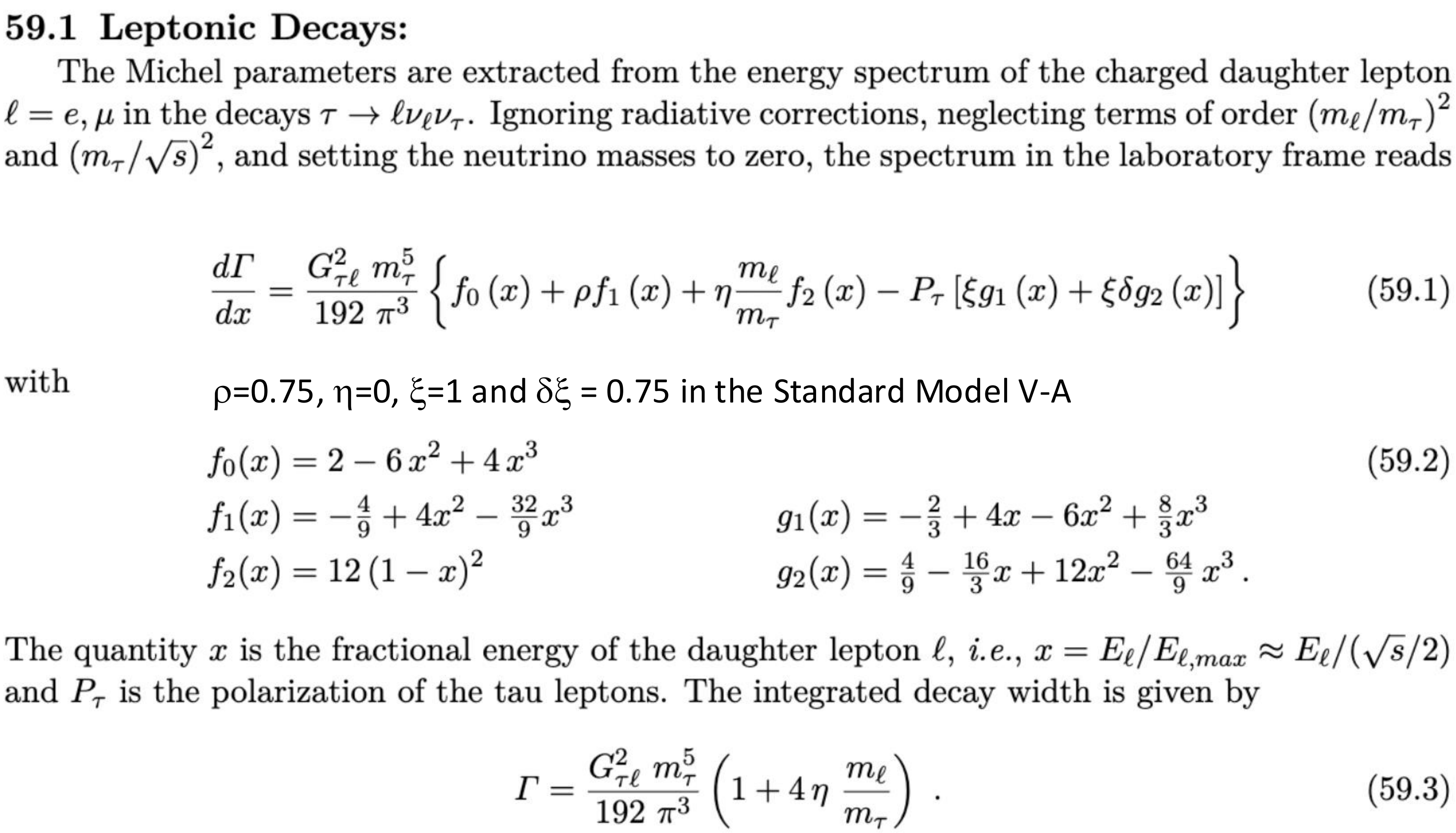
NNLO calculations are required & Systematic uncertainties will be the limiting factor

Deviations from "V-A" indicate New Physics with a number of models out there, including those violating lepton flavour universality: compare $\tau \rightarrow e\,\nu\,\bar{\nu}$ *to* $\mu \rightarrow e\,\nu\,\bar{\nu}$

* Projections based on Denis Epifanov's Tau2021 Workshop presentation on Super Tau Charm Factory (STCF)

τ Michel Parameters

from PDG Article: τ-Lepton Decay Parameters
February 2024 by A. Stahl (RWTH Aachen U.)



59.1 Leptonic Decays:

The Michel parameters are extracted from the energy spectrum of the charged daughter lepton $\ell = e, \mu$ in the decays $\tau \to \ell \nu_\ell \nu_\tau$. Ignoring radiative corrections, neglecting terms of order $(m_\ell/m_\tau)^2$ and $(m_\tau/\sqrt{s})^2$, and setting the neutrino masses to zero, the spectrum in the laboratory frame reads

$$\frac{d\Gamma}{dx} = \frac{G_{\tau\ell}^2\, m_\tau^5}{192\,\pi^3} \left\{ f_0(x) + \rho f_1(x) + \eta \frac{m_\ell}{m_\tau} f_2(x) - P_\tau \left[\xi g_1(x) + \xi\delta g_2(x) \right] \right\} \tag{59.1}$$

with

ρ=0.75, η=0, ξ=1 and δξ = 0.75 in the Standard Model V-A

$$f_0(x) = 2 - 6\,x^2 + 4\,x^3 \tag{59.2}$$

$$f_1(x) = -\tfrac{4}{9} + 4x^2 - \tfrac{32}{9}x^3 \qquad g_1(x) = -\tfrac{2}{3} + 4x - 6x^2 + \tfrac{8}{3}x^3$$

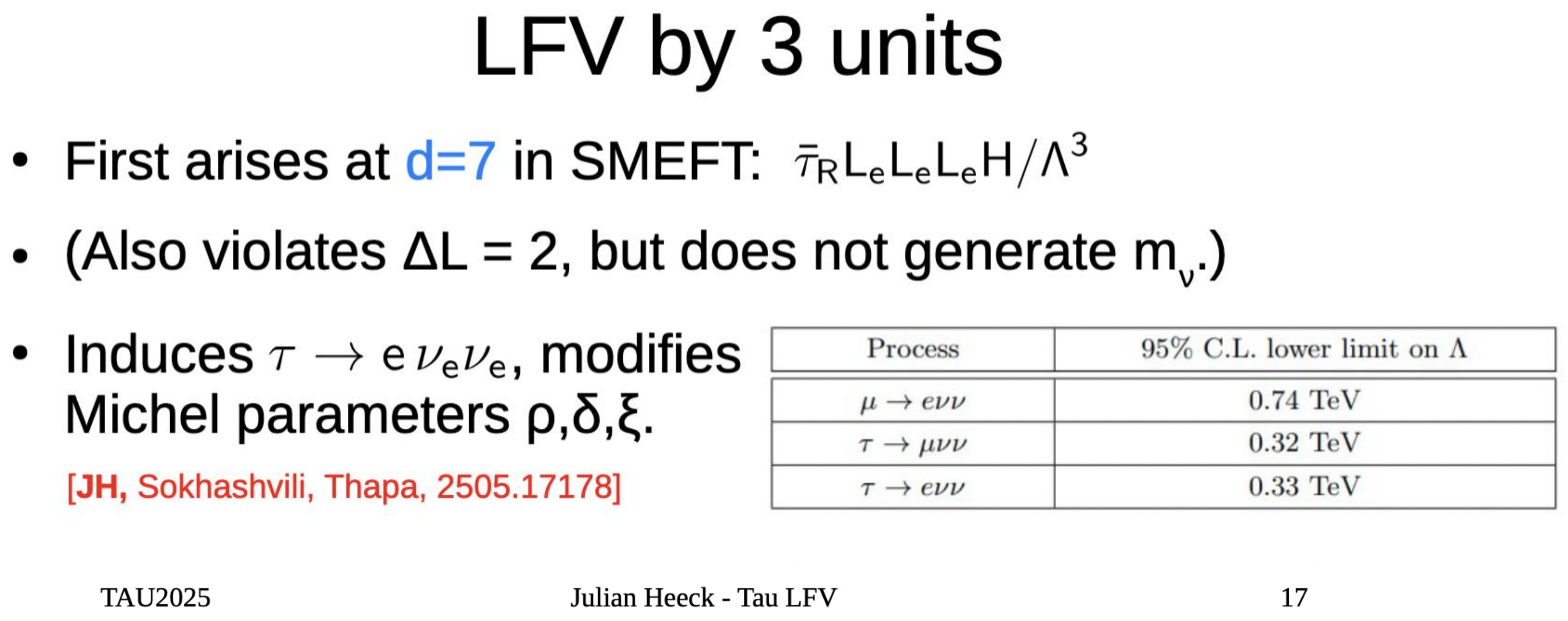
$$f_2(x) = 12\,(1-x)^2 \qquad g_2(x) = \tfrac{4}{9} - \tfrac{16}{3}x + 12x^2 - \tfrac{64}{9}\,x^3 \,.$$

The quantity x is the fractional energy of the daughter lepton ℓ, *i.e.*, $x = E_\ell/E_{\ell,max} \approx E_\ell/(\sqrt{s}/2)$ and P_τ is the polarization of the tau leptons. The integrated decay width is given by

$$\Gamma = \frac{G_{\tau\ell}^2\, m_\tau^5}{192\,\pi^3} \left(1 + 4\,\eta\, \frac{m_\ell}{m_\tau} \right) \,. \tag{59.3}$$

τ Michel Parameters

Julian Heck's talk at Tau 2025 in Marseille details the motivation for improving the precisions on the τ Michel Parameters



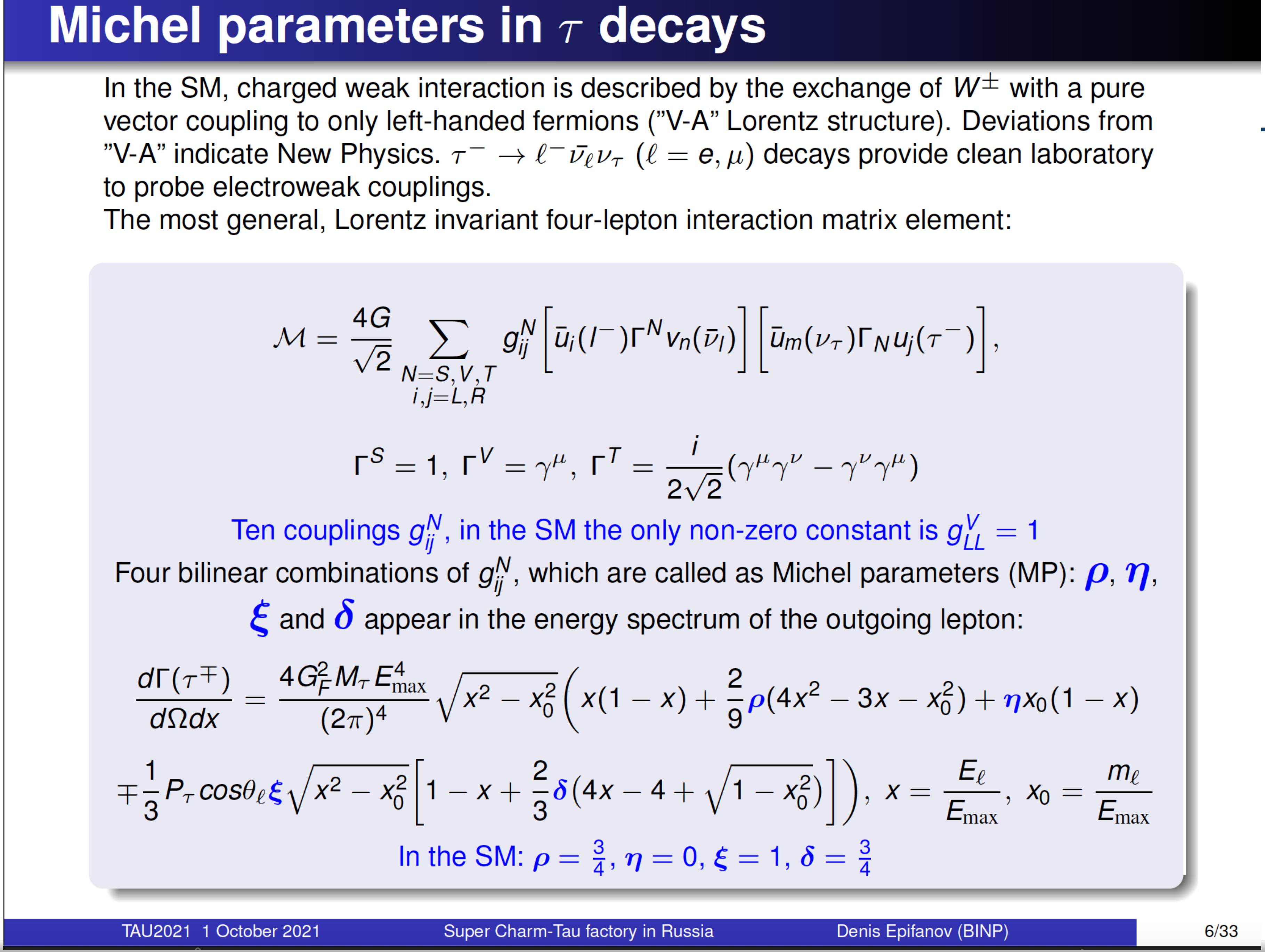
LFV by 3 units

- First arises at d=7 in SMEFT: $\bar{\tau}_R L_e L_e L_e H/\Lambda^3$
- (Also violates $\Delta L = 2$, but does not generate m_ν.)
- Induces $\tau \to e \nu_e \nu_e$, modifies Michel parameters ρ,δ,ξ.

  [JH, Sokhashvili, Thapa, 2505.17178]

Process	95% C.L. lower limit on Λ
$\mu \to e\nu\nu$	0.74 TeV
$\tau \to \mu\nu\nu$	0.32 TeV
$\tau \to e\nu\nu$	0.33 TeV

TAU2025 Julian Heeck - Tau LFV 17



Michel parameters in τ decays

In the SM, charged weak interaction is described by the exchange of $W^{\pm}$ with a pure vector coupling to only left-handed fermions ("V-A" Lorentz structure). Deviations from "V-A" indicate New Physics. $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ $(\ell = e, \mu)$ decays provide clean laboratory to probe electroweak couplings.

The most general, Lorentz invariant four-lepton interaction matrix element:

$$\mathcal{M} = \frac{4G}{\sqrt{2}} \sum_{\substack{N=S,V,T\\ i,j=L,R}} g^N_{ij} \left[\bar{u}_i(l^-)\Gamma^N v_n(\bar{\nu}_l)\right]\left[\bar{u}_m(\nu_\tau)\Gamma_N u_j(\tau^-)\right],$$

$$\Gamma^S = 1,\ \Gamma^V = \gamma^\mu,\ \Gamma^T = \frac{i}{2\sqrt{2}}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$$

Ten couplings g^N_{ij}, in the SM the only non-zero constant is $g^V_{LL} = 1$

Four bilinear combinations of g^N_{ij}, which are called as Michel parameters (MP): $\boldsymbol{\rho}$, $\boldsymbol{\eta}$, $\boldsymbol{\xi}$ and $\boldsymbol{\delta}$ appear in the energy spectrum of the outgoing lepton:

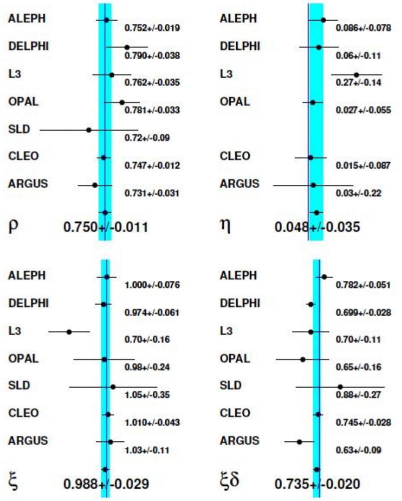
$$\frac{d\Gamma(\tau^\mp)}{d\Omega dx} = \frac{4G_F^2 M_\tau E^4_{\max}}{(2\pi)^4}\sqrt{x^2 - x_0^2}\Bigg(x(1-x) + \frac{2}{9}\boldsymbol{\rho}(4x^2 - 3x - x_0^2) + \boldsymbol{\eta} x_0(1-x)$$

$$\mp\frac{1}{3}P_\tau cos\theta_\ell \boldsymbol{\xi}\sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\boldsymbol{\delta}\left(4x - 4 + \sqrt{1 - x_0^2}\right)\right]\Bigg),\ x = \frac{E_\ell}{E_{\max}},\ x_0 = \frac{m_\ell}{E_{\max}}$$

In the SM: $\boldsymbol{\rho} = \frac{3}{4}$, $\boldsymbol{\eta} = 0$, $\boldsymbol{\xi} = 1$, $\boldsymbol{\delta} = \frac{3}{4}$

Michel parameters of τ, current status, NP

Michel par.	Measured value	Experiment	SM value
ρ (e or μ)	$0.747 \pm 0.010 \pm 0.006$ 1.2%	CLEO-97	3/4
η (e or μ)	$0.012 \pm 0.026 \pm 0.004$ 2.6%	ALEPH-01	0
ξ (e or μ)	$1.007 \pm 0.040 \pm 0.015$ 4.3%	CLEO-97	1
$\xi\delta$ (e or μ)	$0.745 \pm 0.026 \pm 0.009$ 2.8%	CLEO-97	3/4
ξ_h (all hadr.)	$0.992 \pm 0.007 \pm 0.008$ 1.1%	ALEPH-01	1



In BSM models the couplings to τ are expected to be enhanced in comparison with μ.

- **Type II 2HDM:** $\eta_\mu(\tau) = \frac{m_\mu M_\tau}{2}\left(\frac{\tan^2\beta}{M^2_{H\pm}}\right)^2$; $\frac{\eta_\mu(\tau)}{\eta_e(\mu)} = \frac{M_\tau}{m_e} \approx 3500$
- **Tensor interaction:** $\mathcal{L} = \frac{g}{2\sqrt{2}} W^\mu \left\{ \bar\nu\gamma_\mu(1-\gamma^5)\tau + \frac{\kappa^W_\tau}{2m_\tau}\partial^\nu\left(\bar\nu\sigma_{\mu\ nu}(1-\gamma^5)\tau\right)\right\}$,
  $-0.096 < \kappa^W_\tau < 0.037$: DELPHI Abreu EPJ C16 (2000) 229.
- **Unparticles:** Moyotl PRD 84 (2011) 073010, Choudhury PLB 658 (2008) 148.
- **Lorentz and CPTV:** Hollenberg PLB **701** (2011) 89
- **Heavy Majorana neutrino:** M. Doi *et al.*, Prog. Theor. Phys. **118** (2007) 1069.

From PDG:

$\mu \rightarrow e\, \nu\, \bar{\nu}$

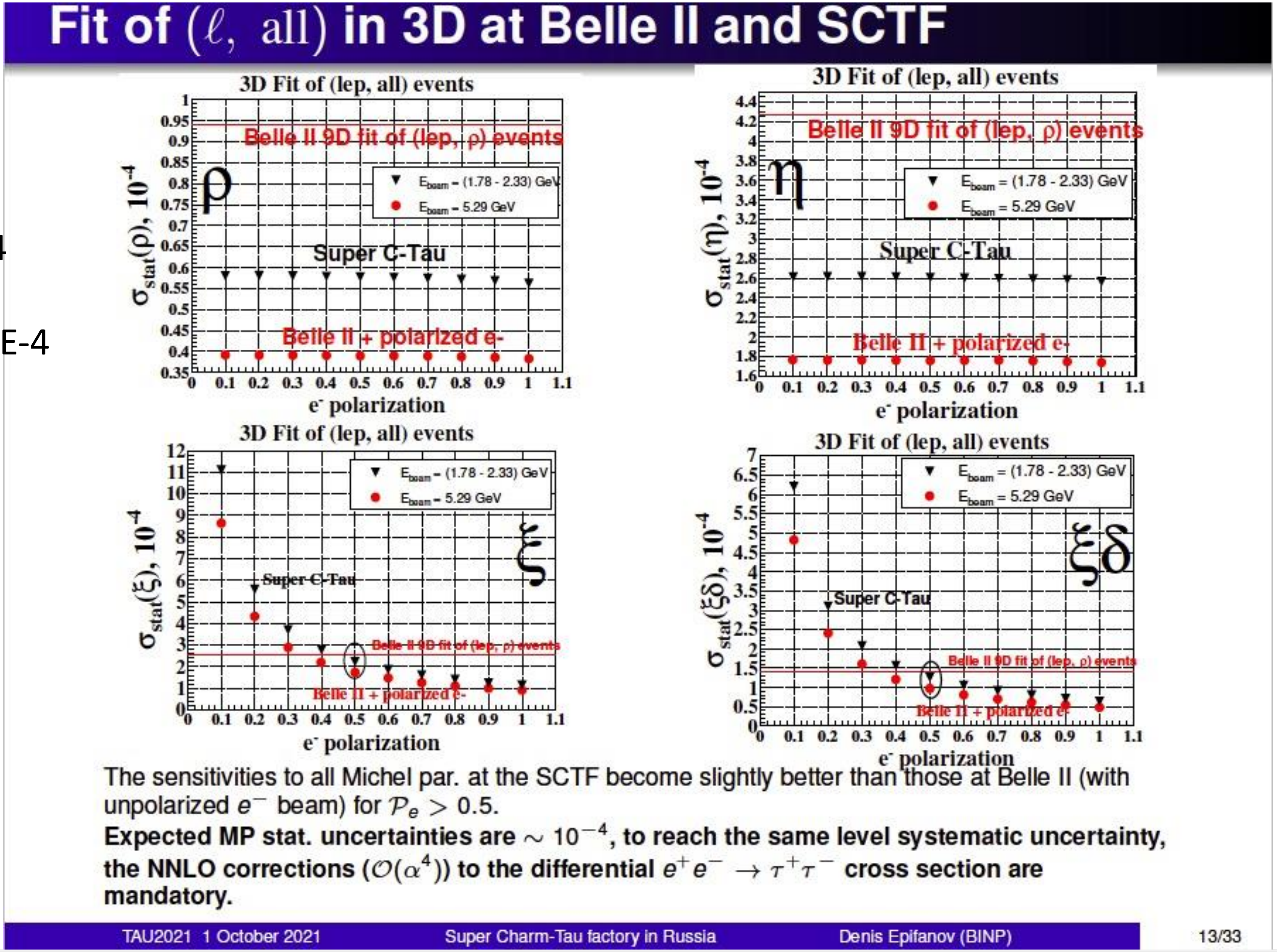
Decay parameters [b]

$$\rho = 0.74979 \pm 0.00026$$
$$\eta = 0.057 \pm 0.034$$
$$\delta = 0.75047 \pm 0.00034$$
$$\xi P_\mu = 1.0009^{+0.0016}_{-0.0007} \ [c]$$
$$\xi P_\mu \delta/\rho = 1.0018^{+0.0016}_{-0.0007} \ [c]$$

τ Michel Parameter with polarized e- beam

from Denis Epifanov’s Tau2021 Workshop talk on Super Tau Charm Factory (STCF)

Rho: .4E-4
Eta: 1.8E-4
Xi : 1E-4
Xi-delta: 1E-4



Fit of (ℓ, all) in 3D at Belle II and SCTF

The sensitivities to all Michel par. at the SCTF become slightly better than those at Belle II (with unpolarized e^- beam) for $\mathcal{P}_e > 0.5$.

Expected MP stat. uncertainties are $\sim 10^{-4}$, to reach the same level systematic uncertainty, the NNLO corrections ($\mathcal{O}(\alpha^4)$) to the differential $e^+e^- \to \tau^+\tau^-$ cross section are mandatory.

TAU2021 1 October 2021 Super Charm-Tau factory in Russia Denis Epifanov (BINP) 13/33

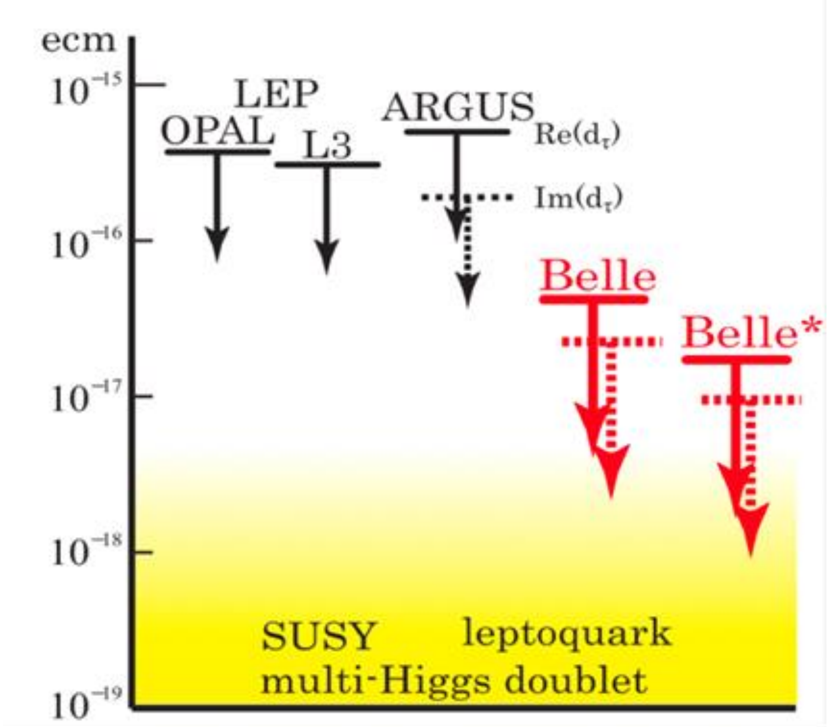
It would be very exciting to have both projects probing tau sector with polarized e- beams

50/ab of polarized Belle II data assumed in these studies

Staging of Chiral Belle Precision electroweak measurements

Fermion *f*	g_V^f **(Standard Model)**	g_V^f **(World Average)**	$\sigma(g_V^f)$ **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 20ab^{-1}**
b-quark	-0.3437 ± 0.0001	-0.3220 ±0.0077 (2.8σ off SM)	0.0026 **3x better than World Ave σ**	0.0022 **>3x better than World Ave σ**	0.0018 **>4x better than World Ave σ**	0.0017 **>4x better than World Ave σ**
c-quark	0.1920 ± 0.0002	0.1873 ± 0.0070	0.005	0.0036 **2x better than World Ave σ**	0.0018 **4x better than World Ave σ**	0.0011 **>6x better than World Ave σ**
Tau	-0.0371 ± 0.0003	-0.0366 ± 0.0010	0.0069	0.0049	0.0022	0.0011 (~ W.A. σ)
Muon	-0.0371 ± 0.0003	-0.03667 ± 0.0023	0.0043	0.0031	0.0014 **1.6x better than World Ave σ**	0.0007 **>3x better than World Ave σ**
Electron	-0.0371 ± 0.0003	-0.03816 ± 0.00047	0.0055	0.0039	0.0017	0.0009

Electric dipole moments of τ lepton



Belle; 833 fb-1 data (arXiv:2108.11543 [hep-ex])

$$\mathrm{Re}(d_\tau) = (-0.62 \pm 0.63) \times 10^{-17}\ ecm,$$
$$\mathrm{Im}(d_\tau) = (-0.40 \pm 0.32) \times 10^{-17}\ ecm.$$

- 95% confidence intervals

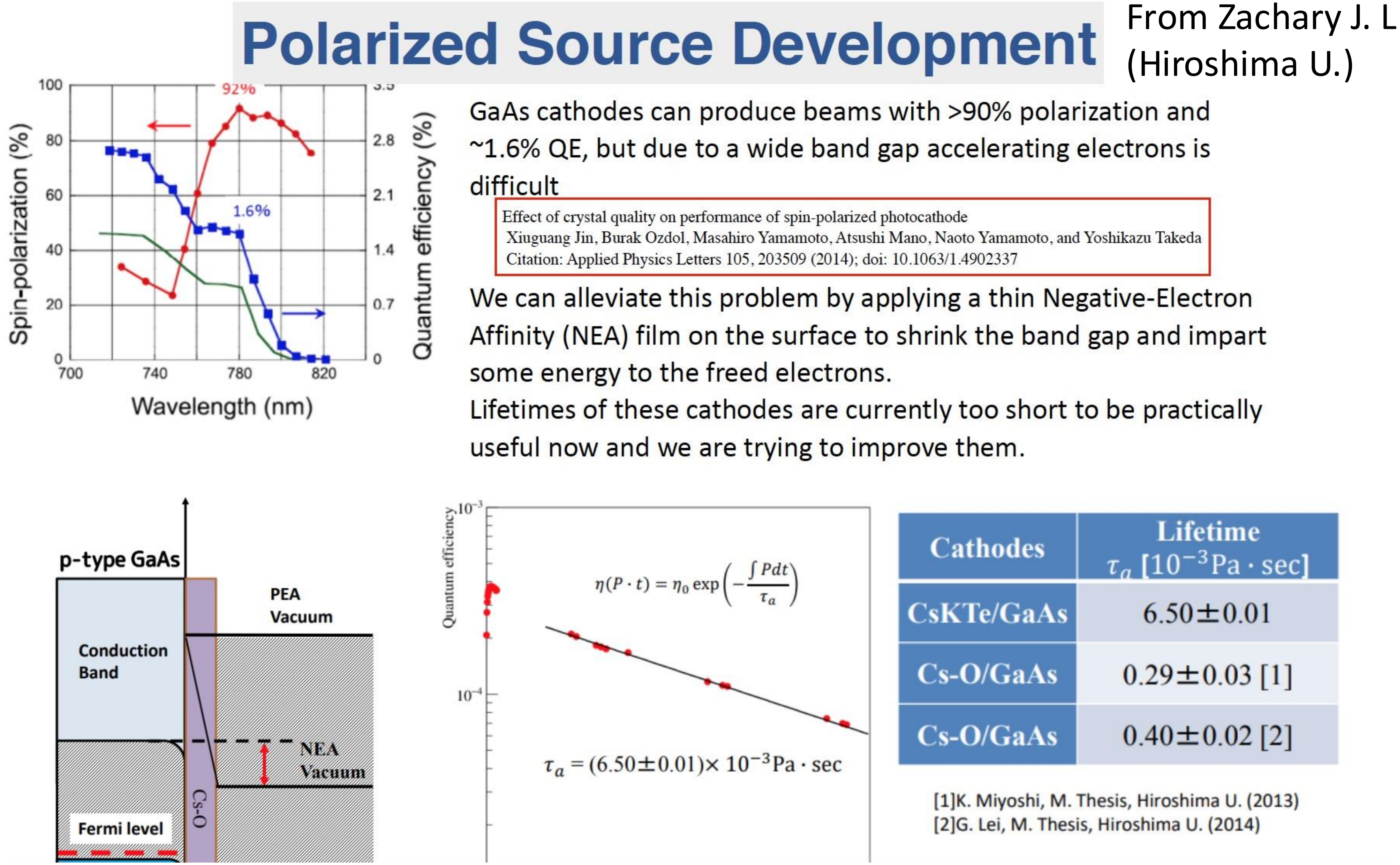
$$-1.85 \times 10^{-17} < \mathrm{Re}(d_\tau) < 0.61 \times 10^{-17}\ \mathrm{ecm},$$
$$-1.03 \times 10^{-17} < \mathrm{Im}(d_\tau) < 0.23 \times 10^{-17}\ \mathrm{ecm}.$$

- Consistent with zero EDM
- Systematic errors similar to statistical
- Dominant systematics: Data-MC mismatch in momentum/angular distributions

- Preliminary studies at Belle II show much better control in agreement between Data-MC
- After improved control of systematics, extrapolation based on statistical errors only
- **With 50 ab^{-1} data at Belle II: $Re(d_\tau)$ ~ 8 x 10^{-19}, $Im(d_\tau)$ ~ 4 x 10^{-19}**
- Further improvement expected from proposed upgrade of polarized e- beams.

Polarization in SuperKEKB

From Zachary J. Liptak
(Hiroshima U.)



Polarized Source Development

GaAs cathodes can produce beams with >90% polarization and ~1.6% QE, but due to a wide band gap accelerating electrons is difficult

Effect of crystal quality on performance of spin-polarized photocathode
Xiuguang Jin, Burak Ozdol, Masahiro Yamamoto, Atsushi Mano, Naoto Yamamoto, and Yoshikazu Takeda
Citation: Applied Physics Letters 105, 203509 (2014); doi: 10.1063/1.4902337

We can alleviate this problem by applying a thin Negative-Electron Affinity (NEA) film on the surface to shrink the band gap and impart some energy to the freed electrons.
Lifetimes of these cathodes are currently too short to be practically useful now and we are trying to improve them.

$$\eta(P\cdot t) = \eta_0 \exp\left(-\frac{\int P dt}{\tau_a}\right)$$

$$\tau_a = (6.50 \pm 0.01) \times 10^{-3}\,\mathrm{Pa\cdot sec}$$

Cathodes	Lifetime τ_a [10^{-3}Pa · sec]
CsKTe/GaAs	6.50±0.01
Cs-O/GaAs	0.29±0.03 [1]
Cs-O/GaAs	0.40±0.02 [2]

[1]K. Miyoshi, M. Thesis, Hiroshima U. (2013)
[2]G. Lei, M. Thesis, Hiroshima U. (2014)

See recent developments in Maseo Kuriki's (Hiroshima U.) presentation yesterday "Polarized Beam Generation from RF photo-injector"

A sample of other 2025 Theory/Phenomenology Papers of interest for Chiral Belle Physics Program

- *Characterizing Dark Bosons at Chiral Belle* [C.H. de Lima, D. McKeen, A. Omar, D. Tuckler, 2507.15931 [hep-ph] 2025]
- *Left-right asymmetry calculation comparisons and projected sensitivity to the weak mixing angle in polarized Bhabha scattering at 10.58GeV,* [Miller&Roney, Phys.Rev.D 112 (2025) 1, 013006]
- *Prospects for P and CP violation in* Λ_c^+ *decays with polarized beam at Super Tau-Charm Facility,* [Wang *et al,* 2508.12217 [hep-ph](Aug 2025)]

Beam-Beam Effects on Polarization

The effect of beam-beam interactions on the polarization will have to be studied in simulations.

To 1st-order, the beam-beam effect is a focusing force that affects spin-transparency. At HERA it was observed that the optimum polarization at strong beam-beam required slightly different optimization of the machine but was recoverable to a large extent. [1]

Beam-beam in SuperKEKB will be stronger, but only by a modest factor, not by an order of magnitude as the luminosity is increased by extremely small (not by an extremely large) beam-beam parameter. We note that the beam-beam effects experienced by the electrons in HERA were not particularly small, due to the strong proton bunches, and was one of the factors limiting the luminosity.[2]

At SuperKEKB, with short beam lifetime and constant injection of freshly polarized electrons, a high equilibrium polarization is a realistic expectation.

1. M. Boge and T. Limberg, Conf. Proc. C 950501, 2901 (1996); M. Bieler *et al.,* in "Workshop on Beam-Beam Effects in Large Hadron Colliders" (1999) pp.12-19.
2. J. Shi, L. Jin, and G. Hoffstaetter, Conf.Proc.C 030512 (2003), 369, (2003)

Compact spin rotator

Y. Peng's (Uvictoria) + Uli Wienands (ANL)

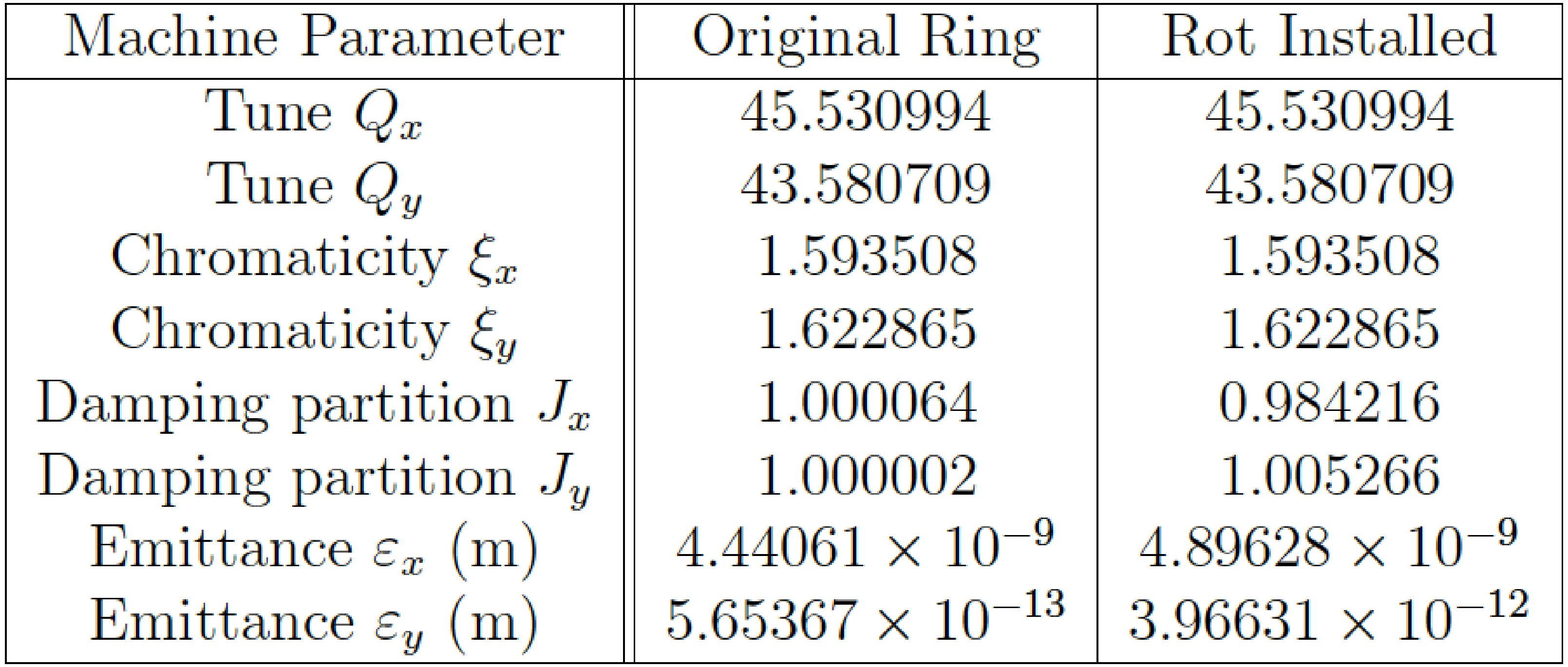
Working Constraints for the Design

- **Transparency**: Need to maintain the original **beam dynamics,** make the spin rotator transparent to the ring as much as possible (the spin rotator is for the polarization purpose only)
- **Physical constraints**: All new magnets must be manufacturable and installable. Brett Parker (BNL) provided these preliminary physical constraints
  - Solenoid strength can not exceed **5** T
  - Skew-quad can not exceed **30** T/m (~ 3T at the coil)
- Yuhao Peng (UVic) used BMAD, working with Uli Wienands (ANL) & Demin Zhou(KEK) and consulting with David Sagan (Cornell), found a solution under these constraints

Compact spin rotator

Y. Peng’s (UVictoria)

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



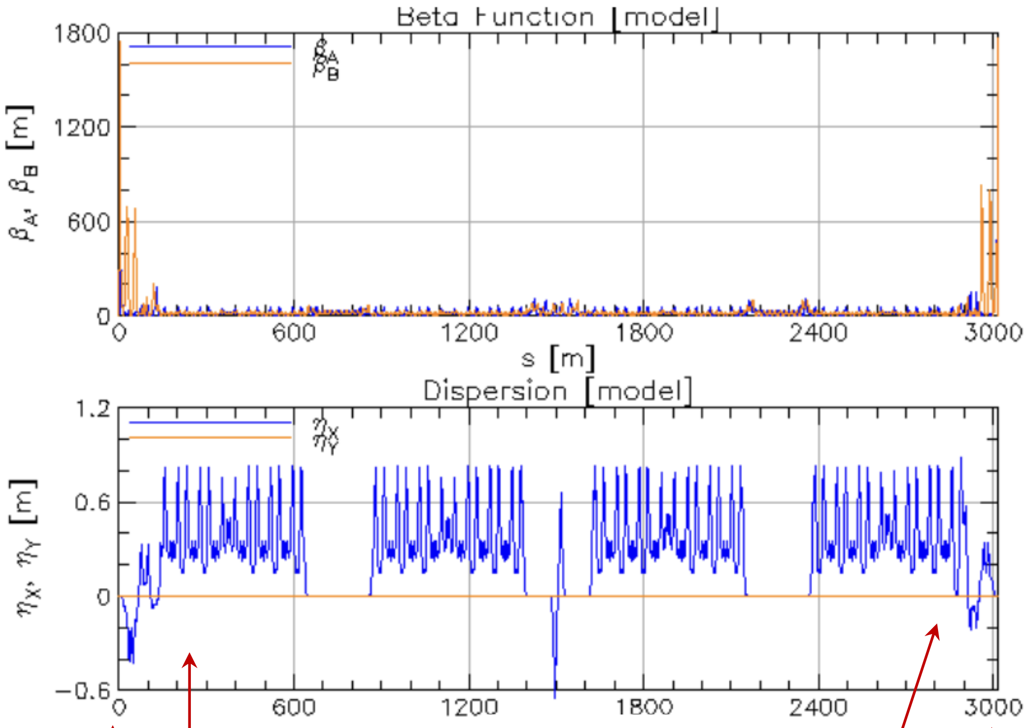
Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}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

HER optical functions with and without Compact Spin Rotators

N. Tessema & Y. Peng's (UVictoria)

beta
X & Y

Dispersion
X & Y



s (m)

Left Rotator

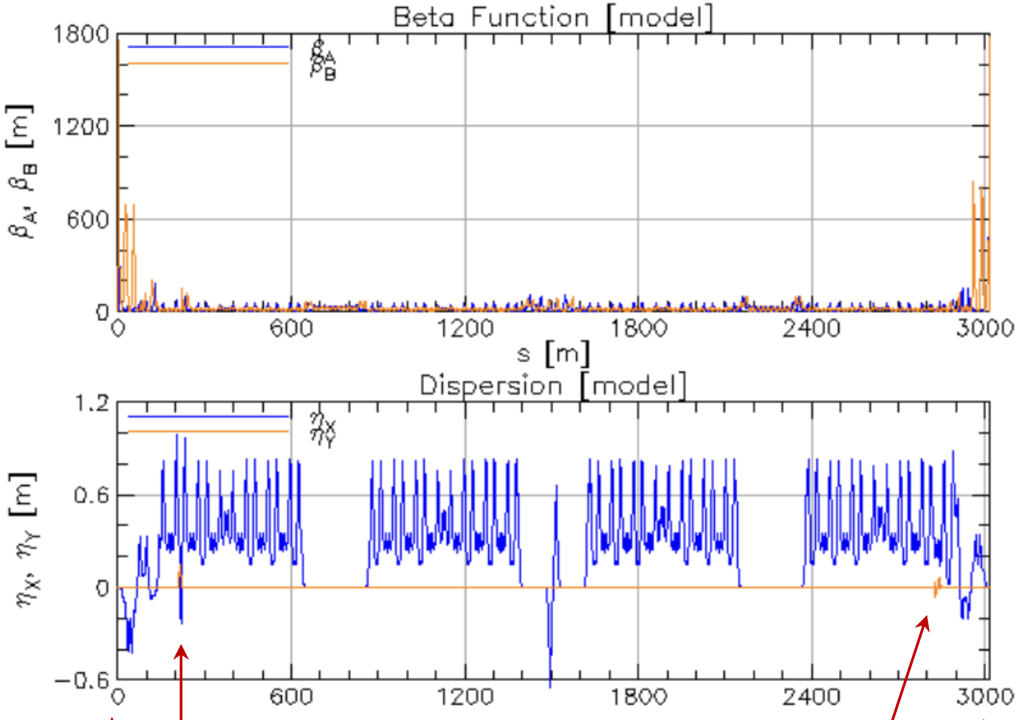
Right Rotator

Interaction Point

Injection Point

Interaction Point

Original High Energy Ring



s (m)

Left Rotator

Right Rotator

Interaction Point

Injection Point

Interaction Point

High Energy Ring with Spin Rotators (156 model)

X in yellow

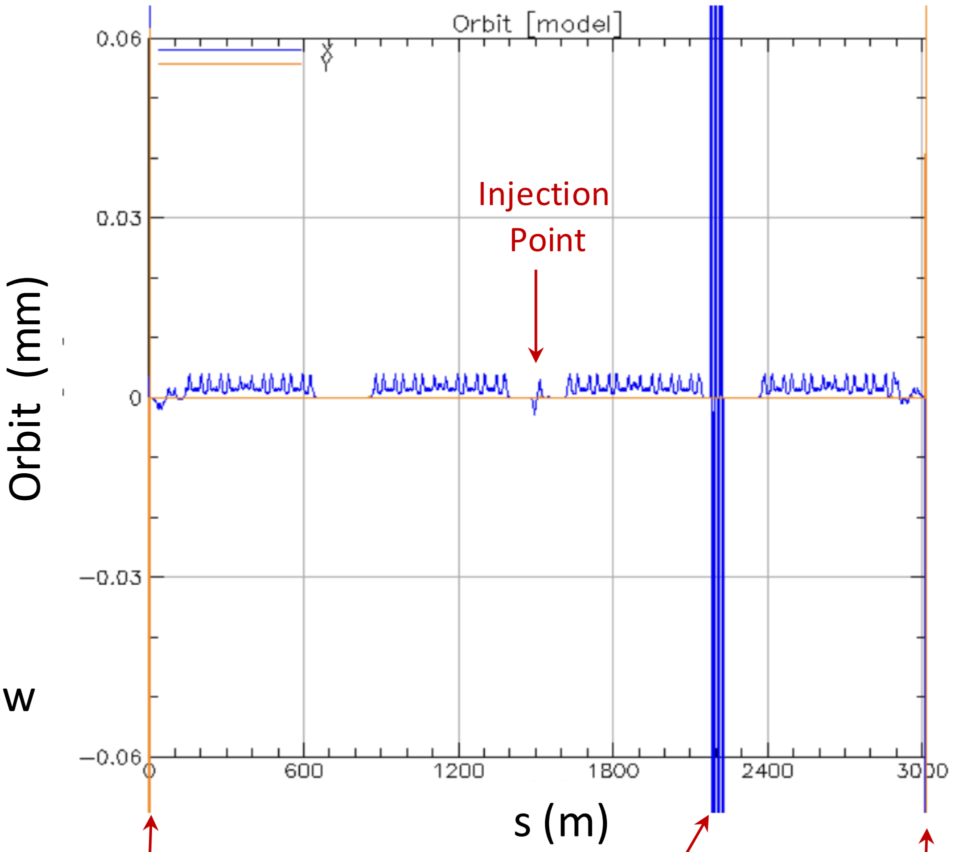
Y in blue

Orbit of HER with and without Compact Spin Rotators

N. Tessema & Y. Peng's (UVictoria)

X in yellow

Y in blue



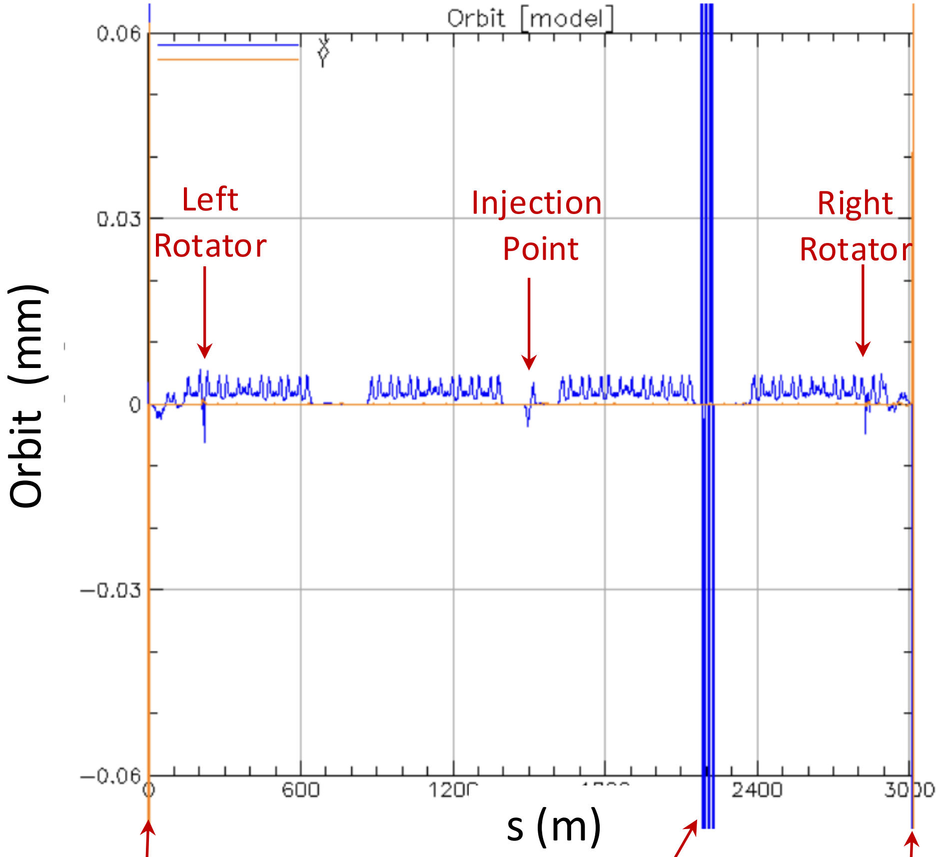
Injection Point

Interaction Point

Wiggler

Interaction Point

Original High Energy Ring



Left Rotator

Injection Point

Right Rotator

Interaction Point

Wiggler

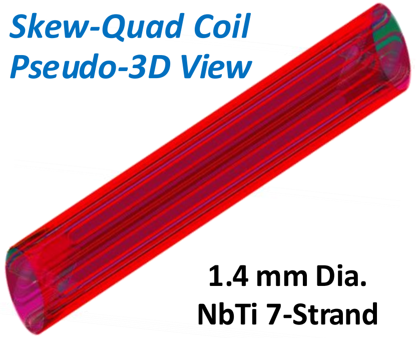
Interaction Point

High Energy Ring with Spin Rotators (156 model)

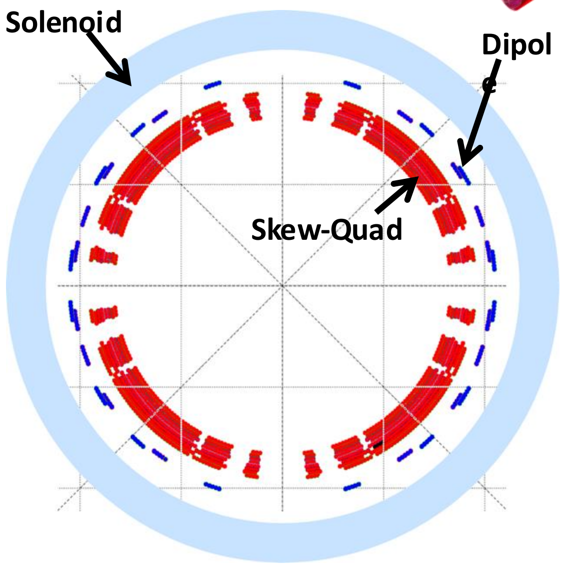
Compact Spin Rotator – Coil Feasibility

Brett Parker (BNL)

Skew-Quad Coil Pseudo-3D View



1.4 mm Dia. NbTi 7-Strand Cable



Coil Cross Section at Skew-Quad Center

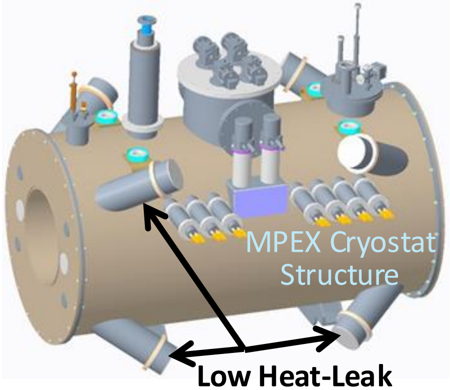
Solenoid Field 4.85 T
Skew Gradient 24 T/m
Dipole Field 0.2 T

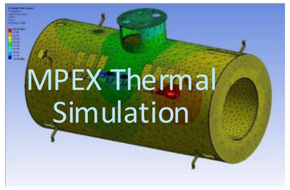
Combined Field @ Skew-Quad is 6.15 T
I_{op} = 729 A
I_q = 1050 A
for 69% Short Sample

- **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.**

Compact Spin Rotator

Status of Chiral Belle Spin Rotator: Spin Rotator Unit Practical Considerations, Brett Parker (BNL)

BNL Side Responsibilities:

- Direct Wind dipole and skew-quads
- Estimate heat load
  - ❖ Tentative heat shield & supports
  - ❖ Estimate current leads
- Conceptual cryocooler layout
  - ❖ Cryocooler number/capacity
  - ❖ Wet vs. Dry system (He volume)
- Magnet parameter interface


AGS Snake in Tunnel

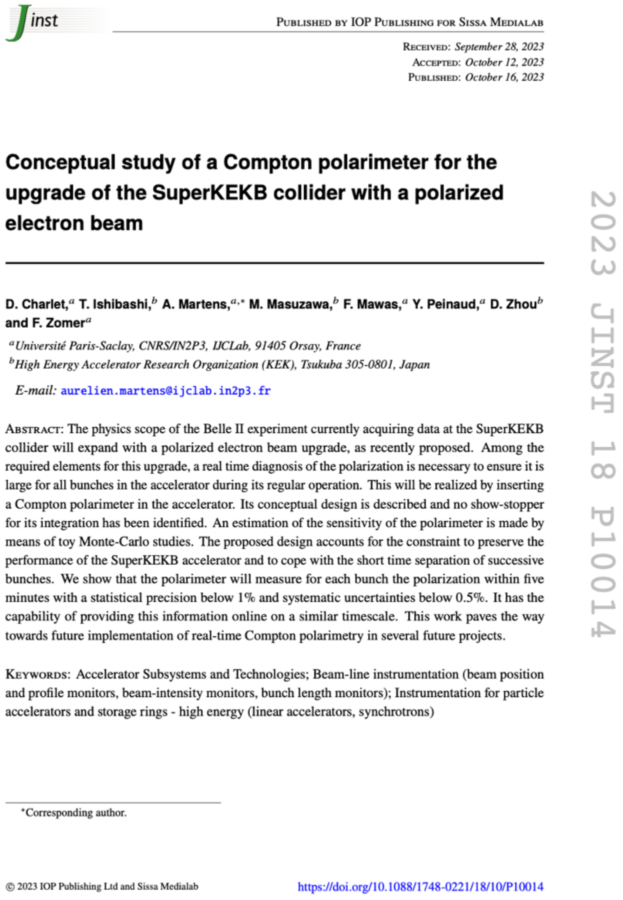

HER Warm Dipoles in Tunnel at KEK.

KEK Side Responsibilities:

- Solenoid coil (use SuperKEKB experience)
- Interface accelerator requirements
  - ❖ Minimum warm bore size
  - ❖ Space for positron beam
  - ❖ Installation space in tunnel
  - ❖ Check all 4 locations
  - ❖ Check cryo-safety requirements
- Magnet parameter interface

Polarization in SuperKEKB: Compton polarimeter

IJCLab IN2P3 team (A. Martens, Y. Peinaud,F. Zomer, P. Bambade,F. Le Diberder, K. Trabselsi) **HERA Compton Polarimeter experience**



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

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]

[a] *Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France*
[b] *High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan*

E-mail: aurelien.martens@ijclab.in2p3.fr

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.

© 2023 IOP Publishing Ltd and Sissa Medialab

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

2023 JINST 18 P10014

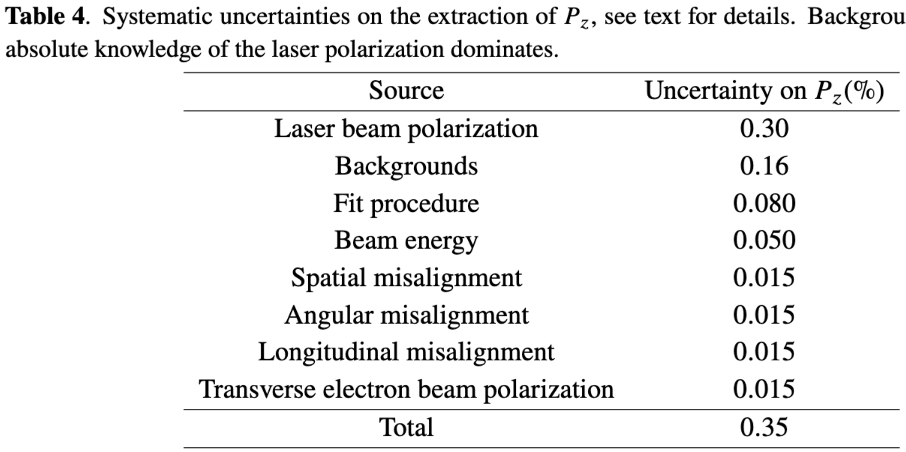


Table 4. Systematic uncertainties on the extraction of P_z, see text for details. Background modeling and absolute knowledge of the laser polarization dominates.

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

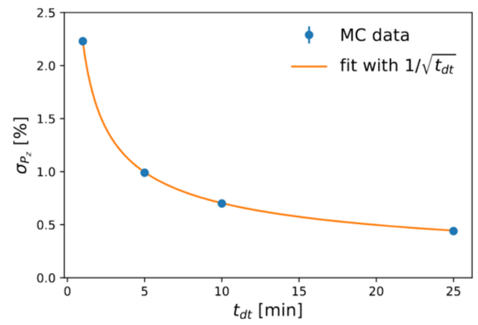


Figure 7. Statistical precision of the Compton polarimeter as a function of the duration of the data taking t_{dt} for a single bunch. For 25 minutes of data taking, a 0.5% statistical precision is obtained. Monte Carlo uncertainties on the points are negligible and smaller than the size of the points. The orange curve is a $1/\sqrt{t_{dt}}$ fit of the points, showing that the statistical precision behaves as expected.

Polarization in SuperKEKB: Compton polarimeter

U. Manitoba team (J. Mammei, M. Gericke, W. Deconinck)

work on Compton polarimeter at JLab - QWeak and MOLLER –

Using HPVMAPs as Compton e- Detector at MOLLER

HVMAPS Beam Test, Fall 2019, DESY

We recently had a beam test of the 8th (2x1 cm^2) and 9th generation chip at DESY.

Version 10 will be submitted for production by the end of this year (full 2x2 cm^2).

If it performs well, version 11 (2020 submission) will be the production chip we use for MOLLER.

Version 8 at UofM

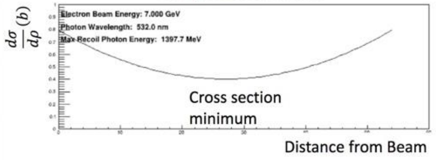
The chip is primarily developed by groups at the U. of Heidelberg and the Karlsruhe Institute of Technology, and intended for various experiments:

- ATLAS
- Mu3e
- PANDA
- P2
- MOLLER

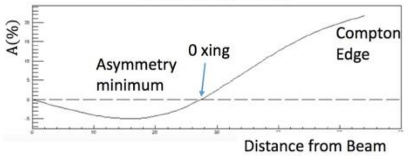
The implementation as a Compton detector is done by the Manitoba group.

Calculations/Simulations

Compton Cross section



Compton Asymmetry



Tau Polarization as Beam Polarimeter

$$P_{z'}^{(\tau-)}(\theta,P_e) = -\frac{8G_F s}{4\sqrt{2}\pi\alpha}\mathrm{Re}\left\{\frac{g_V^l - Q_b g_V^b \Upsilon_{1S,2S,3S}(s)}{1+Q_b^2\Upsilon_{1S,2S,3S}(s)}\right\}\left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2g_A^e\frac{\cos\theta}{1+\cos^2\theta}\right)$$

$$+\boxed{P_e}\frac{\cos\theta}{1+\cos^2\theta}$$

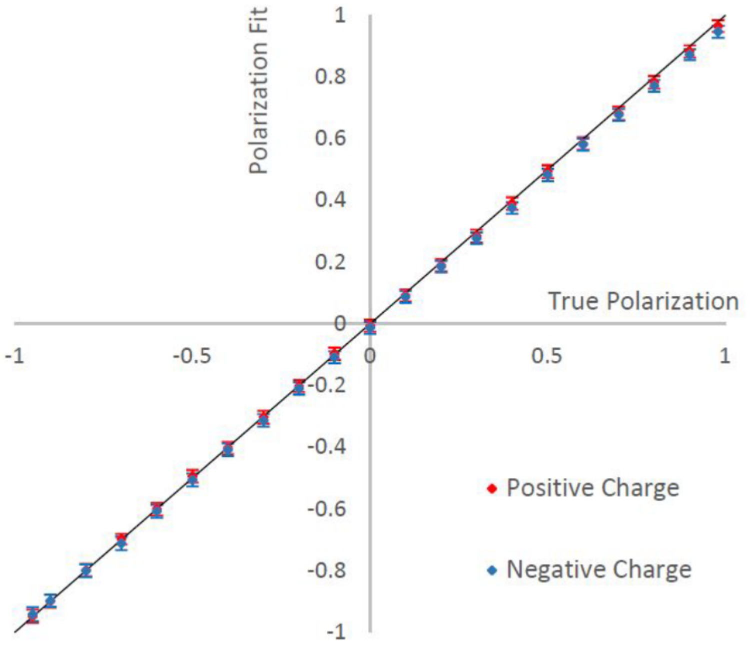
- Dominant term is the polarization forward-backward asymmetry (A^{pol}_{FB}) whose coefficient is the beam polarization
- Measure tau polarization as a function of θ for the separately tagged beam polarization states
- Gives <0.5% absolute precision of the polarization at the interaction point – includes transport effects, lumi-weighting, stray e^+ polarization
- Method assumes tau neutrino is 100% left handed – motivates validation of this

Tau Beam Polarimetry (*BABAR* paper): e- Polarization be measured to < 0.005

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

Beam Polarization MC “Measurement”

- As PEP-II had no beam polarization we performed MC studies of the polarimetry technique for arbitrary beam polarization states for validation of the method
- This is done by splitting each of the polarized tau MC samples in half
- One half of each is used to perform the polarization fit
- The other half is used to mix specific beam polarization states
  - e.g. 70% polarized = 85% left +15% right
- Simulated beam polarization states are produced in steps of 10% beam polarization
- We found the fit responded well and was able to correctly measure any designed beam state



Caleb Miller: Tau 2023 Conference

Tau Beam Polarimetry (*BaBar* paper): :
e- Polarization be measured to < 0.005

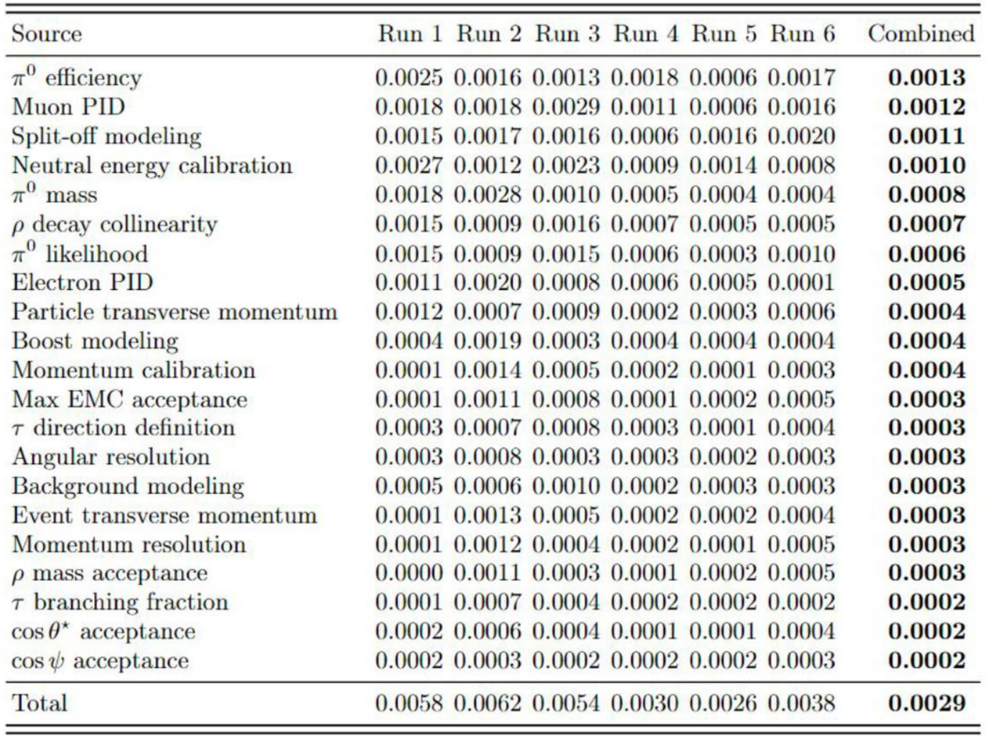
Full Measurement

- Performing the measurement on the full 424.2 fb^{-1}

Sample	Luminosity (fb^{-1})	Average Polarization
Run 1	20.4	0.0062±0.0157
Run 2	61.3	-0.0004±0.0090
Run 3	32.3	0.0048±0.0083
Run 4	99.6	-0.0114±0.0071
Run 5	132.3	-0.0040±0.0063
Run 6	78.3	0.0157±0.0082
Total	**424.2**	**0.0035±0.0024**

- Final measurement:

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



Source	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Combined
π^0 efficiency	0.0025	0.0016	0.0013	0.0018	0.0006	0.0017	**0.0013**
Muon PID	0.0018	0.0018	0.0029	0.0011	0.0006	0.0016	**0.0012**
Split-off modeling	0.0015	0.0017	0.0016	0.0006	0.0016	0.0020	**0.0011**
Neutral energy calibration	0.0027	0.0012	0.0023	0.0009	0.0014	0.0008	**0.0010**
π^0 mass	0.0018	0.0028	0.0010	0.0005	0.0004	0.0004	**0.0008**
ρ decay collinearity	0.0015	0.0009	0.0016	0.0007	0.0005	0.0005	**0.0007**
π^0 likelihood	0.0015	0.0009	0.0015	0.0006	0.0003	0.0010	**0.0006**
Electron PID	0.0011	0.0020	0.0008	0.0006	0.0005	0.0001	**0.0005**
Particle transverse momentum	0.0012	0.0007	0.0009	0.0002	0.0003	0.0006	**0.0004**
Boost modeling	0.0004	0.0019	0.0003	0.0004	0.0004	0.0004	**0.0004**
Momentum calibration	0.0001	0.0014	0.0005	0.0002	0.0001	0.0003	**0.0004**
Max EMC acceptance	0.0001	0.0011	0.0008	0.0001	0.0002	0.0005	**0.0003**
τ direction definition	0.0003	0.0007	0.0008	0.0003	0.0001	0.0004	**0.0003**
Angular resolution	0.0003	0.0008	0.0003	0.0003	0.0002	0.0003	**0.0003**
Background modeling	0.0005	0.0006	0.0010	0.0002	0.0003	0.0003	**0.0003**
Event transverse momentum	0.0001	0.0013	0.0005	0.0002	0.0002	0.0004	**0.0003**
Momentum resolution	0.0001	0.0012	0.0004	0.0002	0.0001	0.0005	**0.0003**
ρ mass acceptance	0.0000	0.0011	0.0003	0.0001	0.0002	0.0005	**0.0003**
τ branching fraction	0.0001	0.0007	0.0004	0.0002	0.0002	0.0002	**0.0002**
$\cos\theta^\star$ acceptance	0.0002	0.0006	0.0004	0.0001	0.0001	0.0004	**0.0002**
$\cos\psi$ acceptance	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**

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

Caleb Miller: Tau 2023 Conference

Tau Polarization as Beam Polarimeter

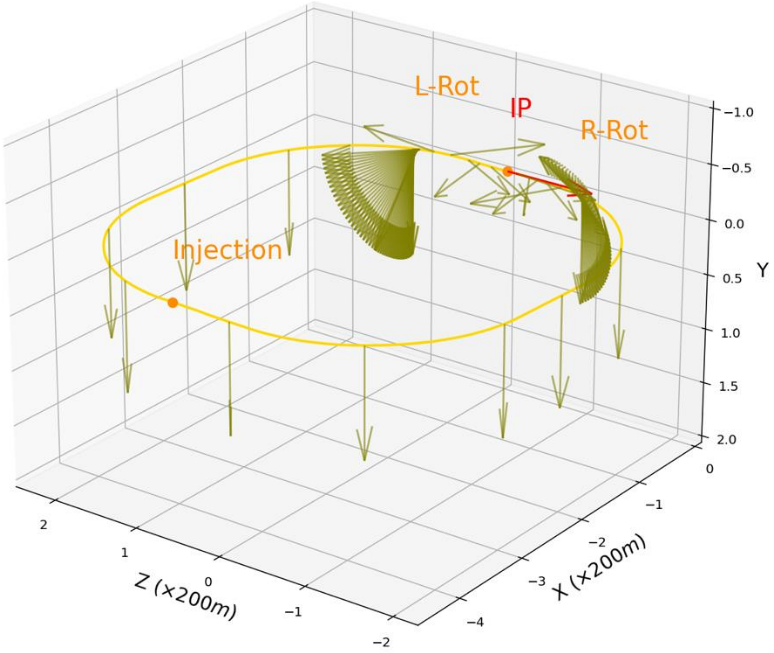
- Advantages:
  - Measures beam polarization at the IP: biggest uncertainty in Compton polarimeter measurement is likely the uncertainty in the transport of the polarization from the polarimeter to the IP.
  - It automatically incorporates a luminosity-weighted polarization measurement
  - If positron beam has stray polarization, its effect is automatically included

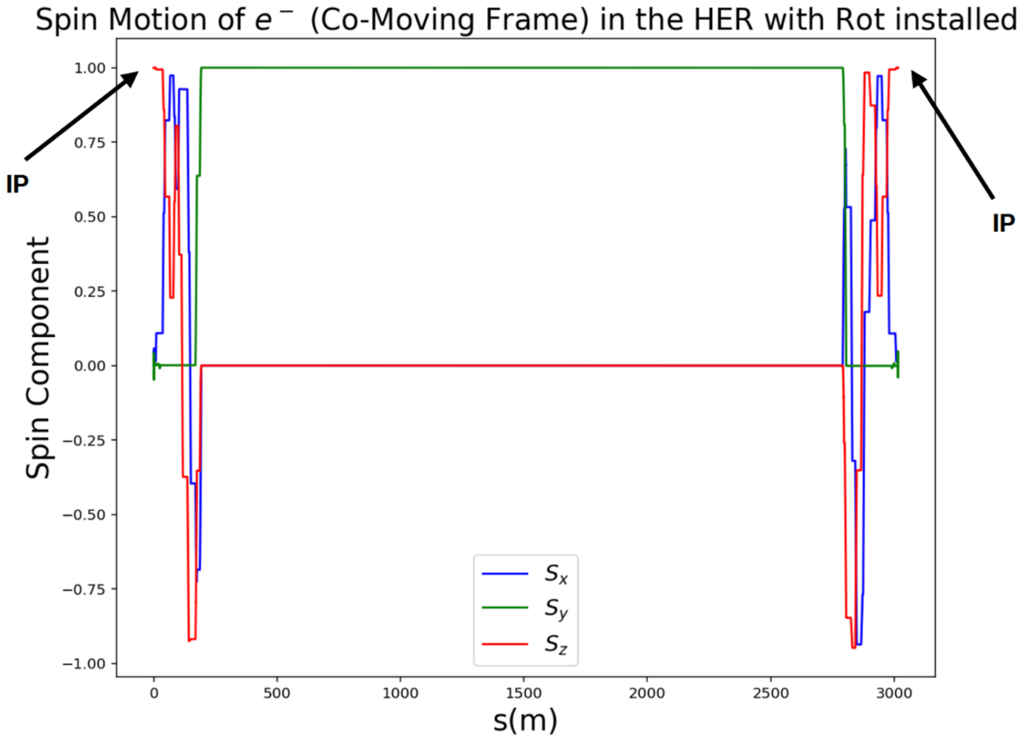
Compact spin rotator

Y. Peng's (UVictoria)

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

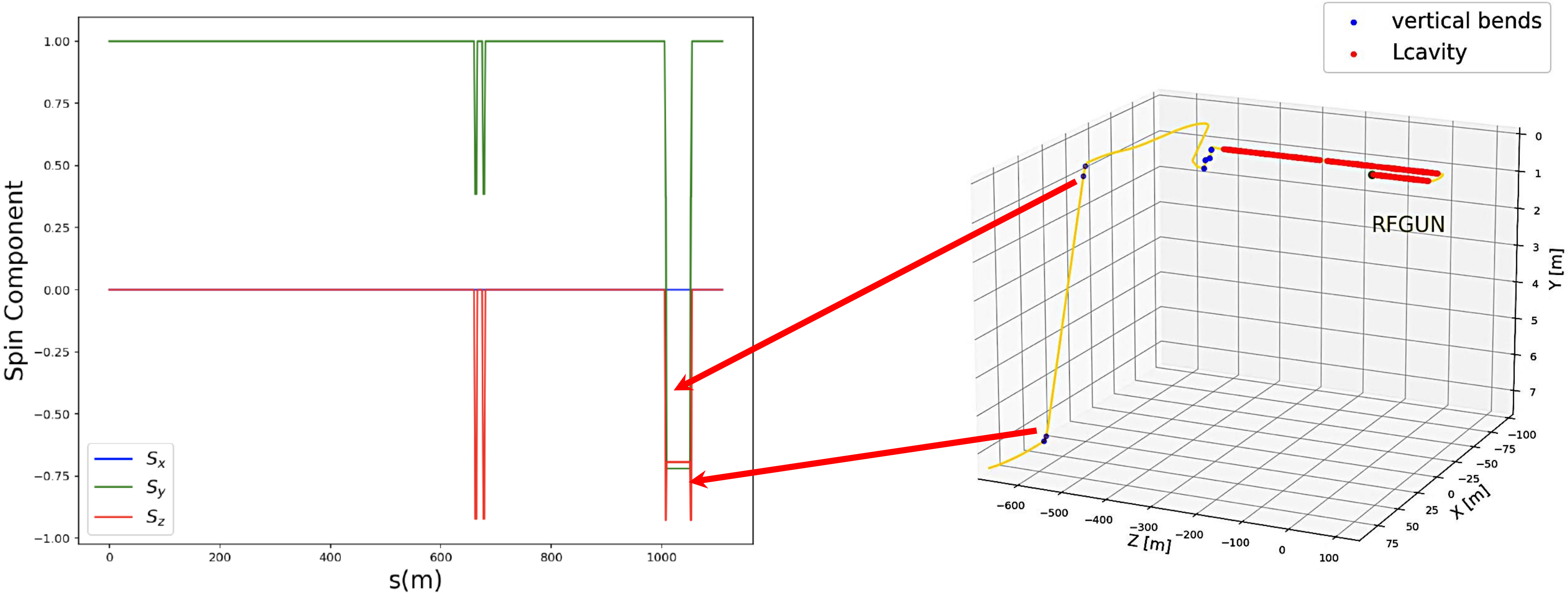



Spin Motion of e^- (Co-Moving Frame) in the HER with Rot installed

Spin motion in the KEK Injection Linac

Y. Peng (UVic)

KEK Linac



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.

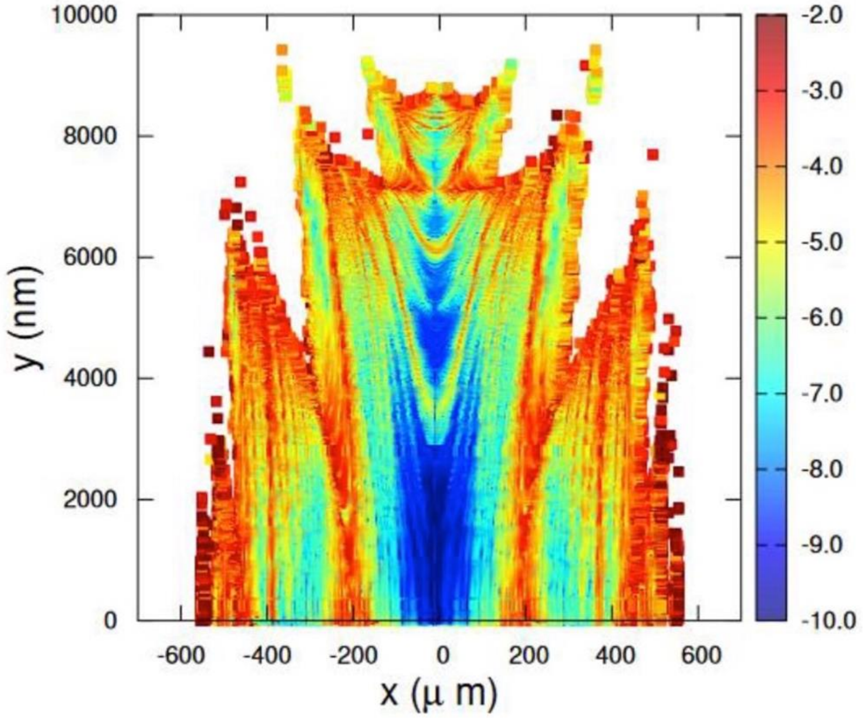
Compact spin rotator

Frequency Map Analysis (FMA)

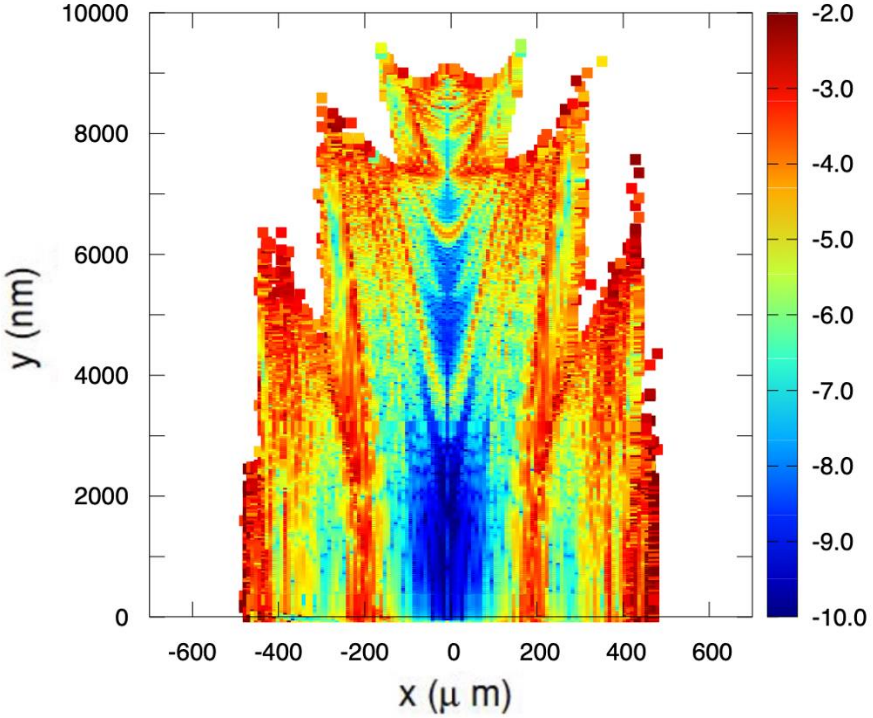
dynamic aperture studies using Bmad – show no large changes

work by D. Zhou (KEK), Noah Tessema (UVictoria), U. Wienands (ANL)

Original HER Lattice



HER Lattice with Compact Spin Rotator



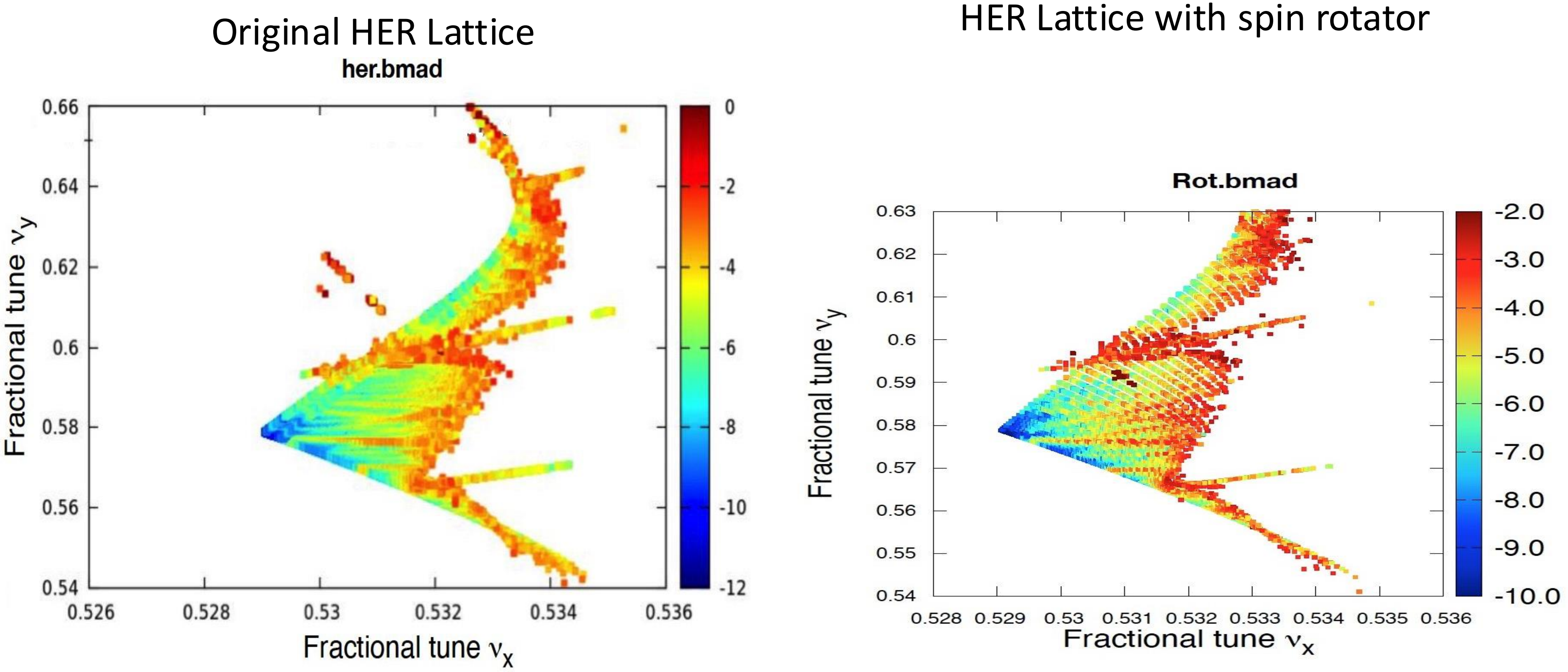
Bmad: A relativistic charged particle simulation library, D. Sagan, *Nucl.Instrum.Meth.A* 558 (2006) 356-359

Compact spin rotator

Frequency Map Analysis (FMA)

dynamic aperture studies using Bmad – show no large changes

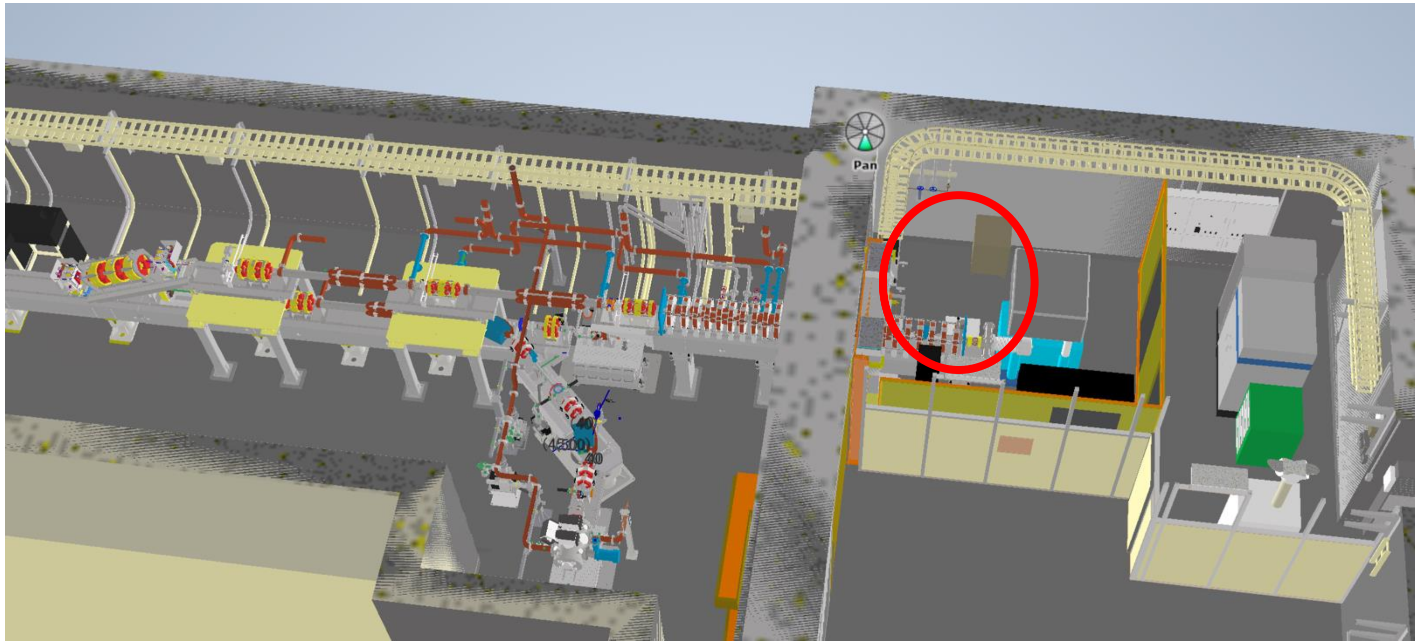
work by D. Zhou (KEK), Noah Tessema (UVictoria), U. Wienands (ANL)

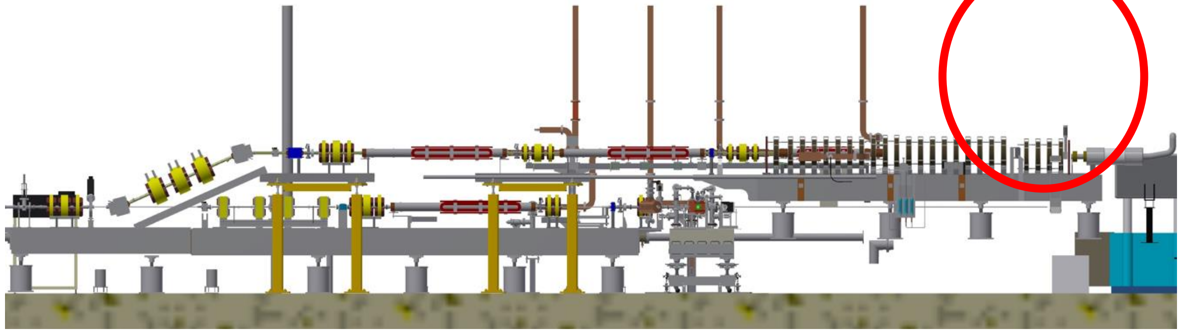


Bmad: A relativistic charged particle simulation library, D. Sagan, *Nucl.Instrum.Meth.A* 558 (2006) 356-359

Work on polarized source: Injection Room Area

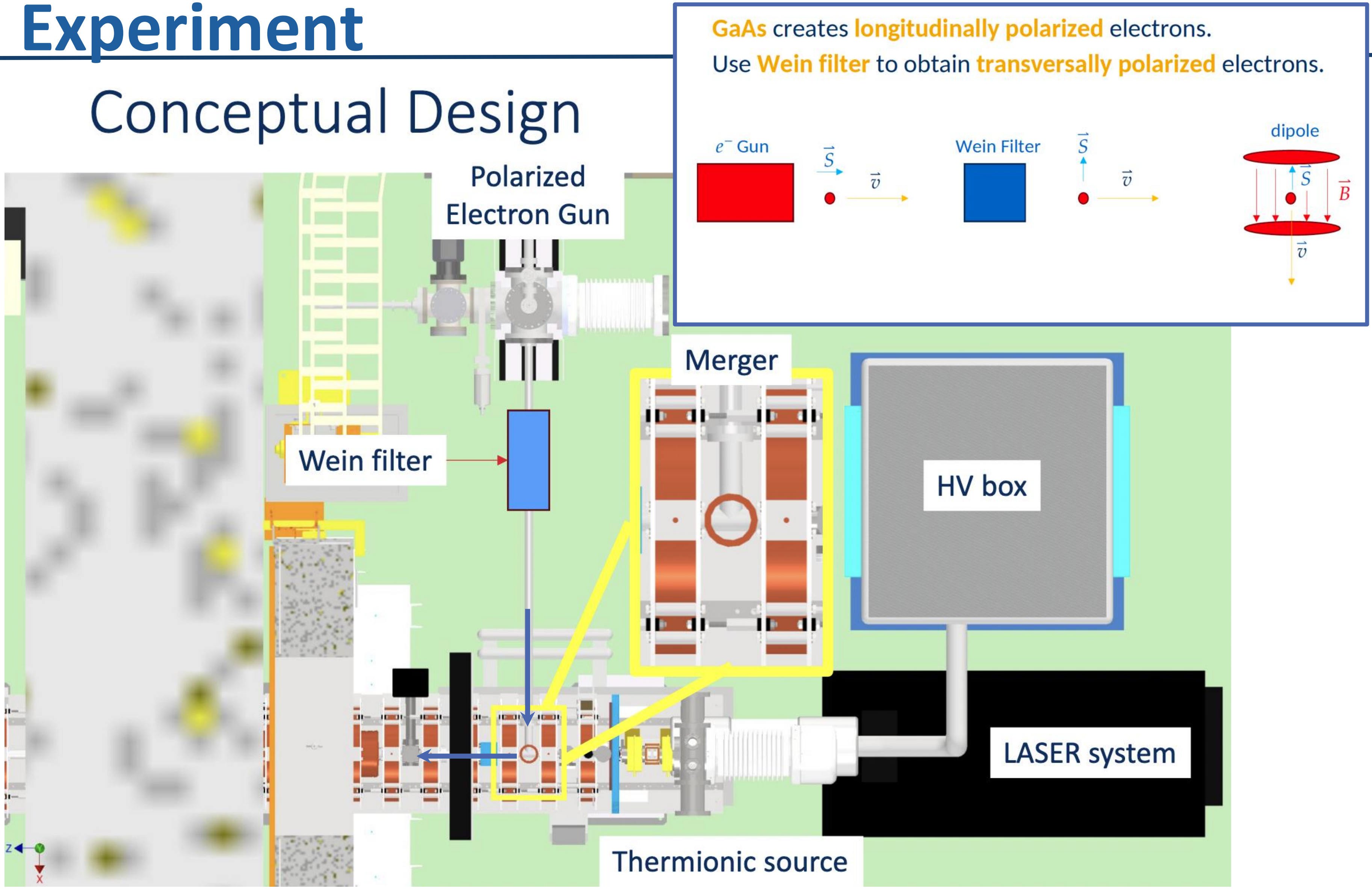
Alexandre Beaubien
(EPECR KEK-TRIUMF Scholar)
working with
Mitsuhiro Yoshida (KEK)





Source for Touschek Polarization Experiment

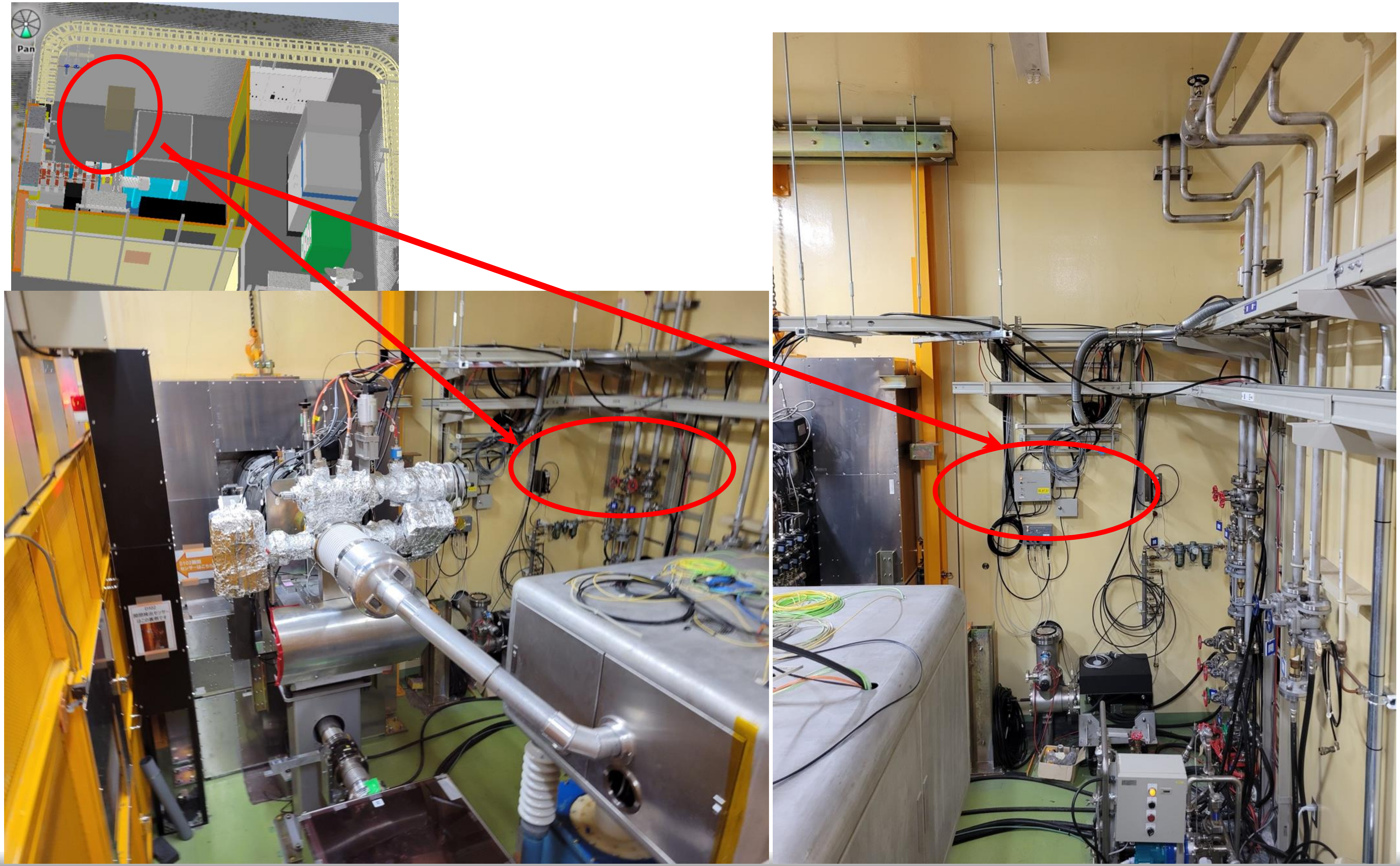
Conceptual Design



GaAs creates **longitudinally polarized** electrons.
Use **Wein filter** to obtain **transversally polarized** electrons.

A. Beaubien, M. Yoshida

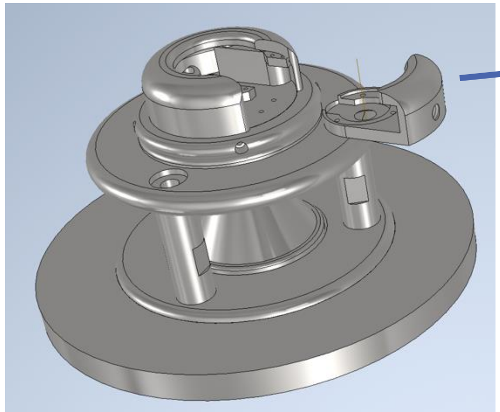
Work on polarized source: Injection Room Area



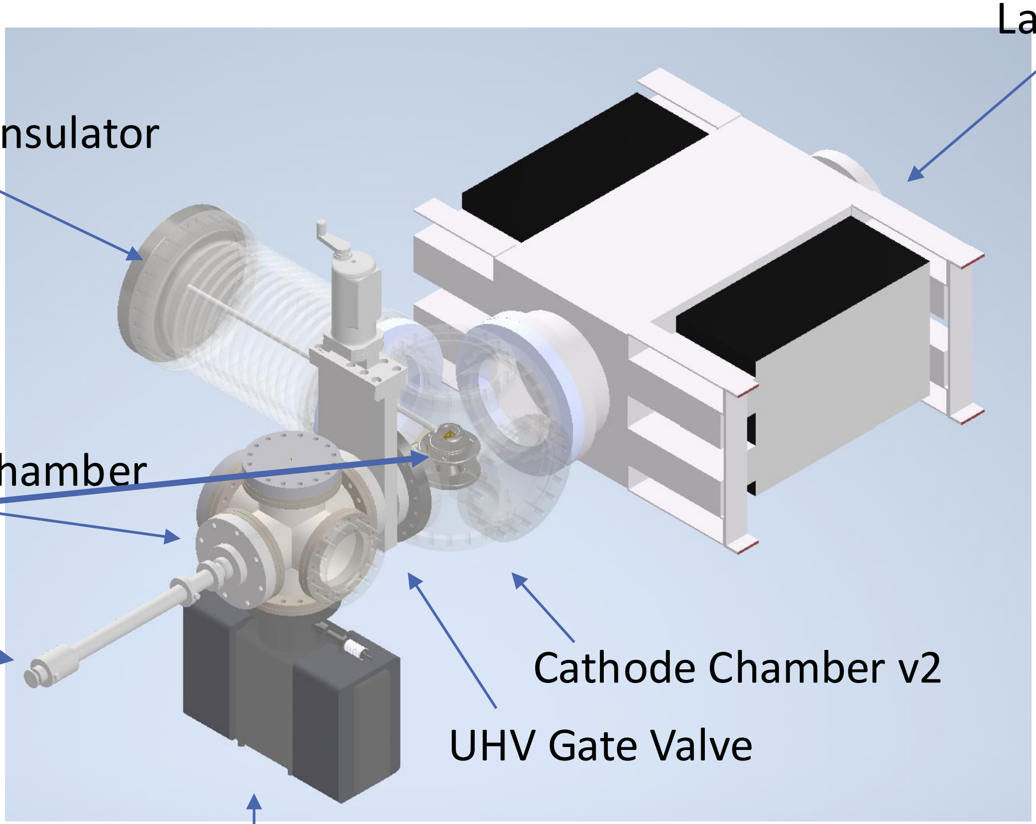
Conceptual Design of Polarized Electron Gun - Holder

Alexandre Beaubien
(EPECR KEK-TRIUMF Scholar)
working with Mitsuhiro Yoshida (KEK)

Cathode Holder



Design from: N. Yamamoto, PhD Thesis



Large Ion Pump

High Voltage Insulator

Evaporation Chamber

Extension Arm

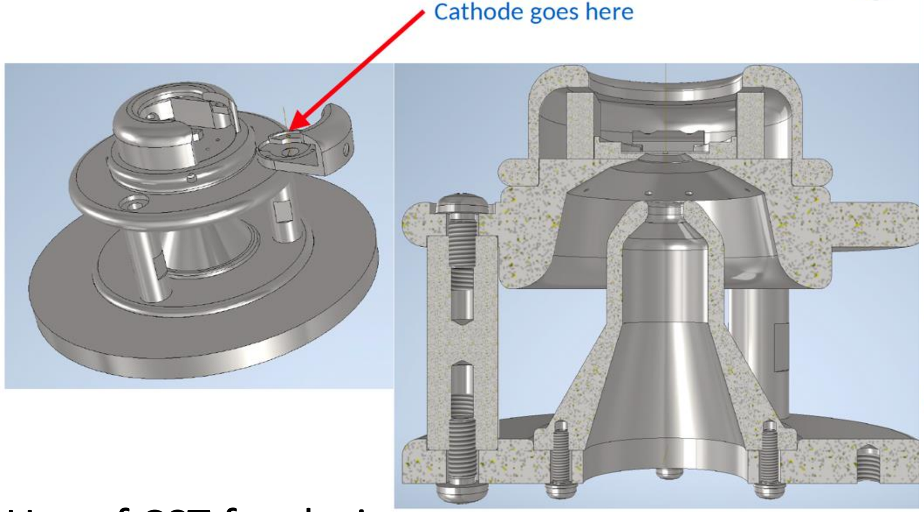
Cathode Chamber v2

UHV Gate Valve

Small Ion Pump

Polarized Source

Cathode & Anode



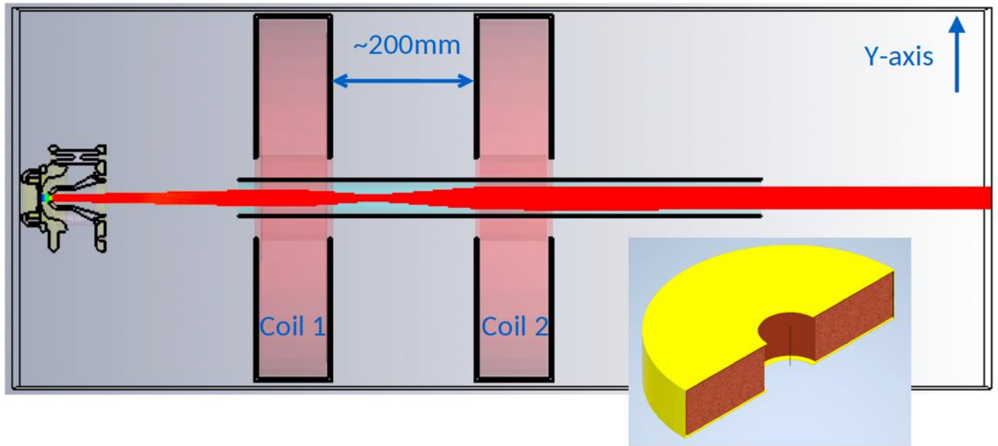
Use of CST for design

Adapted from a design by N. Yamamoto;
Redesigned in part for low emittance at 200keV using Inventor

*Emittance is consistently in O(1 mm*mrad) range i.e. 10^{-6}*
No matter the currents and the distance to anode/cathode

A. Beaubien, M. Yoshida

Focusing Magnet



Create parallel beam for long distance transportation

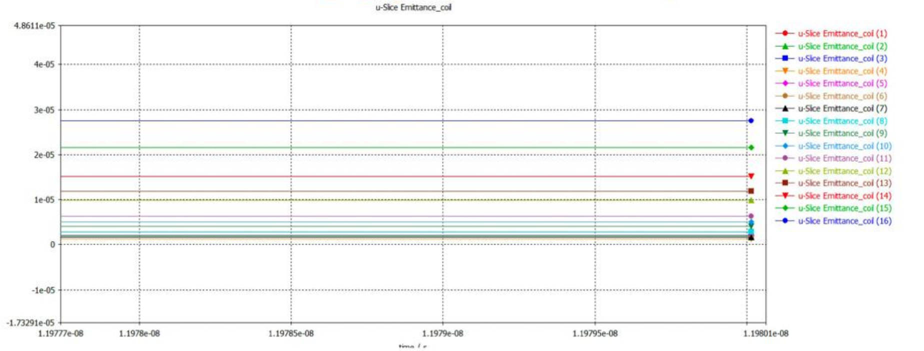
- Coil 1: **1.05 A** — Coil 2: **1.5 A** — **2800 turns**
- Minimize p_t in x-y plane for parallel beam

Emittance

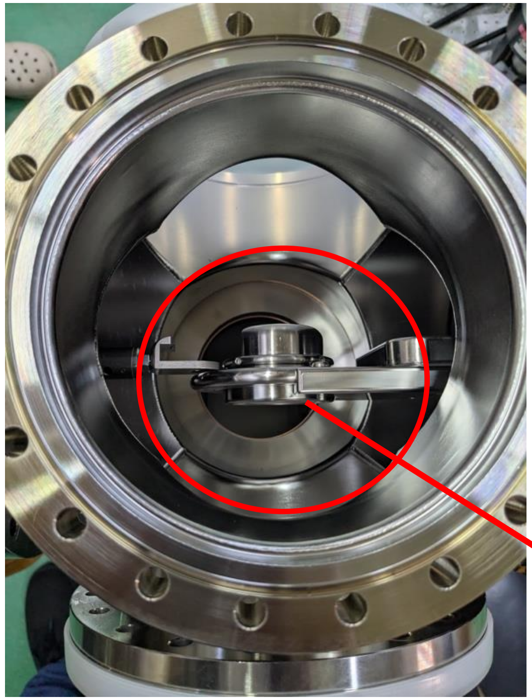
Grid parameter sweep:

- coil 1: 0.75A – 1.25A
- coil 2: 1.25A – 1.75A

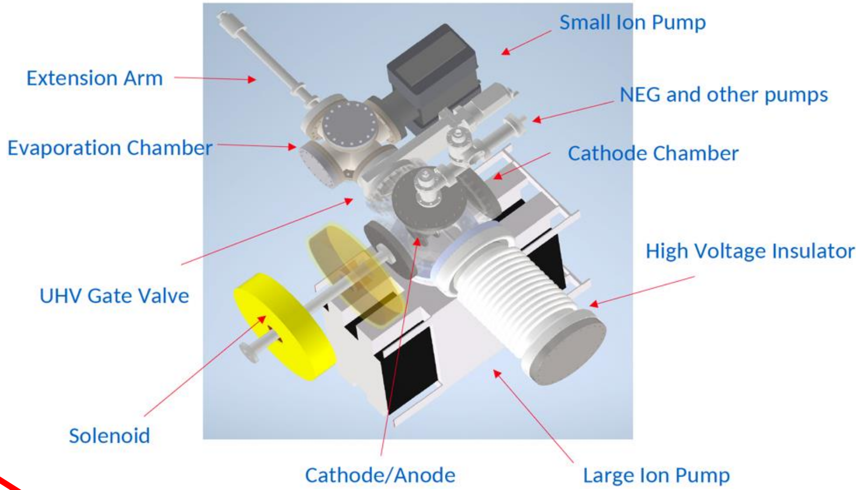
Emittance near the **merging dipole** (~1.6m from cathode)

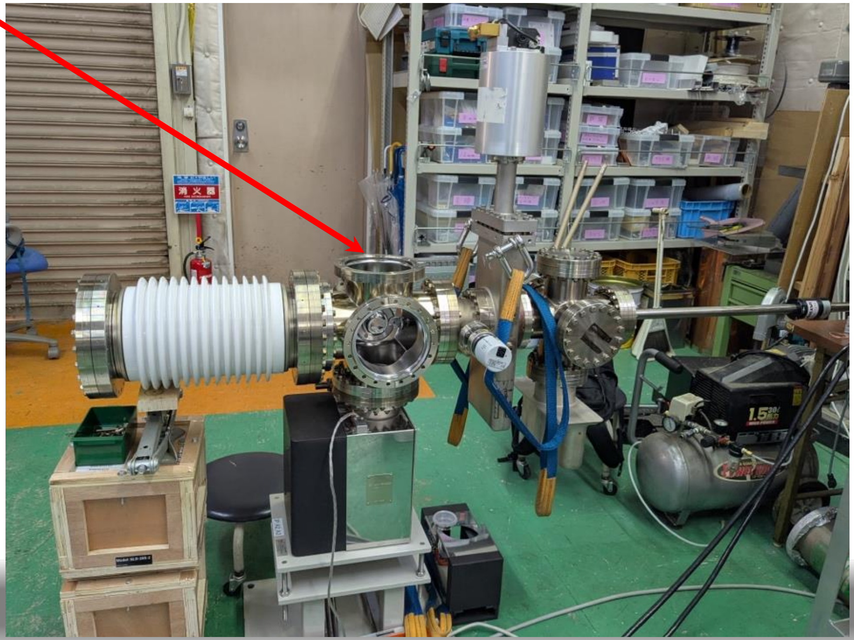


Source anode delivered in Sept 2025



Polarized Electron Gun

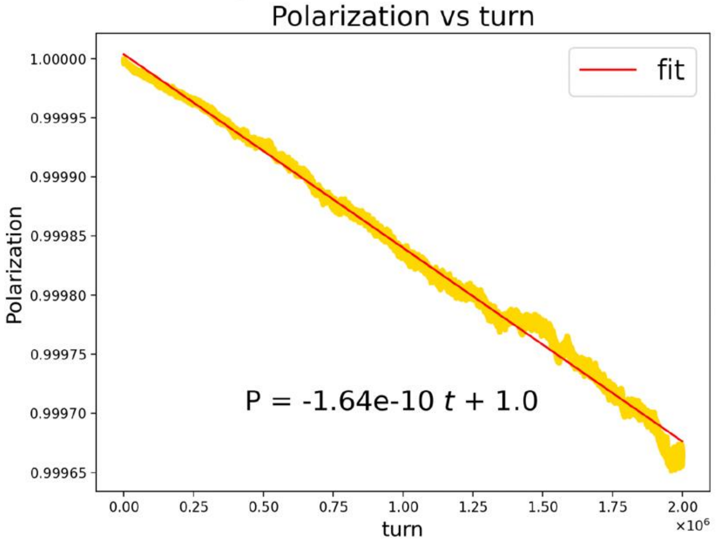




A. Beaubien, M. Yoshida

Touschek Polarization Experiment

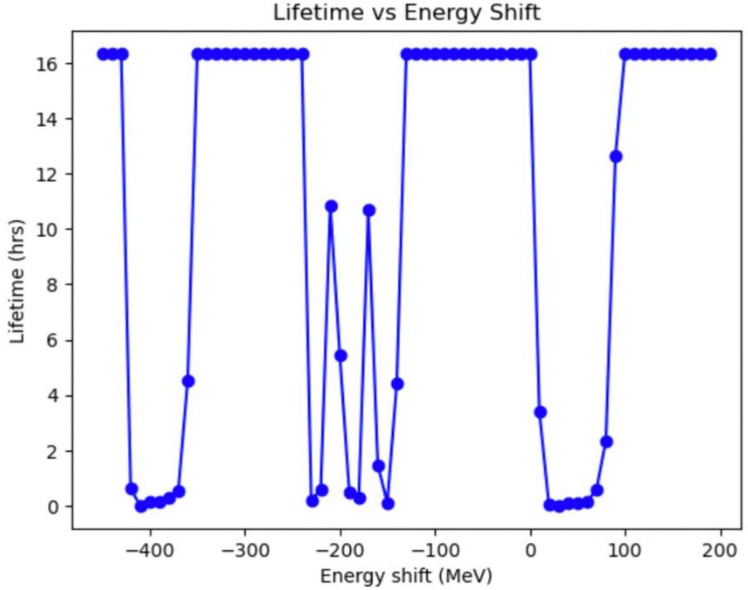
Study of Spin lifetime for the HER



- Tracking 100 particle for 2M turns in the SuperKEKB HER at the design energy: 7.00729GeV
- Lifetime~17hrs

Yuhao Peng (U Victoria)

Study of Spin lifetime for the HER



- Design Energy: 7.00729GeV
- The energy is shifted from the designed energy with 10 MeV as step
- Tracking 100 particle for 20000 turns in the SuperKEKB HER

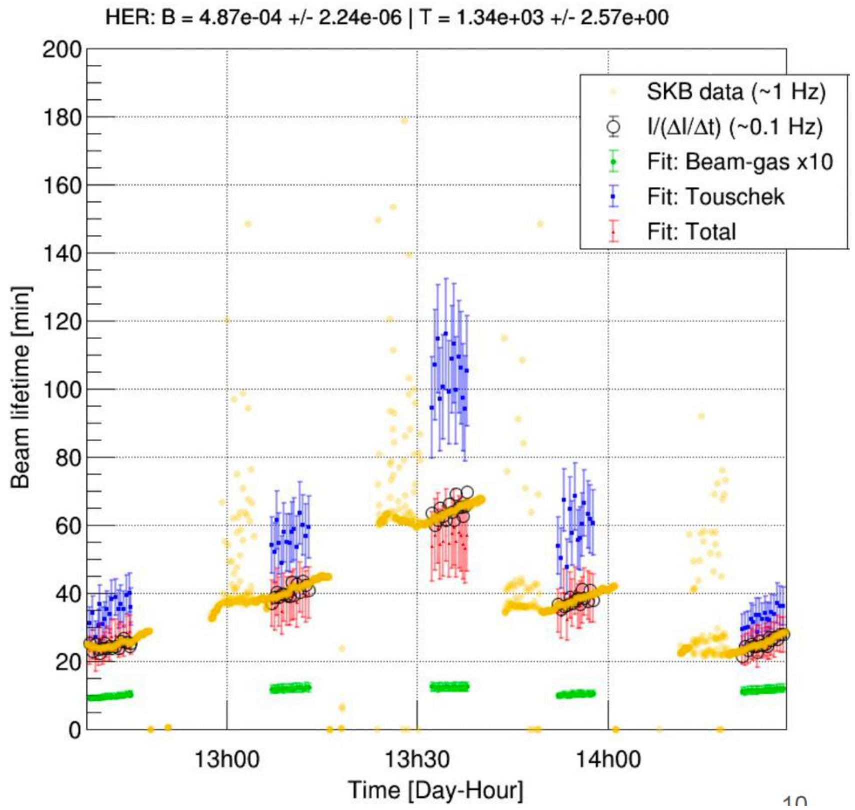
Yuhao Peng (U. Victoria)

Touschek Lifetime Studies

from Andrii Natochii (BNL)

Example of data and results of
heuristic fit for HER

Beam lifetime estimation for June 2020



Period	Experimental HER Touschek Lifetime (minutes) at a current of 1.0 A	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

The Touschek Lifetime in the HER has been measured at the few per-mil level (statistical) – sufficient for seeing changes in lifetime from polarization effects, which are at the 4% level

Chiral Belle: Unique Polarized Beam Physics Program Augmenting Existing Belle II Program

Unique access to program of precision Neutral Current EW physics:

- precision $\sin^2\theta_W$ ±0.0002 : same precision as at Z^0-pole – but at 10GeV

  uniquely probes the running of $\sin^2\theta_W$ with e, μ, τ, c, b

  & 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** (e & τ: Hprecision as at Z^0-pole but at 10GeV)
- **Highest precision neutral-current universality** measurements by many factors (e.g. b:c universality>10x more precise with $20ab^{-1}$ Chiral Belle *cf* World Average)

Beyond Neutral Current EW physics:

- **Highest precision tau g-2** by many orders of magnitude $\mathcal{O}(10^{-5})$ *cf* $\mathcal{O}(10^{-2})$
- **Highest precision tau Michel parameter measurements** by order of magnitude
- other topics reported in Snowmass Whitepaper arXiv:2205.12847

Chiral Belle: Unique Polarized Beam Physics Program Augmenting Existing Belle II Program

R&D work yielding

- **Feasible Design**
  - Polarized source – synergies with e.g. EIC
  - Polarimetry at <0.5%
  - Spin Rotators transparent to rest of HER lattice – designed to have no impact on high luminosity goals of SuperKEKB
    - Planning prototype of spin rotator magnet at BNL

- **Progress on Touchek-Polarization lifetime experiment to test Long Term tracking study predictions**
  - Polarized Source being constructed
  - Merge line being developed
  - Studies of polarization vs beam energy to be used in precision beam energy calibration
  - planned to be conducted following 2026 running period