Belle II

Upgrade Workshop, Feb B2GM 2026

Chiral Belle:
Polarized e^- Beam Upgrade for SuperKEKB

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University of Victoria

28 January 2026

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

University of Victoria

Reminder: Introducing Polarized e- Beams opens an Exciting Enhanced Physics Program for Belle II

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 energy running of $\sin^2\theta_W$ with e, μ, τ, c, b

& unique probe of dark sector with e, μ, τ, c, b

- **Highest precision Z^0-fermion (neutral current) vector current coupling measurements by many factors for μ, b, c** (e and τ: ~same precision as at Z^0-pole)

- **Highest precision neutral-current universality measurements** by many factors (e.g. b:c universality >10x more precise)

Beyond Precision Neutral Current EW physics:

- **Highest precision tau g-2 via $F_2(100GeV^2)$** 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 Chiral Belle Snowmass Whitepaper ***arXiv:2205.12847***

Precision Neutral Current Electroweak Program

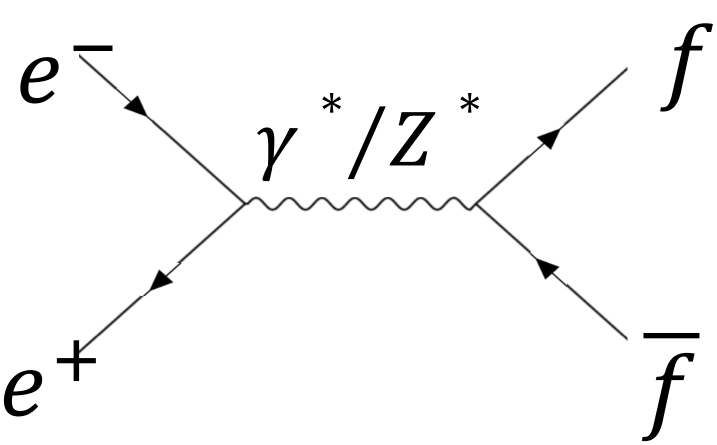
Polarized SuperKEKB e- beams enables determination of A^f_{LR} at $\sqrt{s} = 10.6\text{GeV}$ by measuring left-right asymmetries arising from $\gamma - Z$ interference using Belle II detector

Standard Model predicts left-right asymmetries at level of

10^{-4} (e/mu/tau), 10^{-3} (charm), 10^{-2} (bottom)

- **Polarized collisions and high luminosity are needed!**

Most detector-related systematic errors cancel by flipping laser polarization in known pattern



Lowest-order s-channel

$$A^f_{LR}(\text{SM}) = \frac{\sigma^f_{\mathbf{L}} - \sigma^f_{\mathbf{R}}}{\sigma^f_{\mathbf{L}} + \sigma^f_{\mathbf{R}}} = \frac{sG_F}{\sqrt{2}\pi\alpha Q_f} g^e_A g^f_V$$

$$g^f_V = T^f_3 - 2Q_f \sin^2\theta_W$$

$$g^e_A = T^e_3 = -\tfrac{1}{2}$$

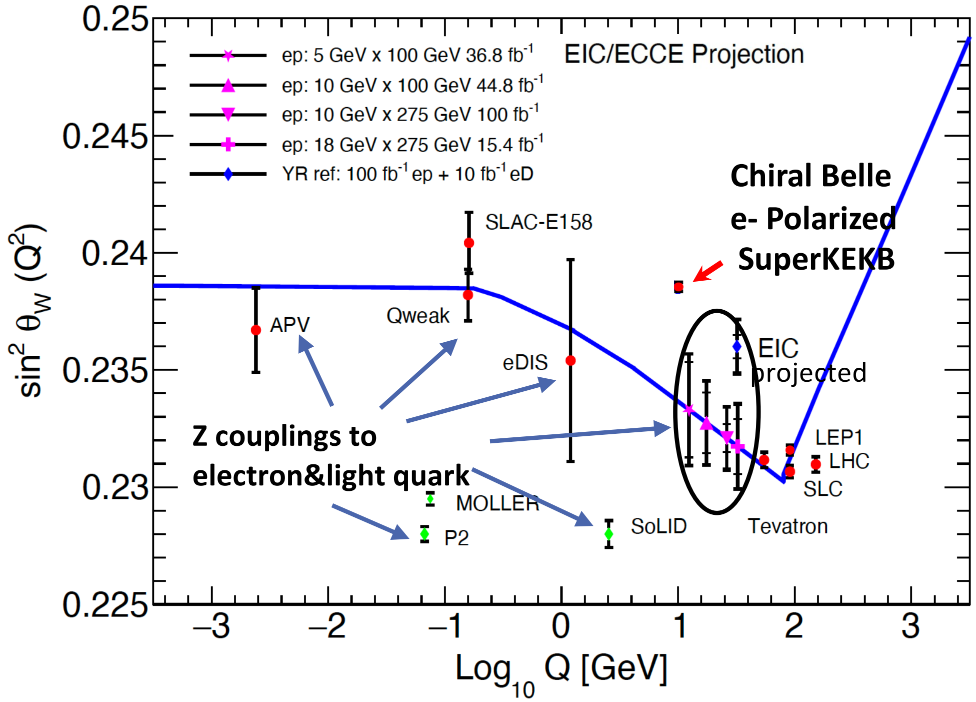
A^f_{LR} (measured) = A^f_{LR} (SM) <Pol>

(<Pol> can be measured to <0.4%)

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



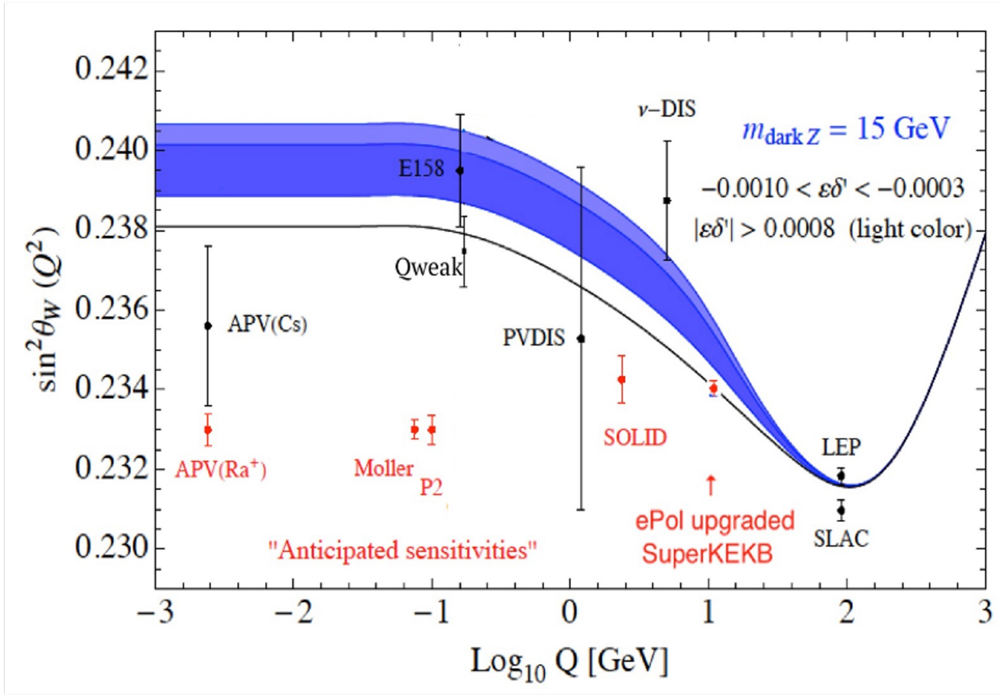


Figure Adapted from *Phys Rev D 106, 016006 (2022)*
(used in EIC Snowmass Whitepaper *arXiv:2203.13199v2*)
using data from PDG 2022 EW review (Erler&Freitas)

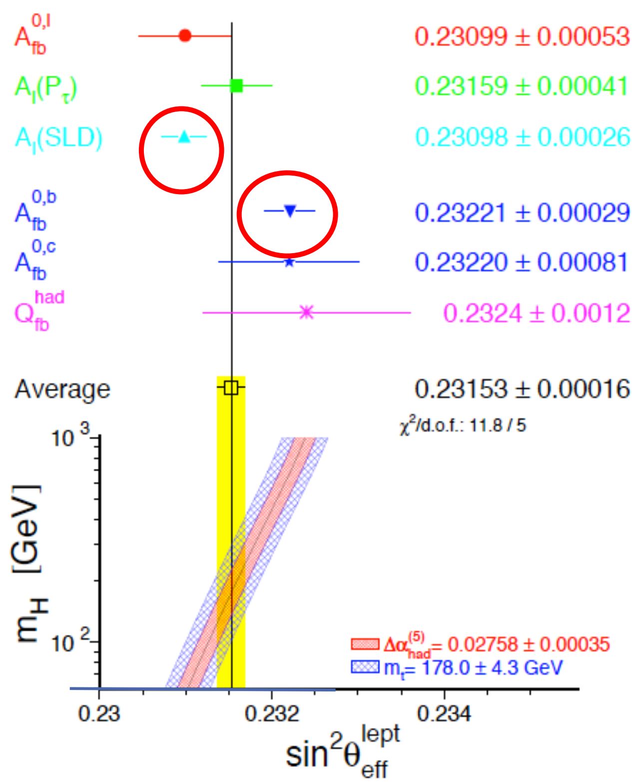
Chiral Belle:
σ = 0.00018 with 40ab^{-1} statistics limited
Using only clean leptonic states (common <Pol> systematic included)

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

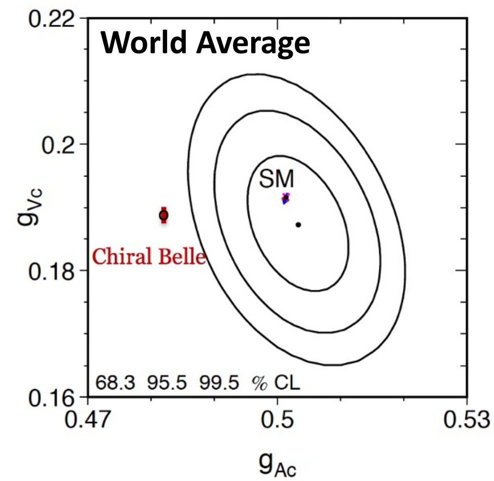
Example of impact of Chiral Belle with only a few ab^{-1} of data:

Substantial improvements can be made to existing World Averages of b and c Neutral Current vector coupling measurements

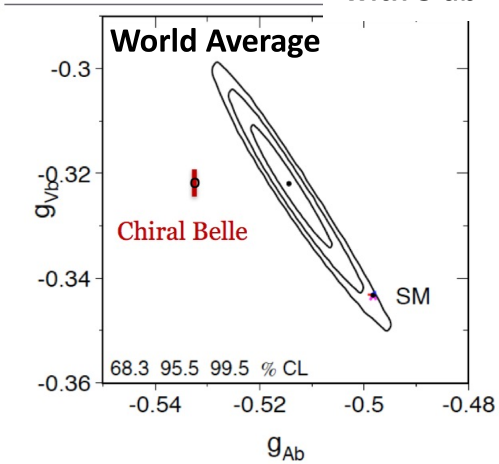
Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD



c-quark:
Chiral Belle ~6 times more precise
with 20 ab^{-1}



b-quark:
Chiral Belle ~4 times more precise
with 5 ab^{-1}



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

Chiral Belle uniquely positioned to resolve whether this tension is early sign of e:b universality violation or a fluctuation

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**

Recent Theory/Phenomenology Papers

- ***Characterizing Dark Bosons at Chiral Belle*** [C.H. de Lima, D. McKeen, A. Omar, D. Tuckler, ***Phys.Rev.D*** **112 (Nov 2025) 9, 095025** (arXiv:2507.15931)]

- *Complete one-loop result for the fully polarized $e^+e^- \to \tau^+\tau^-$ process and its implementation in the Monte-Carlo integrator McMule* [M. Hoferichter and Yannick Ulrich J. High Energ. Phys. **2025** 172 (2025)]
  -> Replaced by: ***Towards Testing $(g-2)_\tau$ in $e^+e^-\to\tau^+\tau^-$: radiative corrections and projections for Belle II*** **[J. Gogniat, M. Hoferichter and Y. Ulrich, JHEP 07(2025) 172,** arXiv:2505.09678 **(July 2025)**

- ***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 (July 2025) 1, 013006]
  (note: this paper motivated new NNLO calculations now underway)

- *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)]

New Dark Sector Sensitivity Studies

Reefat (Theorist at Memorial University of Newfoundland)

Interactions between SM fermions & Dark Vector bosons A'_μ

A Lagrangian describing the interaction between the SM fermions and the dark vector boson A'_μ is:

$$\begin{aligned}\mathcal{L}_{\text{int}} = & - eQ_f \left[\bar{f}\gamma^\mu f\right] . \left(V_\mu + \epsilon_\gamma A'_\mu\right) \\ & - \frac{e}{\sin\theta_W \cos\theta_W}\left[\bar{f}\left(c_V^f \gamma^\mu + c_A^f \gamma^\mu \gamma_5\right) f\right]\left(Z_\mu + \epsilon_{Z'} A'_\mu\right)\end{aligned} \quad (4)$$

Z'_μ

where

- Q_f is the charge of the fermion in units of e
- c_V^f and c_A^f are the SM vector and axial-vector coupling strengths, respectively.

- A'_μ couples to fermions through both parity-conserving and parity-violating terms, which is similar to the Z_μ coupling. This A'_μ is called the dark Z'_μ-boson[2].
- The mixing parameter $\epsilon_{Z'} = \frac{m'_Z}{m_Z}\delta$ where $m_{Z'}$ is the mass of the dark Z'_μ-boson and δ is an arbitrary model-dependent parameter.

[2] Davoudiasl, Hye-Sung Lee, and William J. Marciano. "Dark Side of Higgs Diphoton Decays and Muon g – 2". Physical Review D 85.11 (2012)

New Dark Sector Sensitivity Studies

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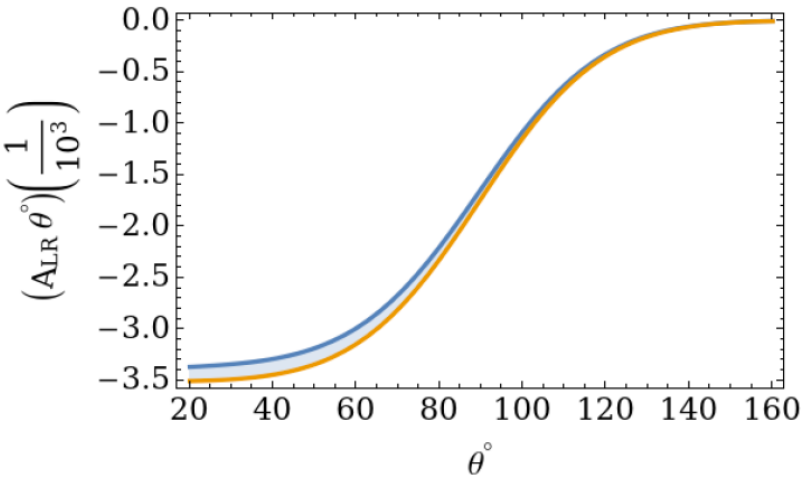
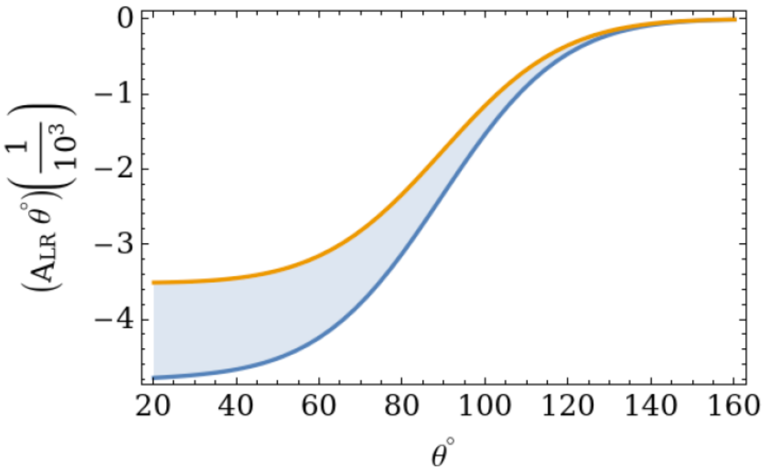


Dark photon A' contribution compared to SM. The blue line shows the asymmetry with the dark photon, and the orange line shows the SM asymmetry.



Dark photon A' and Z' contribution compared to SM. The blue line shows the asymmetry with the dark photon and Z', and the orange line shows the SM asymmetry.

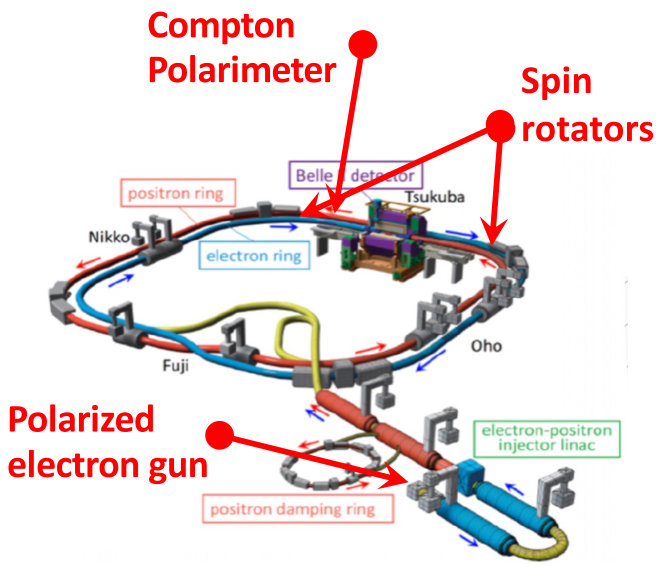
Figure: Comparison of the asymmetries of $e^+ + e^- \to \mu^+ + \mu^-$ scattering. The mass of $m_{A'} = 100$ GeV and $m_{Z'} = 100$ GeV. The mixing parameter $\epsilon_\gamma = 10^{-1}$ and $\epsilon_{Z'} = 10^{-1}$.

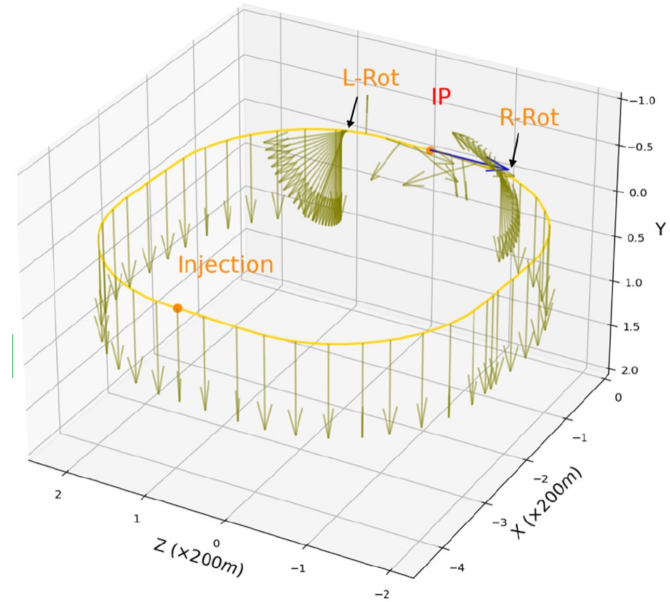
We will consider the following **dark photon** and **Z'** contribution for the following processes:

1. $e^+ + e^- \to \mu^+ + \mu^-$
2. $e^+ + e^- \to \tau^+ + \tau^-$
3. $e^+ + e^- \to$ b bbar
4. $e^+ + e^- \to$ c cbar

This team of theorists is preparing ε vs $m_{A'}$ and ε ' vs $m_{Z'}$ exclusion plots for the different fundamental fermions accessible to Chiral Belle

e- beam polarization in SuperKEKB



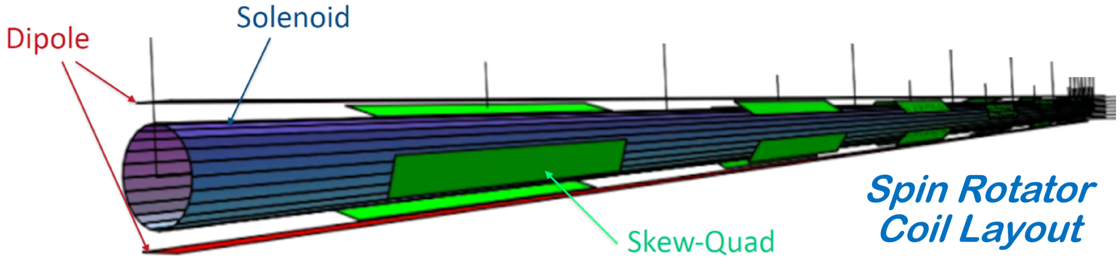


Chiral Belle involves provision of:

1) Polarized source – 70% polarization at IP
2) Spin rotators to provide longitudinal polarization at IP
3) Compton polarimeter for real-time sub-% measurements

Components to be integrated into SuperKEKB without limiting Instantaneous Luminosity

Compact Spin Rotator Solution



Conceptual design of Uli Wienands's (ANL)

HER Warm Dipoles in Tunnel at KEK.

Replace 2 existing ring dipoles on each side of the IP with dipole+solenoid+skew-quad combined function magnets

- Uses original dipole strength to preserve the machine geometry
- Solenoid changes the spin direction
- 6 skew-quads in each rotator section compensates x-y plane coupling caused by solenoids

Each spin-rotator module is a drop-in replacement of an existing HER warm dipole that leaves the overall SuperKEKB ring geometry unchanged

Original High Energy Ring recovered by turning off solenoid and skew-quads leaving only the dipoles

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

Compact Spin Rotator Solution

Frequency Map Analyses: no significant changes in HER dynamic aperture with spin rotators

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

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)

Use Long Term Tracking to map lifetime vs energy to maximize polarization lifetime & for resonant depolarization considerations

CONCLUSION: 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 – Long Term Tracking studies show minimal impact on beam & polarization lifetimes

Planning for Compact Spin Rotator Prototype

¼-Length Chiral Belle Spin Rotator Demonstration Prototype

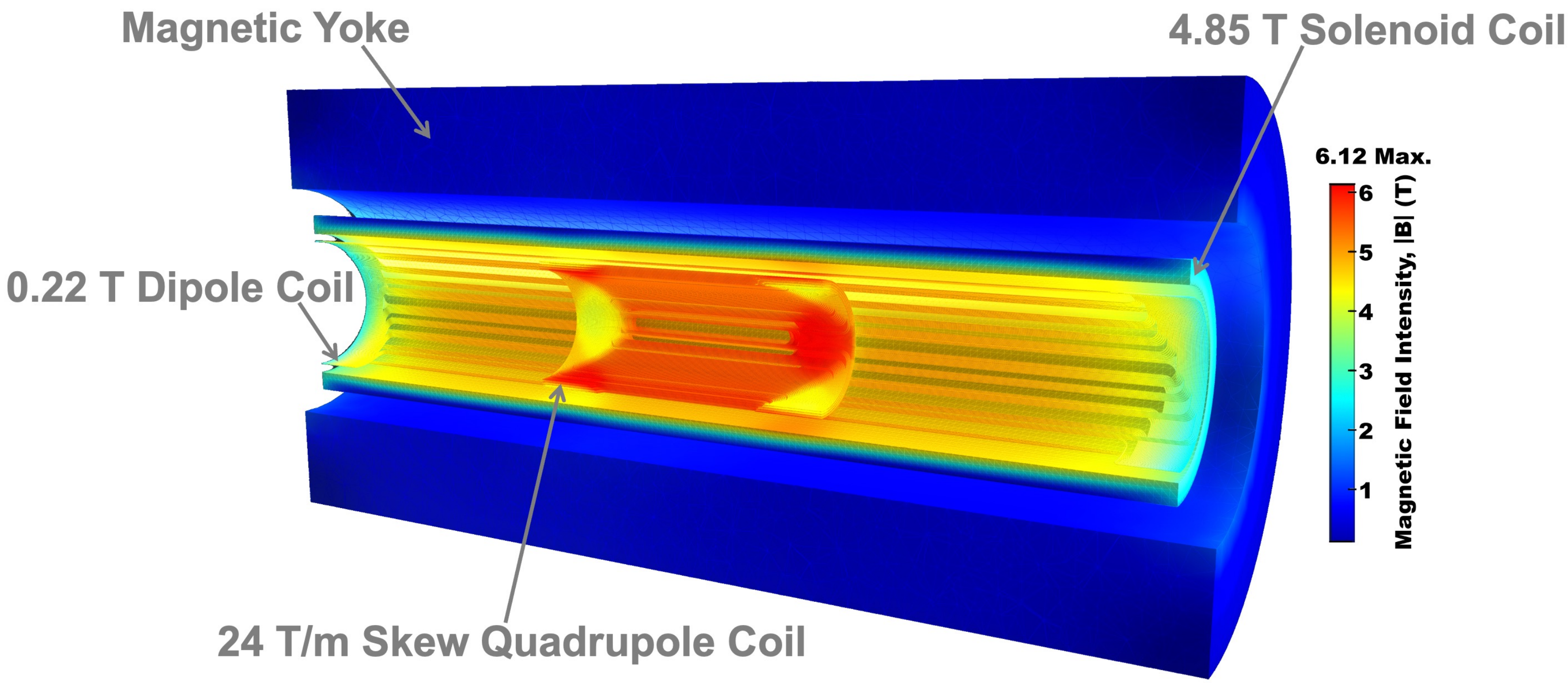


Image from Brett Parker (BNL) presentation eeFACT2025
"A novel spin rotator concept for longitudinally polarized beam for Chiral Belle at SuperKEKB"

Planning for Compact Spin Rotator Prototype

¼-Length Chiral Belle Spin Rotator Demonstration Prototype

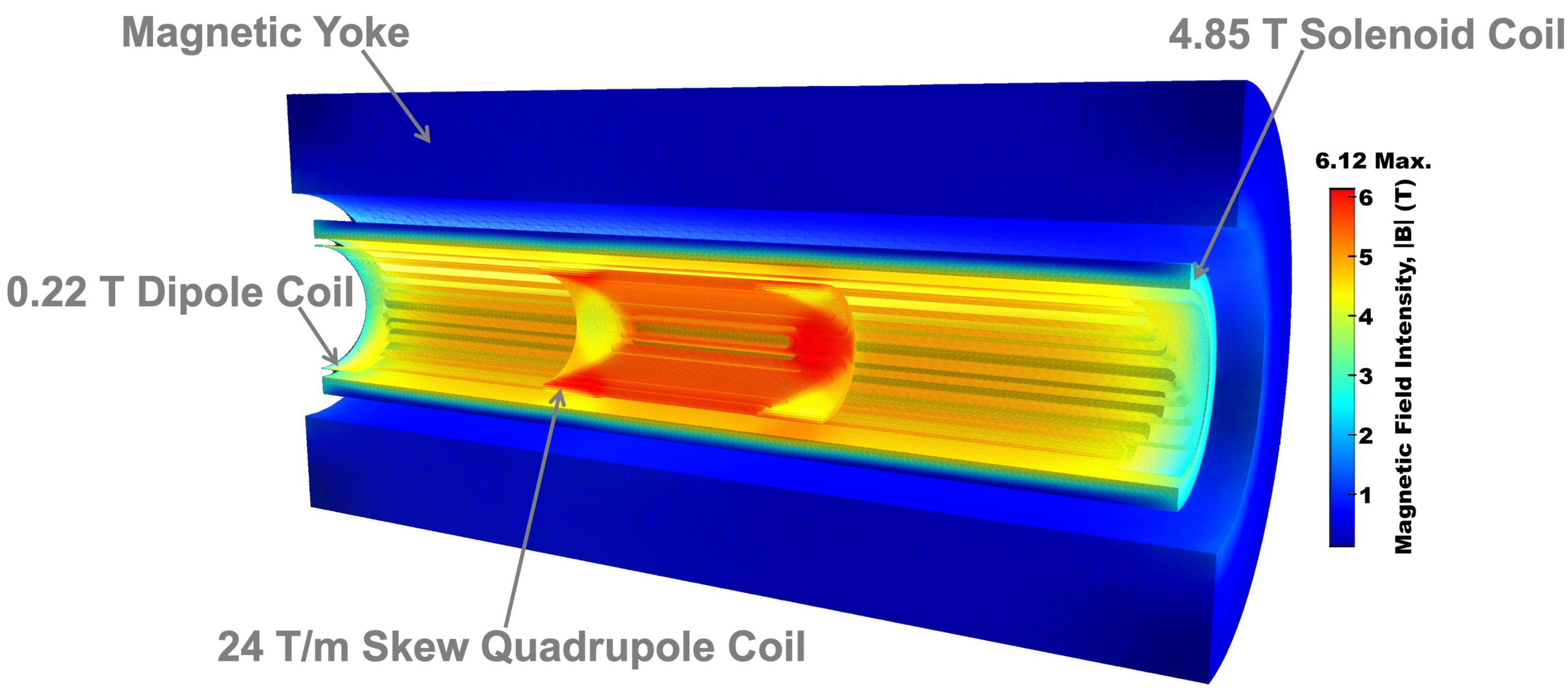


Image from Brett Parker (BNL) presentation eeFACT2025
"A novel spin rotator concept for longitudinally polarized beam for Chiral Belle at SuperKEKB"

NEWS: 4.17M CAD (~468 M ¥) funding has been awarded by CFI (Canadian Foundation for Innovation) to develop the ¼ length Compact Spin Rotator prototype magnet + Compton electron detector (confidential info at this time)

Initial Compact Spin Rotator Engineering tasks

Chiral Belle Engineering contract will include provision of refined, documented EM design meeting basic & functional requirements of the spin-rotator in preparation for production of a ¼ length demonstration prototype:

- Electromagnetic design optimization and cryostat conceptual engineering design
- Perform thermal estimations and electromagnetic analyses
- Develop preliminary layout and drawings
- Preparatory tasks related to integration into SuperKEKB

Tasks in 2026-27 Include:

- Study interaction of synchrotron radiation in the Compact Spin Rotators from nearby arc dipoles in the upstream and downstream arcs for quenching and radiation damage issues.
- Simulate spin depolarization at high beam-beam parameter conditions and with strong crab waist sextupoles in the IP
- Study equilibrium polarization levels for different particle loss conditions – i.e. consider different scenarios for various fractions of injected-beam and stored-beam particles
- Complete the Long Term Tracking studies with off-sets with consideration of corrector magnets

Current Long Term Tracking Studies with Bmad

Beam-beam effect:

Currently being studied - so far they do not show any issues for the design values for LER particles per bunch (the 'strong beam')

Offsets of Position of Magnet Currently being studied :

longitudinal offsets - show no differences

x-y offsets – start to show effects on chromaticity when offsets exceed 0.1 mm

Now considering introduction of corrector magnets to adjust for those – initial concept: incorporate them into the spin rotator magnet

Next steps: Need to implement updated LS2 Lattices for HER and LER

Chiral Belle

Next step:

Put conclusions of Long Term Tracking studies showing long transverse polarization lifetimes in the HER to the test using data in dedicated experiment with TRANSVERSE polarized beam to validate polarization lifetime:

Touschek Polarization Experiment

Touschek Polarization Experiment

Proposing for this study to take place after 2026 Running period

Proven 0.5% Touschek lifetime measurement sufficient to measure the transverse beam polarization and detect the $\gamma G = 16$ depolarizing resonance - its presence would indicate that polarization is preserved and the resonance reduces it

Can be used to precisely calibrate the beam energy via energy scan.

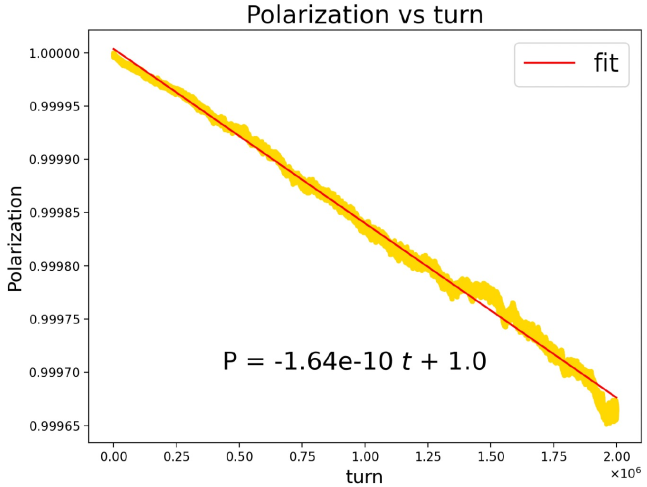
Goals of Experiment:

- Verify spin-transport through the injector chain is understood and preserves the polarization magnitude and direction.
- Verify polarization is preserved upon storage of the electron bunches in the HER, determine the polarization lifetime and map out the topology around the $\gamma G = 16$ spin resonance.
- If possible, to detect and quantify the effect of the beam-beam interaction on the polarization lifetime and develop mitigation strategies.
- If beam-beam effects are detectable, quantify the effect on polarization in terms of the beam-beam parameter

APPROVAL STILL REQUIRED for Touschek Polarization Experiment

Touschek Polarization Experiment

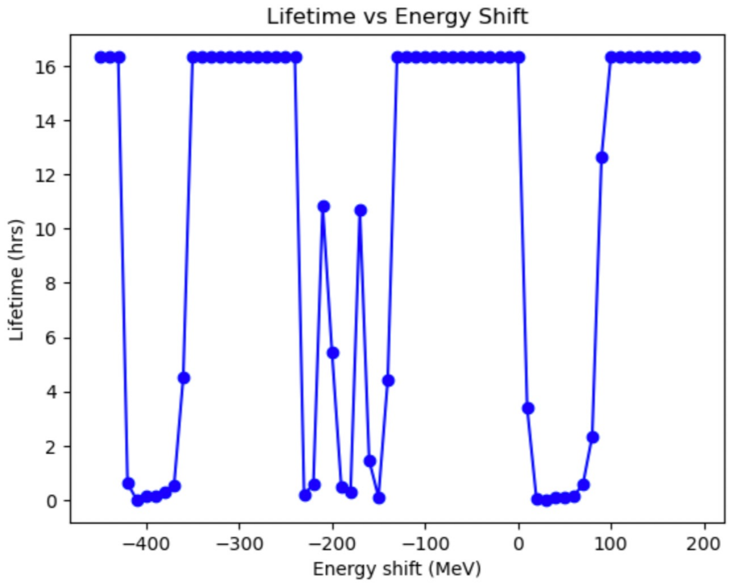
Study of Spin lifetime for the HER



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

Yuhao Peng (UVictoria)

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

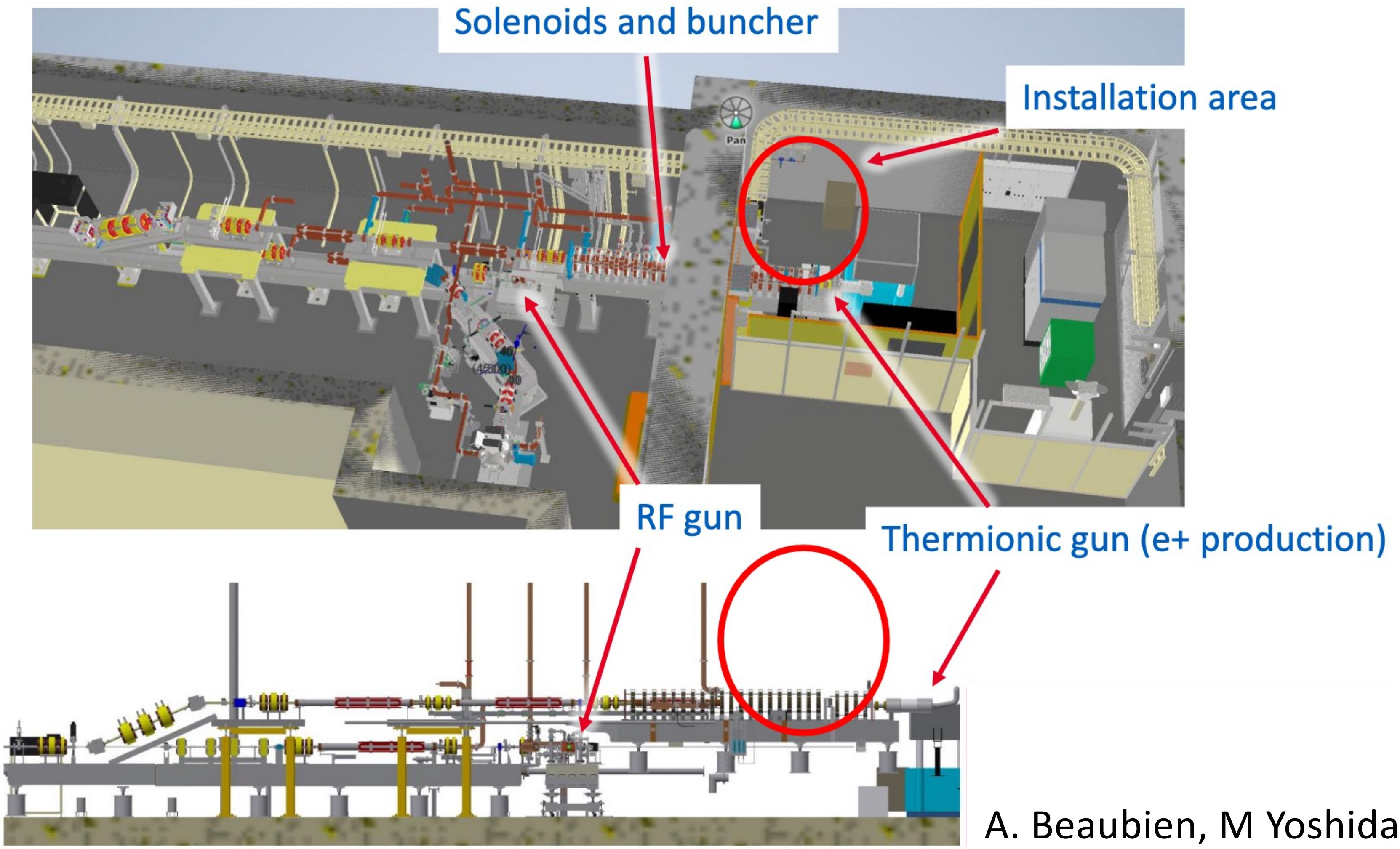
Yuhao Peng (UVictoria)

Touschek Polarization Experiment

- Developing the temporary polarized source to the Touschek Polarization Experiment
  - Design
  - Construction
  - Installation and testing in lab with Mott polarimeter
- Polarized Source line development
  - Source
  - Wein filter
  - Merger
- Integration into source room

Source for Touschek Polarization Experiment

Source Room Available Area



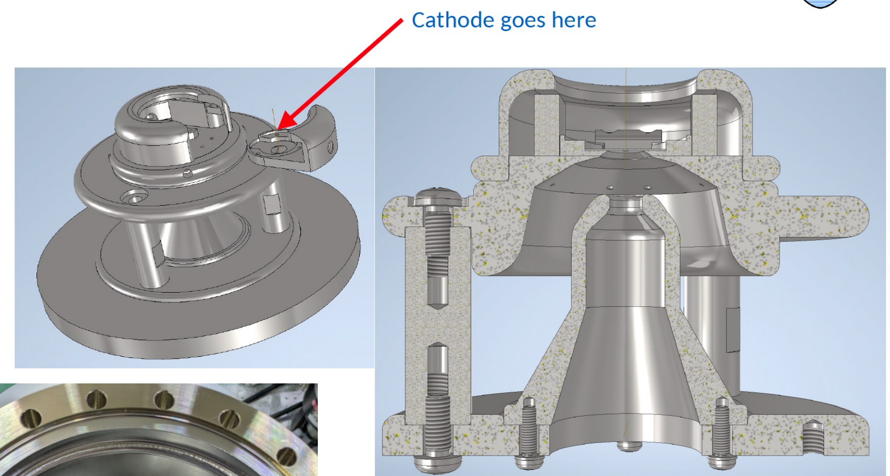
A. Beaubien, M Yoshida

GaAs Polarized Source for Touschek Polarization Experiment

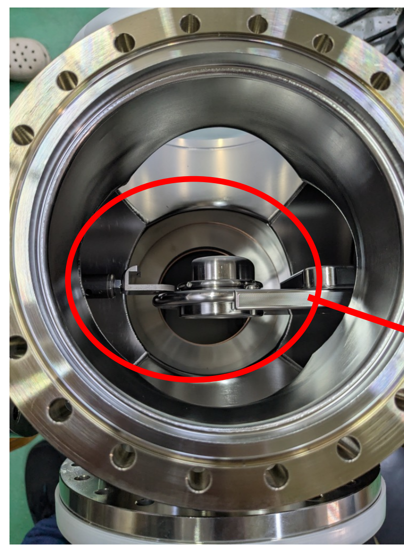
U.of Victoria PhD student Alexandre Beaubien was stationed at KEK for 11 months with EPECR KEK-TRIUMF Scholarship

- Working with Mitsuhiro Yoshida (KEK) to implement source

Cathode & Anode

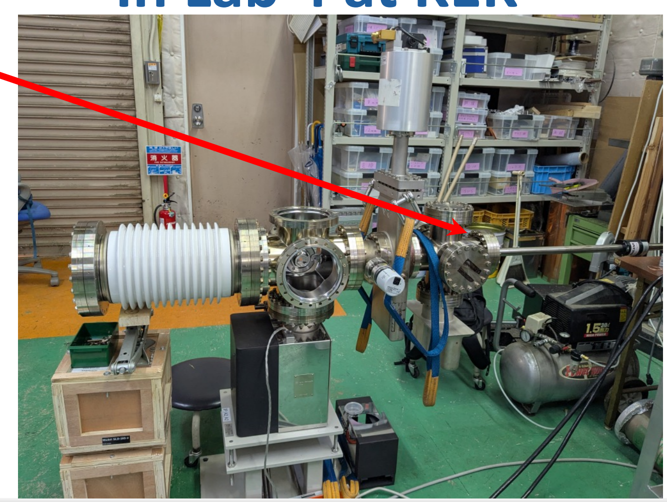


Adapted from a design by N. Yamamoto; Redesigned in part for low emittance at 200keV using Inventor

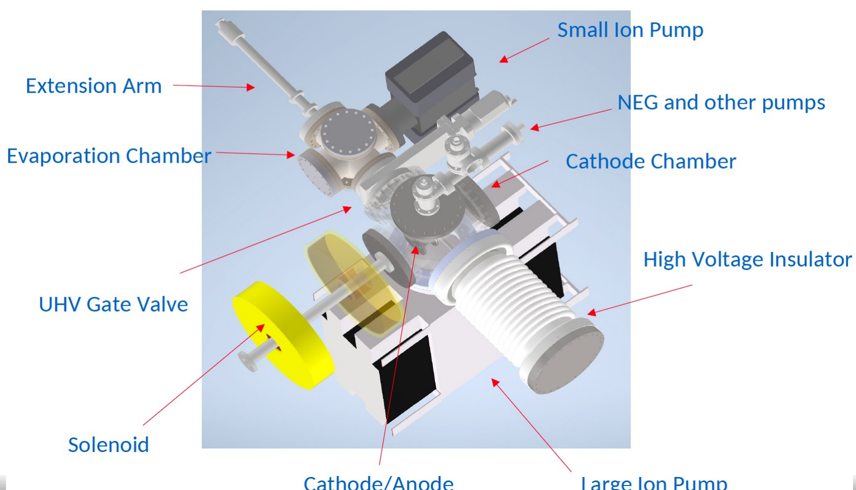


Source anode delivered To KEK in October 2025

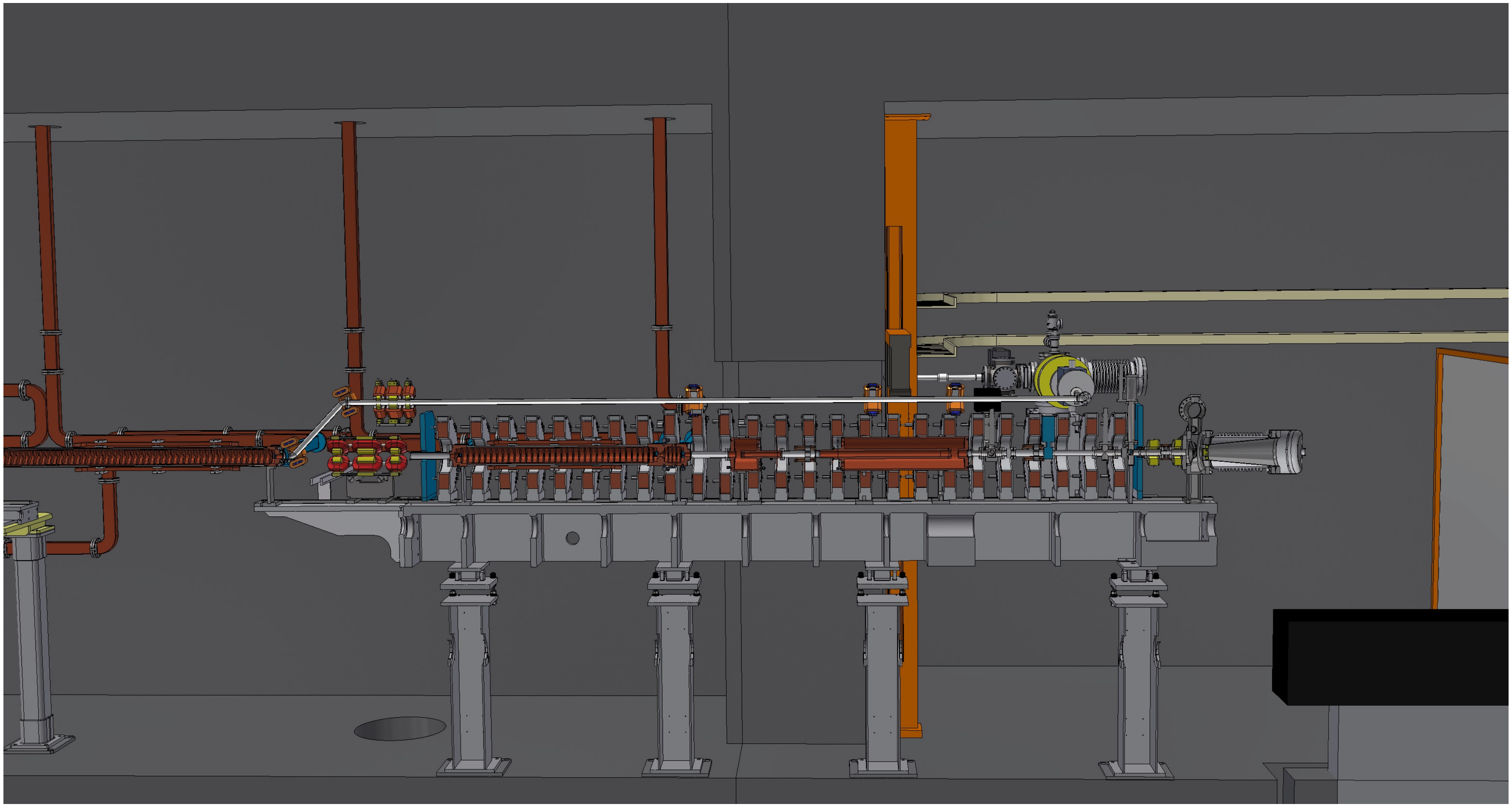
In Lab 4 at KEK



Polarized Electron Gun



Considering New Merger Line Concept



Further Preparations for Touschek Polarization Experiment

Background Group –

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

Andrii Natochii (BNL)

Period	Experimental Touschek Lifetime (minutes)	Ratio of Experimental to SAD Simulation lifetimes
May 2020	37.929 ± 0.057 (0.15%)	0.642 ± 0.002
June 2020	33.656 ± 0.064 (0.19%)	0.746 ± 0.005
June2021	27.93 ± 0.10. (0.36%)	0.601 ± 0.003
December 2021	24.107 ± 0.079 (0.33%)	0.519 ± 0.002

Will want to repeat these studies in 2026 running period

Chiral Belle R&D timelines

Detailed GANTT chart to be prepared

- We anticipate on Stage 1 engineering and construction work will take two years for the Compact Spin Prototype design and construction and another year for the commissioning, testing and measuring.
- The development of the Compton polarimeter electron detector modules in Stage 1 requires design and testing that we estimate will take a total of 3 years.
- Chiral Belle engineering work focuses on tasks related to integration of the spin rotators into SuperKEKB, to be documented in the Technical Design Report
- Stage 1 includes bringing new people to develop strategy for non-invasive integration the Compton polarimeter into SuperKEKB

Chiral Belle rough timelines

- Touschek Polarization experiment - after 2026 run – approval required
  - measure the polarization lifetime & validate Bmad Long term spin tracking simulations
- Stage 1 goals (includes use of awarded CFI funding)
  - Produce a fully engineered Compact Spin Rotator magnet with a precisely characterized prototype (UVictoria, TRIUMF, BNL, U Louisville)
  - Design and prototyping of the Compton polarimeter (U Manitoba and IJCLab France)
  - Polarized source R&D (KEK and Hiroshima and others)
  - Further increasing SuperKEKB luminosity (KEK)

Expect Stage 1 to be completed before end of FY2028 (March 2029)

- Stage 2 goals (requires Chiral Belle approval to submit capital funding requests in 2029)
  - Complete details of fully engineered design – anticipate using operating funds
  - Construction of all final components
  - Goal to Install during LS2
  - Commissioning of all final components
- Plan for first polarized beam physics runs after LS2 – so in mid-2030s

Cost Estimates

Start of engineering work on prototyping includes goal of providing costs estimates for full project

- Will endeavour to get figures for the TDR in 2027

Chiral Belle Related Funding Status

- KEK-TRIUMF Exchange Program for Early Career Researchers (*EPECR*)
  Supported Canadian PhD student (A. Beaubien) to work with Yoshida-san in 2025
- France (ANR): AAPG - Appel à projets générique - 2024 (Coordinated by Aurélien Martens) **News: ANR funded the R&D for BaF2 calorimeter for Chiral Belle upgrade. Official project start in February 2026**
- Hiroshima (Z. Liptak) research on source development
- Canadian Team: 3 year NSERC operating grants:"*The Belle II and Chiral Belle projects"* –submitted application to renew the grant for next 3 years – decision on amount of funding normally provided by beginning of April
- **News: Canadian Team awarded funds for 'Stage 1'** of Chiral Belle equipment to fund spin rotator prototype to be constructed at BNL and the parts of the Compton polarimeter (U Manitoba electron detector) from Canadian Foundation for Innovation (CFI)
  - The experience and knowledge gained from engineering, development and construction prototype using Direct Wind technologies likely useful in the future development of new Crab Waist sextupoles for SuperKEKB
- Plan to submit US-Japan application next year for accelerator R&D

Contributors - by Project Group include

Polarized Source:

U. Hiroshima(M. Kuriki, Z. Liptak);KEK (M. Yoshida);U.Victoria (A. Beaubien)

- Also, expect to make use of R&D performed at BNL for EIC

Spin Rotator and Beam Dynamics

-Compact Rotator: U. Victoria (T. Junginger, Y. Peng, N. Tessema, J.M. Roney); BNL (B. Parker, V. Teotia); TRIUMF (R. Baartman, T. Planche); U. Louisville (Sw. Banerjee); ANL (U. Wienand); SLAC(Mike Sullivan)

-Conventional Rotator Studies: BINP (I. A. Koop, A. V. Otboev, Yu. M.Shatunov)

-SuperKEKB interface: Y. Ohnishi, D. Zhou

Compton Polarimetry:

-Laser and Photon Detector: CNRS/IN2P3 IJCLab (D. Charlet, F. R. Le Diberder, A. Martens, Y. Pienaud, K. Trabelsi, F. Zomer)

-Electron Detector:U.Manitoba (W. Deconinck, M. Gericke, S. Longo, J. Mammei)

-Integration into SuperKEKB: KEK (T. Ishibashi, M. Masuzawa);

Contributors to Physics Sensitivity Studies*

EW and Tau g-2 Physics:

McGill U. (A. Warburton);

St. Francis Xavier U. (H. Ahmed);

U.of Alberta (S. Robertson);

U.of British Columbia (C. Hearty, J. McKenna);

U.of Cincinnati (A. Schwartz);

U.of Louisville (Sw. Banerjee);

U.of Manitoba (W. Deconinck, M. Gericke, S. Longo, J. Mammei);

U.of Victoria (A. Beaubien, R. Kowalewski, C.Miller, K.Moorthy, J.M.Roney, S. Taylor)

Tau Michel Parameters:

D. Epifanov (BINP)

* Includes past contributions to Snowmass Whitepaper and future intentions to contribute (people who signed the Chiral Belle CFI Grant)

Contributing Theorists include

Tau g-2: M. Hoferichter(BERN); A. Crivellin (Zurich/PSI)

Hadronic studies: Jefferson Lab (A. Accardi [Hampton U], A. Signori [Pavia/INFN], A. Vossen [Duke U])

Generators: McMULE, Y. Ulrich (Bern); REneSCANCe, R Sadykov, A Arbuzov, S Bondarenko, Y Dydyshka, L Kalinovskaya, L Rumyantsev and V Yermolchyk (Dubna); KKMC, Z. Was (Krakow)

Dark Sector Studies : TRIUMF (C.H. de Lima, D. McKeen, A. Omar, D. Tuckler), Memorial U (Reefa)

EW Theory Calculations: Dubna (Yu. Bystritskiy V. Zykunov), Memorial U (A. Aleksejevs, S. Barkanova, Mahumm Ghaffar)

Questions from Peter Lewis

1. Does your funding agency need any sort of green light or approval from MEXT to approve?

The peer reviewers would likely expect to see this

2. Does your funding agency need a completed TDR to approve?

The peer reviewers would likely expect to see this

3. Is there any custom approval necessary? *No*

4. Which upgrade projects would be included in the project?

Chiral Belle: Polarized Source, Compact Spin Rotators, Compton Polarimeter

5. What would be the funding period for the project (and what application deadline)?

Country-dependent – will get more information for summer UWG Workshop

For Canada: Stage 1- until end of FY2028; Stage 2 from FY2029-LS2

6. What would be the projected funding sum?

Work in progress

Relationship to rest of UWG Program

Chiral Belle relies on:

- SuperKEKB achieving high luminosity
- Belle II maintaining excellent performance in a high luminosity/high background environment

Upgrades to Belle II and SuperKEKB, together with the Chiral Belle Upgrade, open entirely new – ***and unique*** – windows of discovery

Questions:

How does Chiral Belle get integrated into planning for other upgrades?

Should it be incorporated into consideration by the UPO and if so when?

Summary

This Chiral Belle beam polarization upgrade program provides

- Exciting, high-impact enhancement of Belle II physics program
  - Substantial, world-leading improvements in many measurements – many exclusive to Belle II
- Unique opportunities for technical innovations
- Reasonable levels of funding have now been awarded for the R&D prototyping in Stage 1
- CDR to be completed before end of FY2025
- Plan for inclusion in TDR in 2027
- Stage 2 – plan for completion of engineering & construction to enable installation during LS2

Additional Slides

Staging of Chiral Belle Precision neutral current 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	0.0006 (~ W.A. σ)

τ Michel Parameter with polarized e- beam

($\tau \rightarrow e\, \nu\, \bar{\nu}$ and $\tau \rightarrow \mu\, \nu\, \bar{\nu}$ decay parameters)

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

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)

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 precision for relative measurements (arXiv:1009.6178) - needed for real time polarimetry
- Use tau decays to get absolute average polarization at IP

e- beam polarization in SuperKEKB

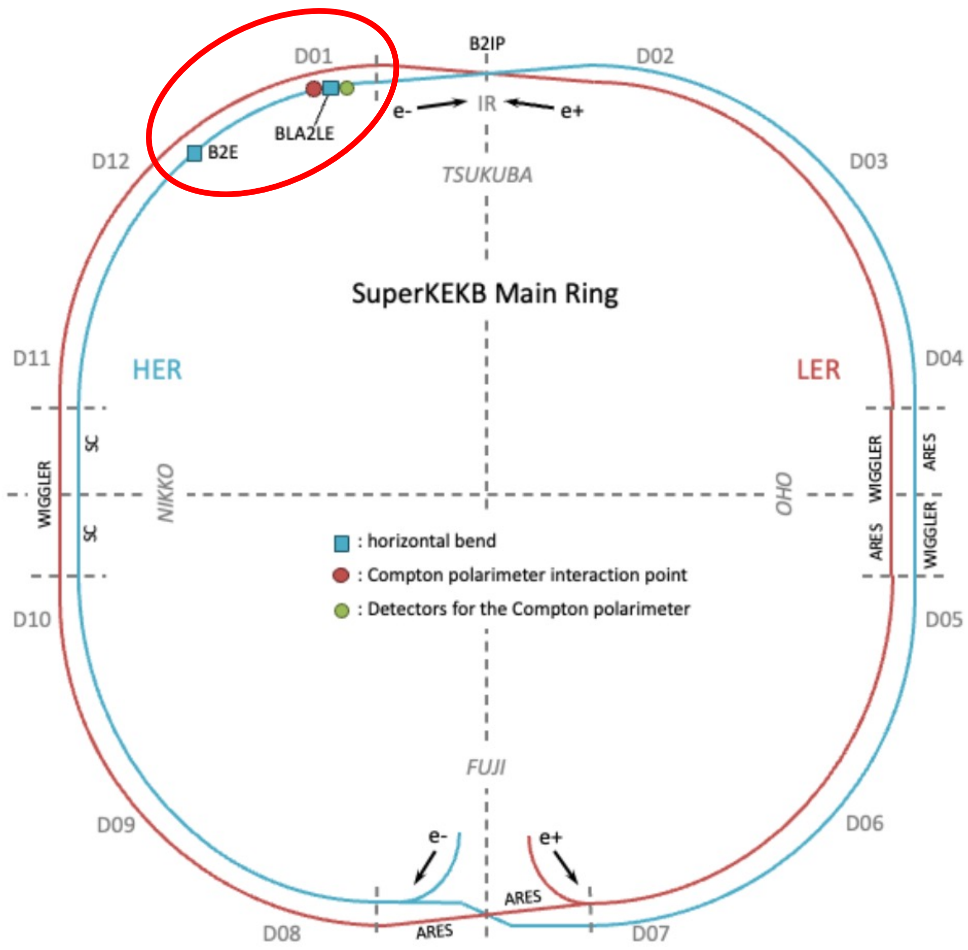
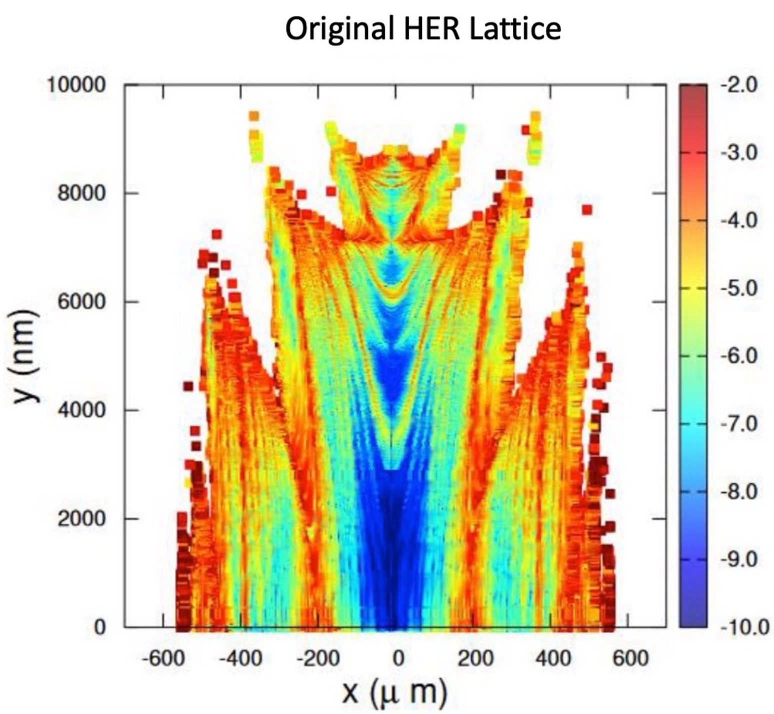


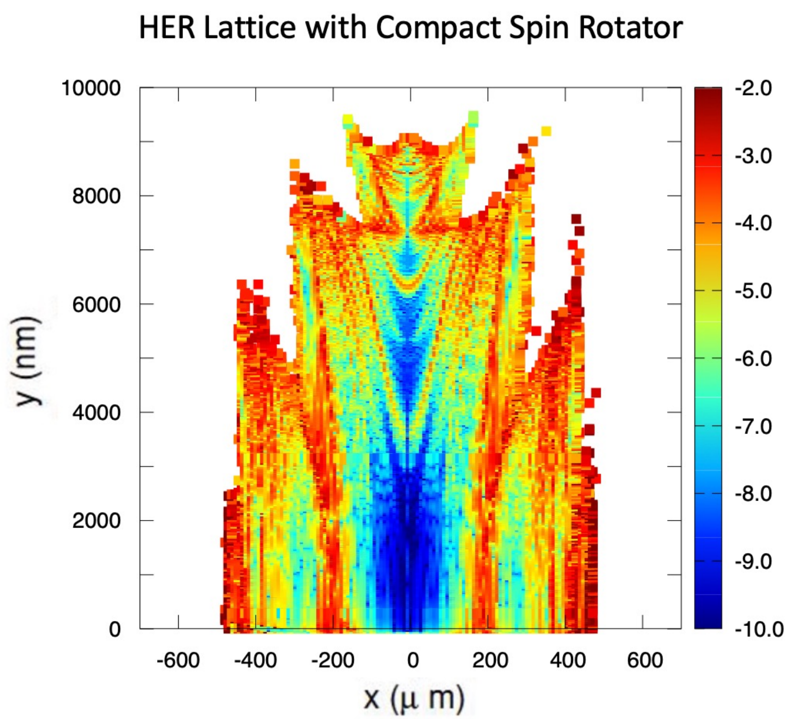
Figure 1. Schematic drawing of the main SuperKEKB ring, where the current B2E dipole to be replaced by spin rotators is identified. The location of the Compton polarimeter is also shown as well as Belle II interaction point.

Compact Spin Rotator Solution:
2 dipole-solenoid-skew-quad magnets replace existing dipoles on either side of IP

Frequency Map Analysis (FMA) – x-y space
dynamic aperture studies using Bmad – show no large changes

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





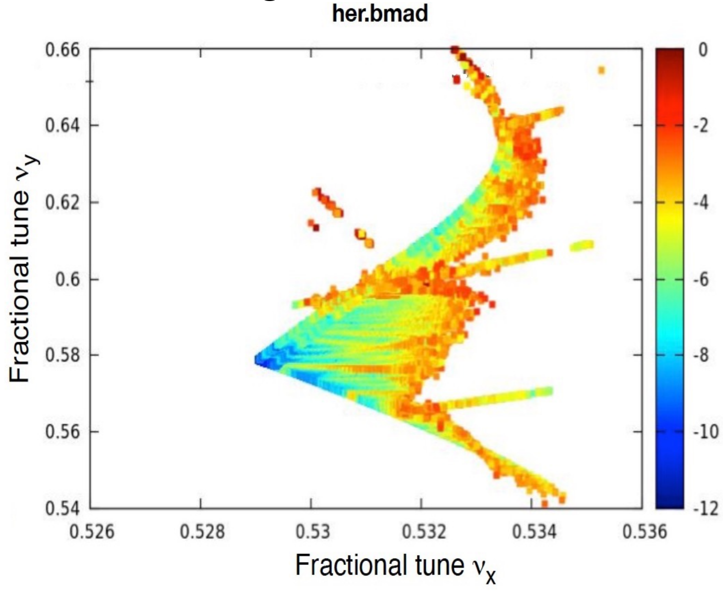
Bmad: A relativistic charged particle simulation library, D. Sagan, *Nucl.Instrum.Meth.A* 558 (2006) 356-359

Compact Spin Rotator Solution:
2 dipole-solenoid-skew-quad magnets replace existing dipoles on either side of IP

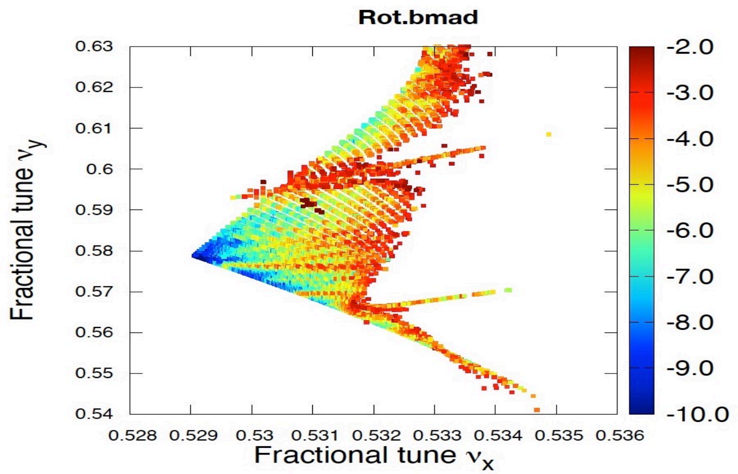
Frequency Map Analysis (FMA) – tune space
dynamic aperture studies using Bmad – show no large changes

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

Original HER Lattice



HER Lattice with spin rotator

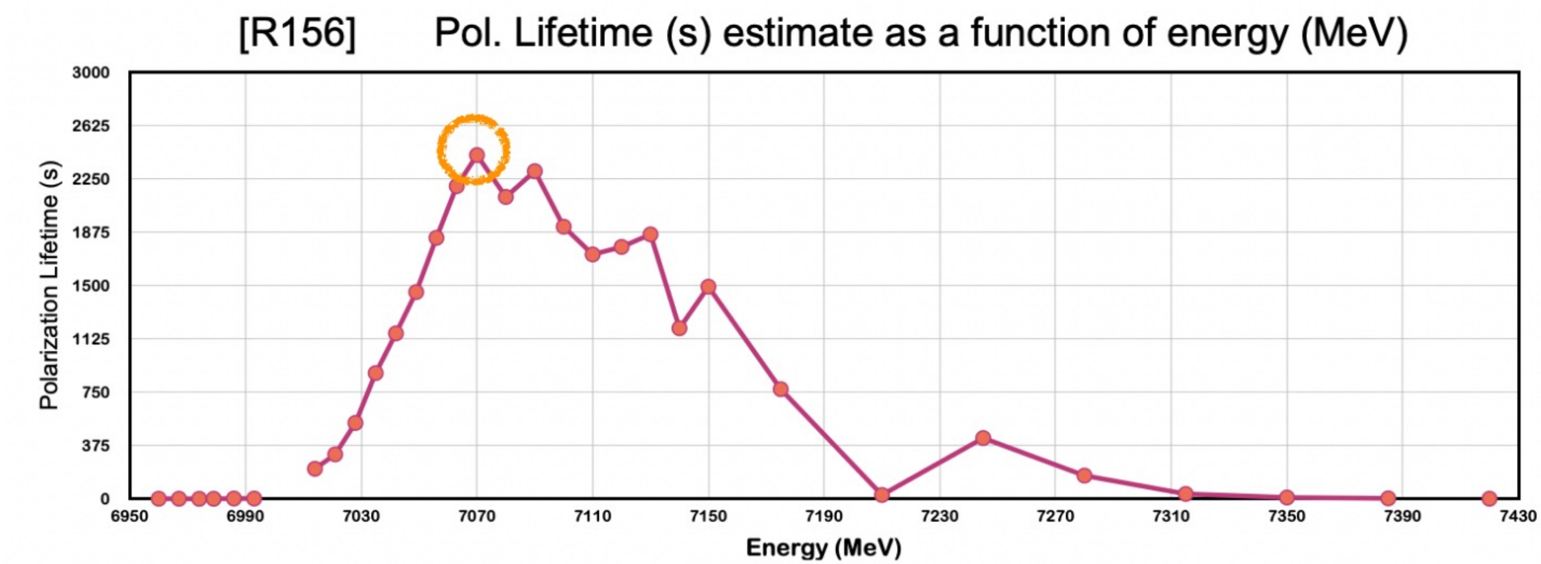


Bmad: A relativistic charged particle simulation library, D. Sagan, *Nucl.Instrum.Meth.A* 558 (2006) 356-359

Compact Spin Rotator Solution:
2 dipole-solenoid-skew-quad magnets replace existing dipoles on either side of IP

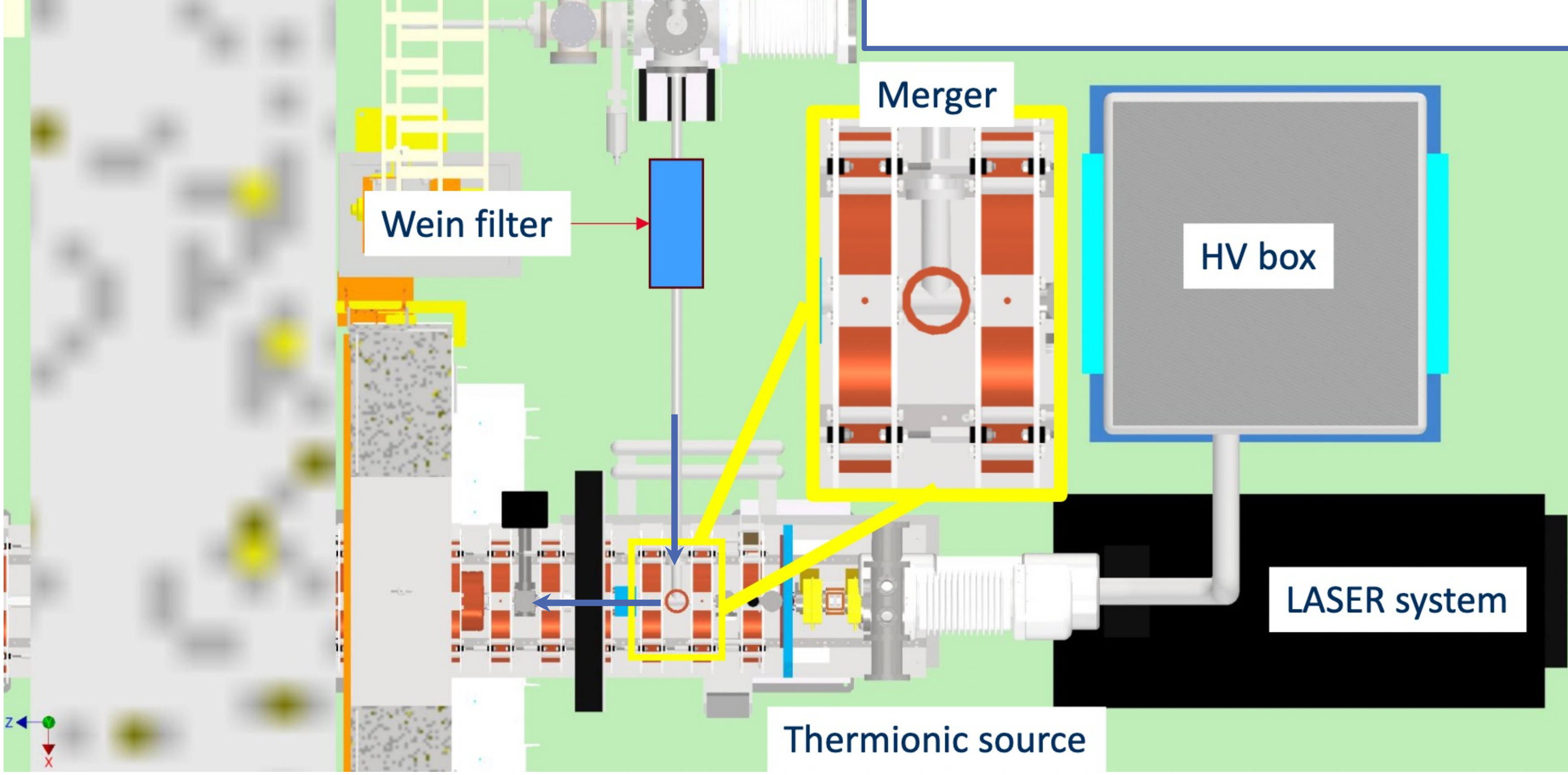
Long Term Tracking(LTT): Explores *non-linear* features of beam lifetime and polarization lifetime with radiation damping and radiation fluctuations/quantum excitation

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

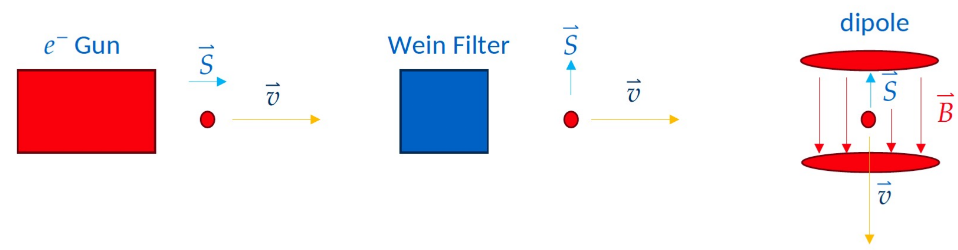


Source for Touschek Polarization Experiment

Initial Conceptual Design



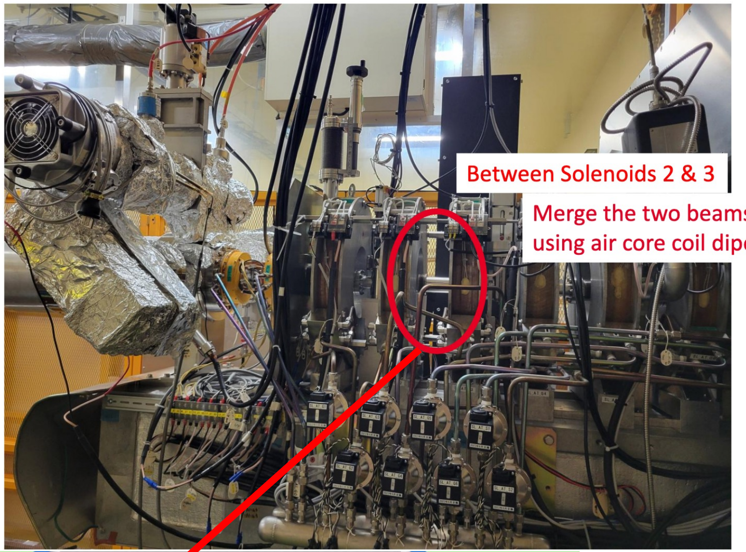
GaAs creates **longitudinally polarized** electrons.
Use **Wein filter** to obtain **transversally polarized** electrons.



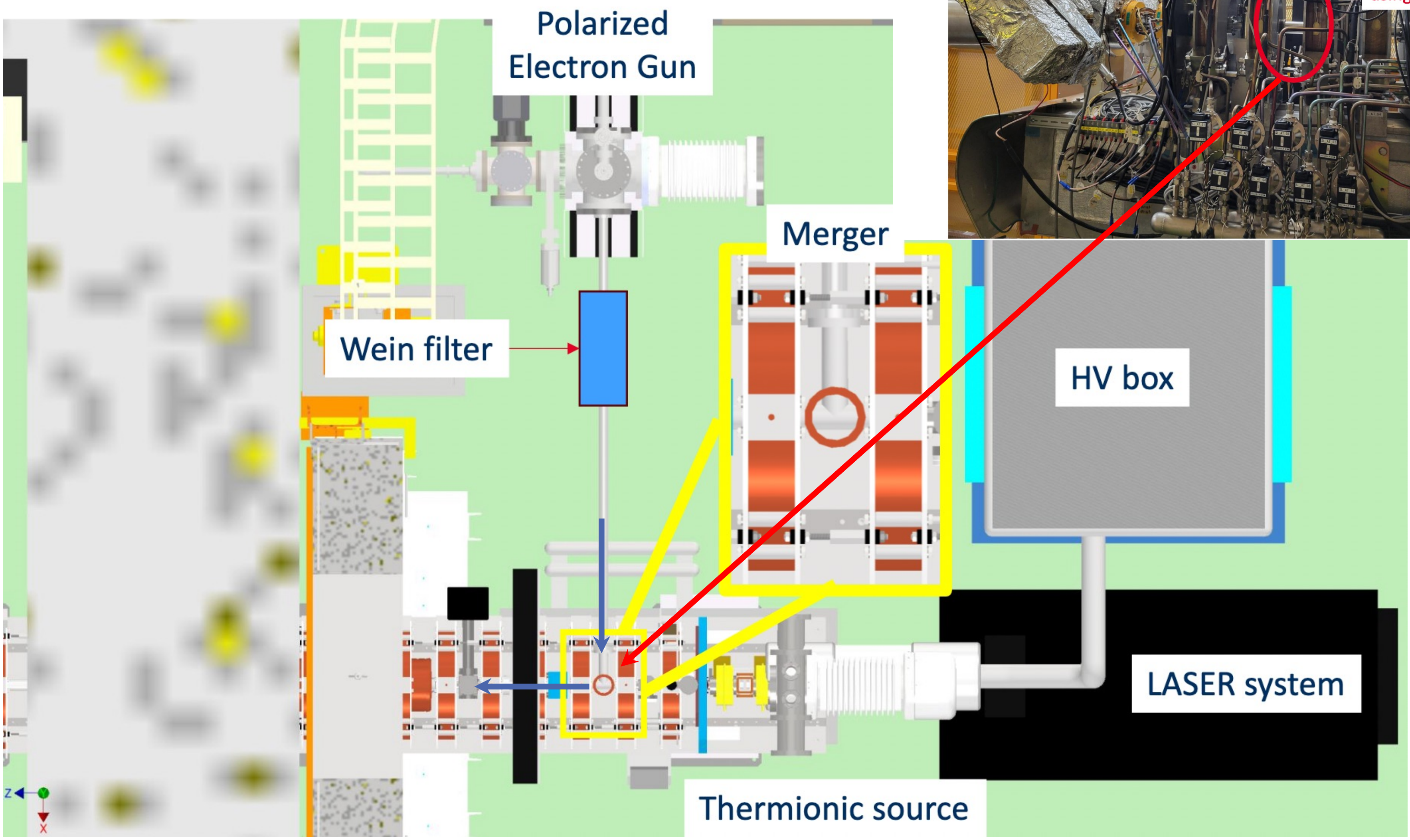
A. Beaubien, M. Yoshida

Source for Touschek Polarization Experiment

Merge Location



Initial Conceptual Design



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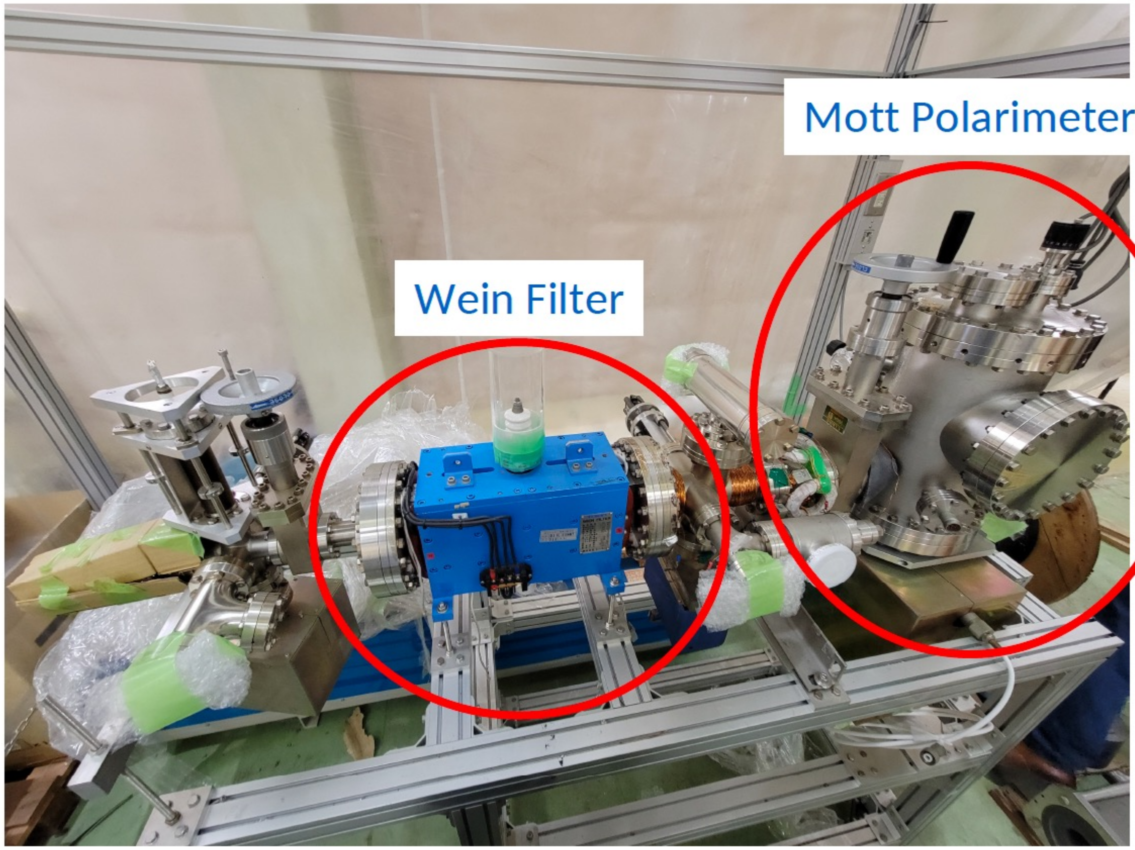
Source for Touschek Polarization Experiment

Wein Filter and Mott Polarimeter



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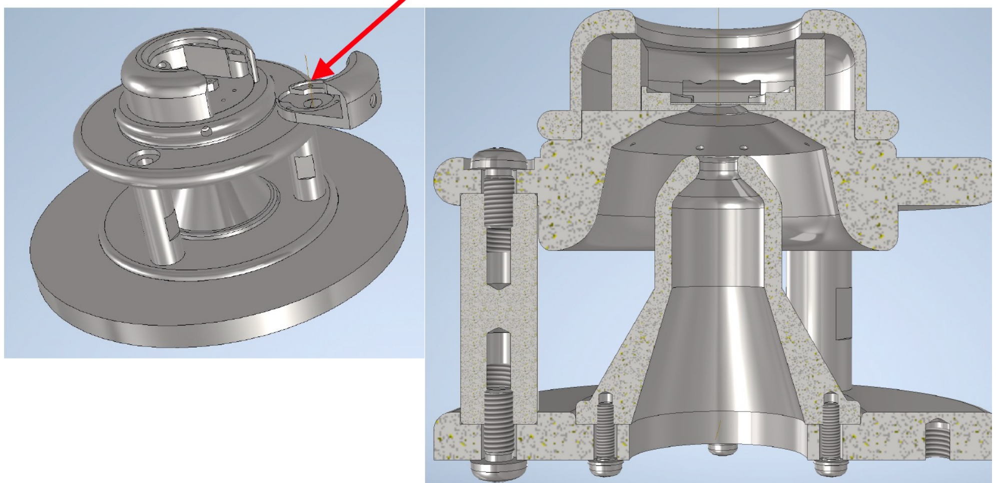
Polarized Source

Cathode & Anode

Cathode goes here



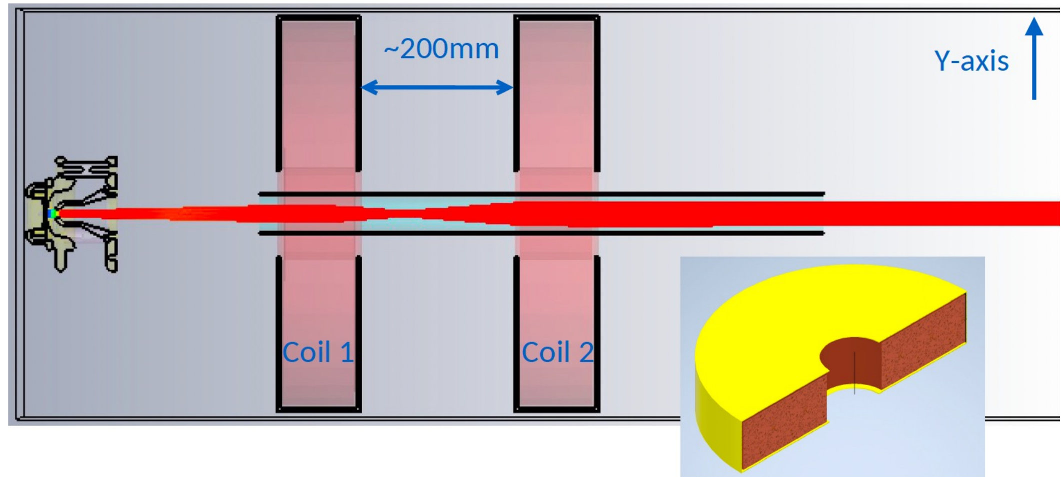
Use of CST for design

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

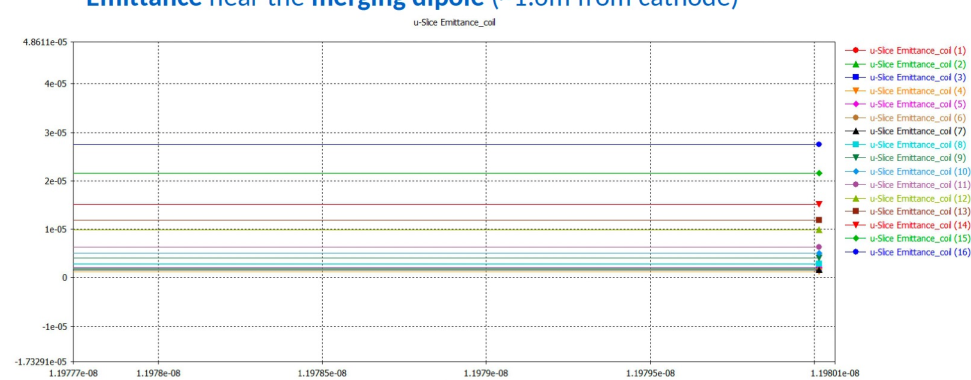
- Coil 1: **1.05 A** — Coil 2: **1.5 A** — **2800 turns**
- Minimize p_t in x-y plane for parallel beam

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)



Precision measurement of polarization: Tau Polarimetry Caleb Miller (PhD UVic)

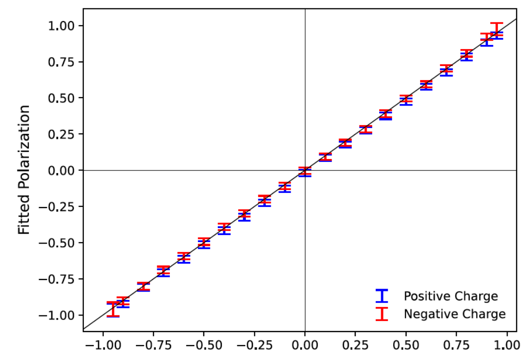
BABAR paper demonstrates that beam polarization can be measured with 0.5ab^{-1} to 0.4% at IP with analysis of tau-pair events by exploiting the sensitivity of τ decay kinematics to the longitudinal polarization of the beams

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

PRD 108, 092001 (2023)

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

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



MC sensitivity validation

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

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

Precision measurement of polarization: Compton Polarimetry - Aurélien Martens (IJCLab)

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

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

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

*Corresponding author.

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

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

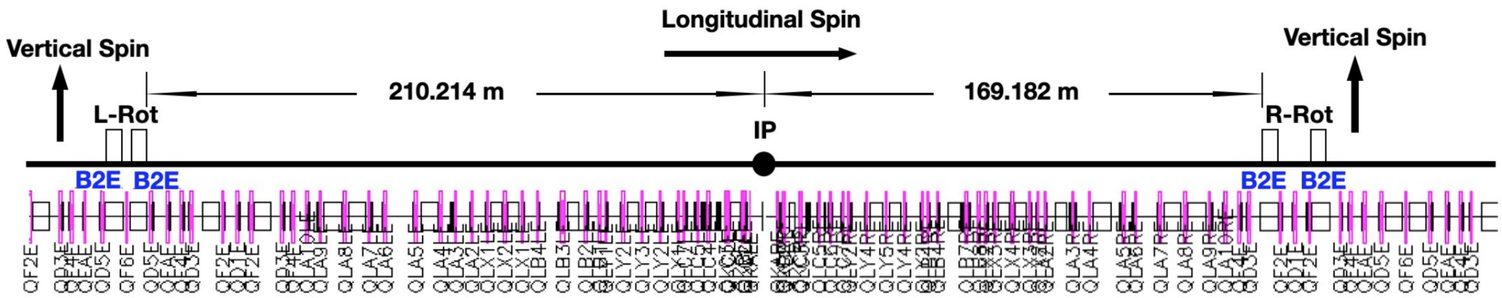
Source	Uncertainty on P_z(%)
Laser beam polarization	0.30
Backgrounds	0.16
Fit procedure	0.080
Beam energy	0.050
Spatial misalignment	0.015
Angular misalignment	0.015
Longitudinal misalignment	0.015
Transverse electron beam polarization	0.015
Total	0.35

Open points

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

Compact spin rotator

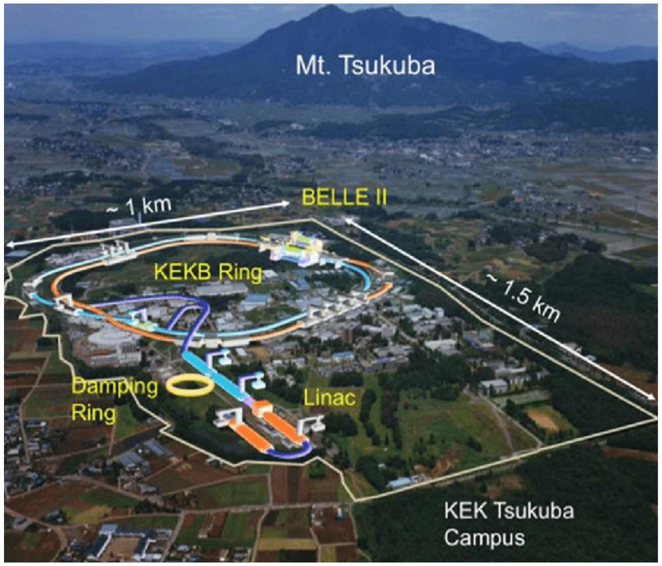
Work by Y. Peng (UVic)

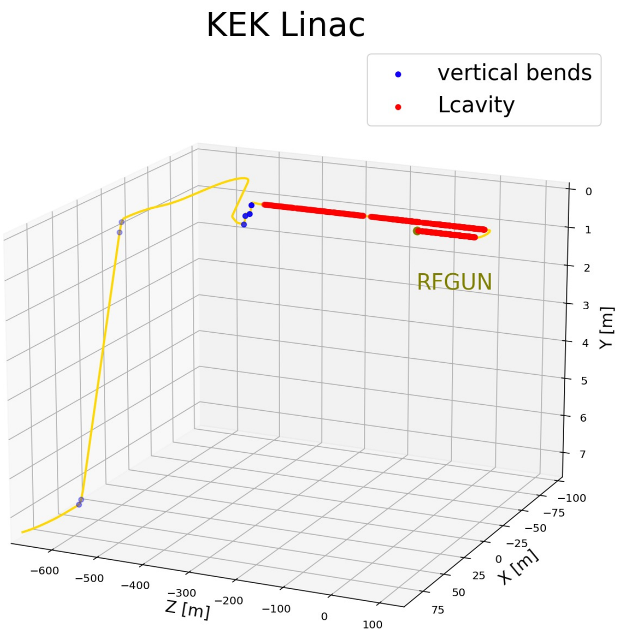


- Left Rotator (L-Rot) rotates the spin from the vertical to the horizontal plane
- Right Rotator (R-Rot) rotates the spin back to the vertical direction
- 4 **B2E** dipoles (using SAD lattice naming convention for HER) shown above to be replaced with the spin rotator magnets

KEK Injection Linac polarization BMAD studies

Y. Peng's (UVictoria)

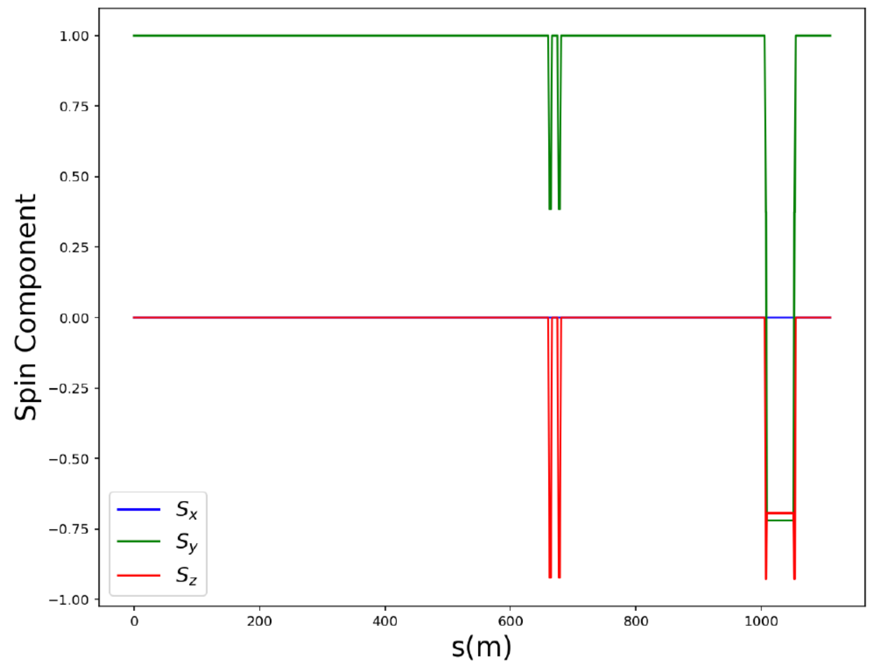




Need transversely polarized beam at the injection point of the e- storage ring (High Energy Ring -HER)

Spin motion in the KEK Injection Linac

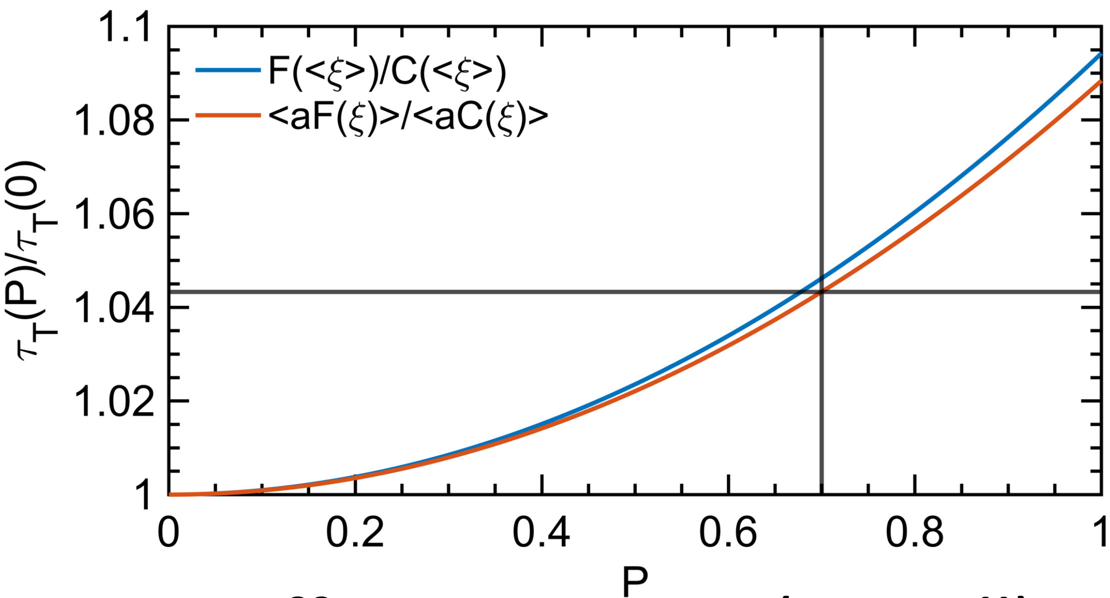
Y. Peng's (UVictoria)



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

For SuperKEKB

From
Farah MAWAS
Aurélien MARTENS
Slides at Feb
Chiral Belle meeting



- It is ~4% effect assuming (overall) momentum acceptance of 0.6%

Electromagnetic analysis of HER dipole in OPERA

- For ensuring the dipole field of the proposed spin rotator with the existing HER dipole, Electromagnetic analysis of the existing magnet is being carried out using OPERA.
- Thanks to Mika san for providing Drawings and measured parameters of the HER dipole.
- The magnetic field strength along the beamline at a radius of $50mm$ was found to have a magnitude of 0.2978 T, reproducing the nominal field value of the original HER dipole magnet, which was measured at 0.2997 T [2]. The difference in the magnetic properties of the yoke material can be one of the source for the difference.
- Further work is under way to understand the longitudinal variation of the magnetic field profile
- This will follow with EM design of the dipole magnet based on BNL's direct wind magnet technology.

Brookhaven National Laboratory

Discovery Technologies Directorate

3

Vikas Teotia

Opera EM analysis

Brianna Romasky
Stony Brook University , New York

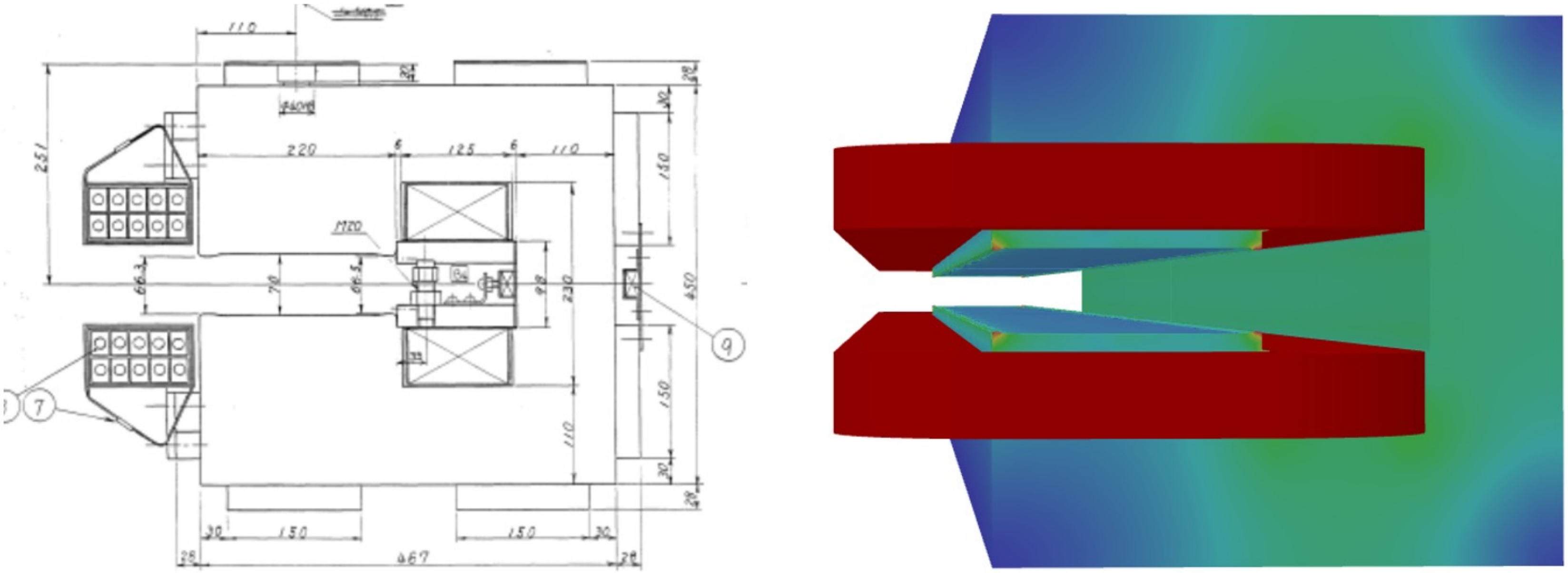


Figure 1. Left: Cross section of the dipole magnet from original CAD diagram, Right: Opera 3D model.

Iron Yoke		Racetrack Coils	
Yoke length	$5804\ mm$	Coil Radius	$13.38\ mm$
Aperture width	$220\ mm$	Coil thickness	$65\ mm$
Aperture height	$70\ mm$	Current density	$1.086\ A/mm^2$

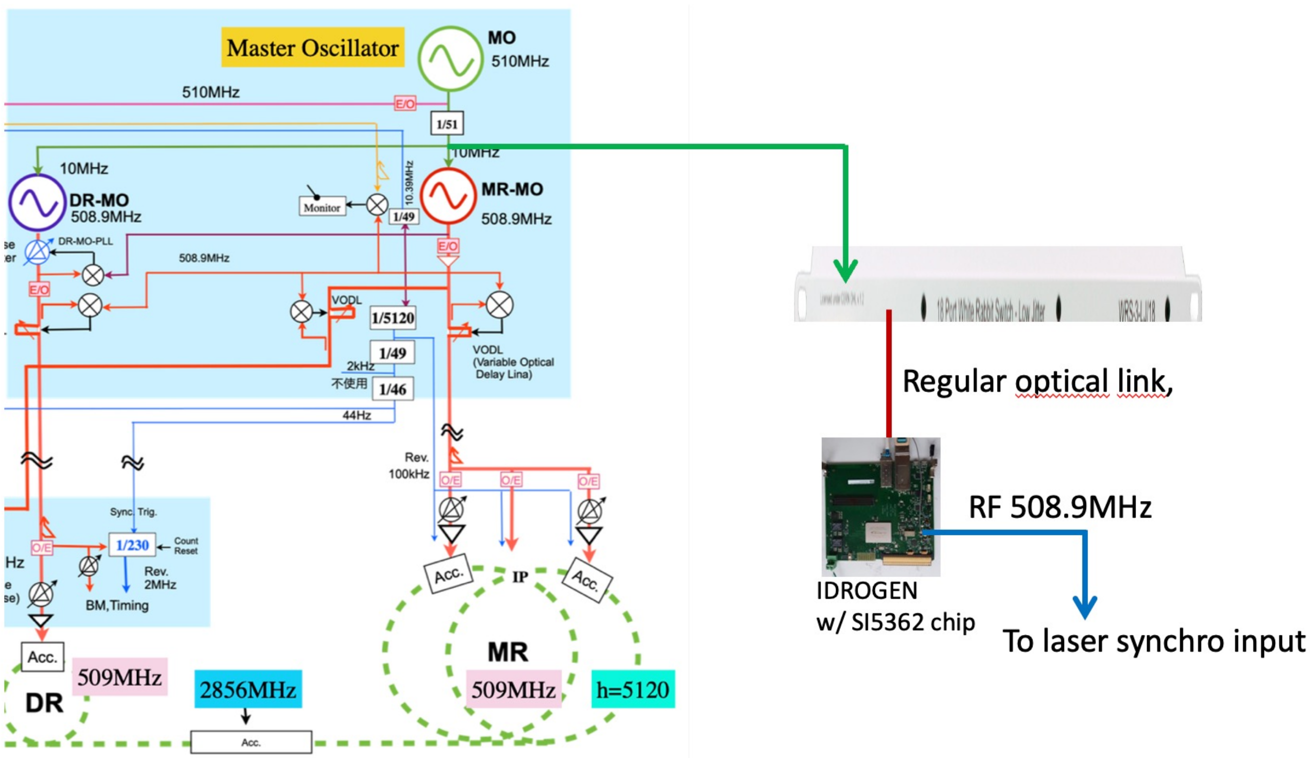
Table 1. Geometry parameters for iron yoke and racetrack coil parameters

Compton polarimetry for SuperKEKB: Synchronisation tests Oct' 25

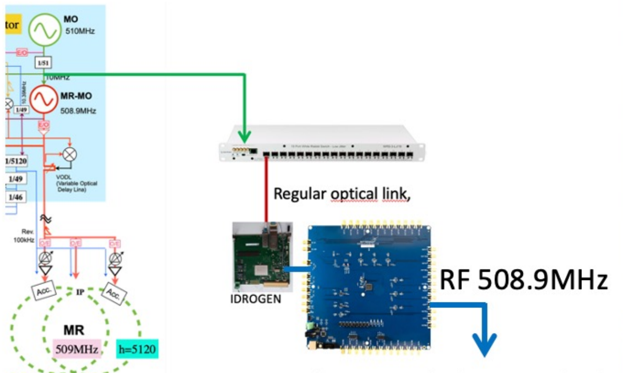
Aurélien MARTENS, Daniel CHARLET (IJCLab)
+ contributions from
T. Kobayashi (KEK SuperKEKB), H. Kaji (KEK SuperKEKB),
K. Popov (KEK ATF iCASA)

Funded by the European Union
EAJADE Europe-America-Japan Accelerator Development Exchange Programme
The resea

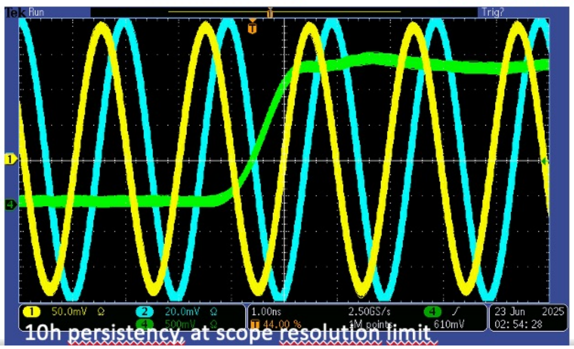
Final goal



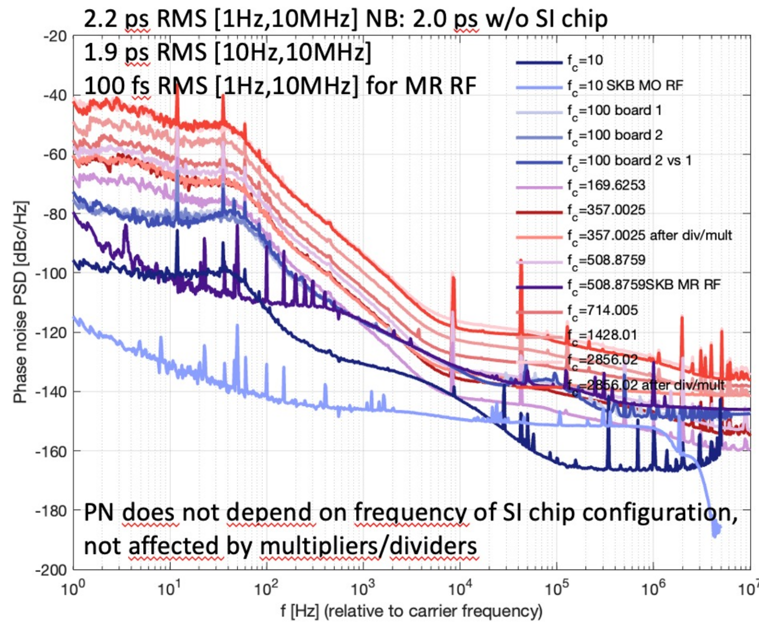
First validation test at SKB (oct'25)



Comparison of SKB and idrogen clocks



Phase noise measurements @SKB

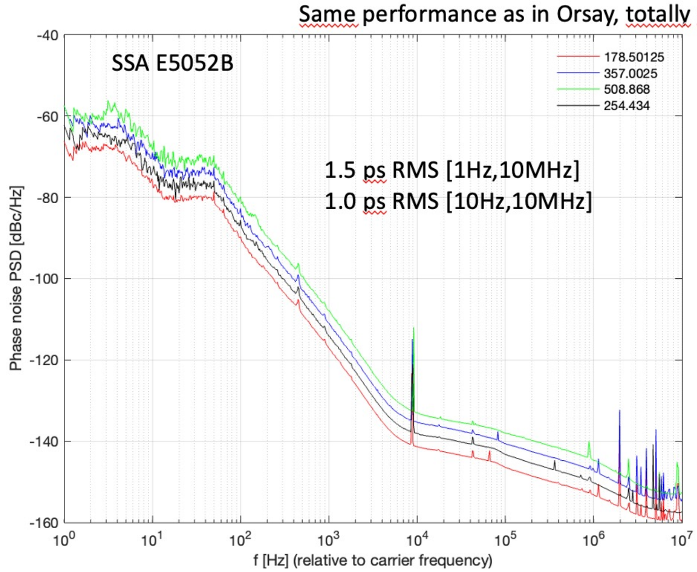


Synchronization Studies

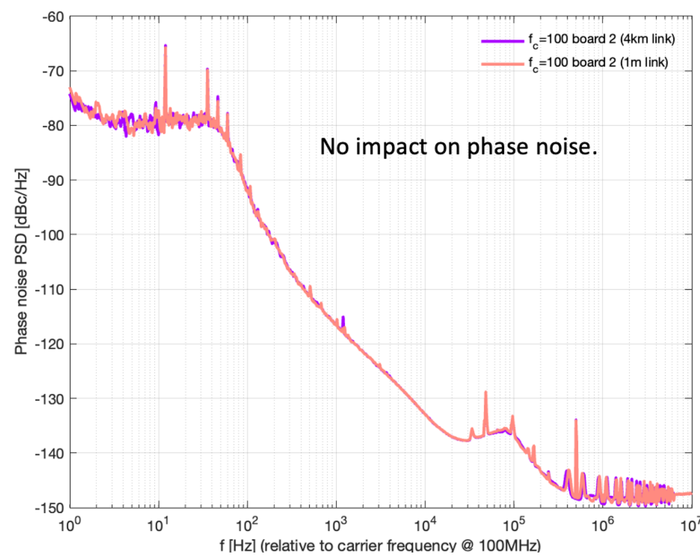
(A. Martens)

Phase noise measurements @ATF

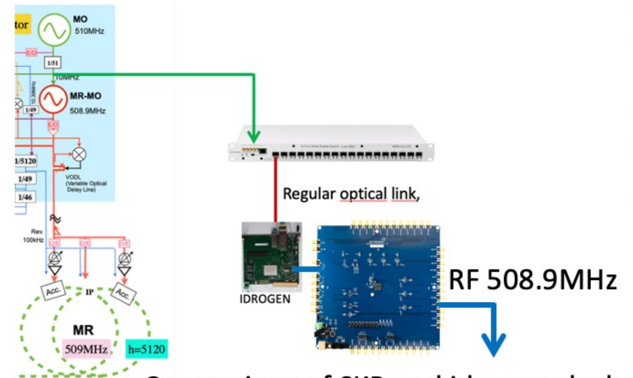
Same performance as in Orsay, totally different environments



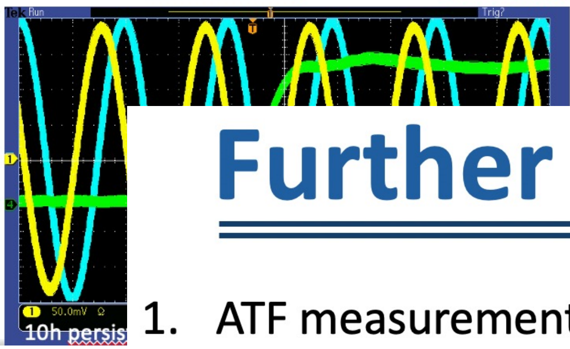
Long distance fibre (4km)



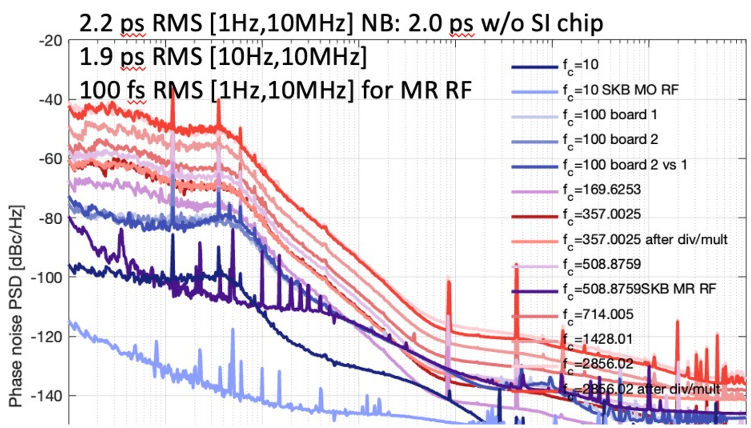
First validation test at SKB (oct'25)



Comparison of SKB and idrogen clocks



Phase noise measurements @SKB



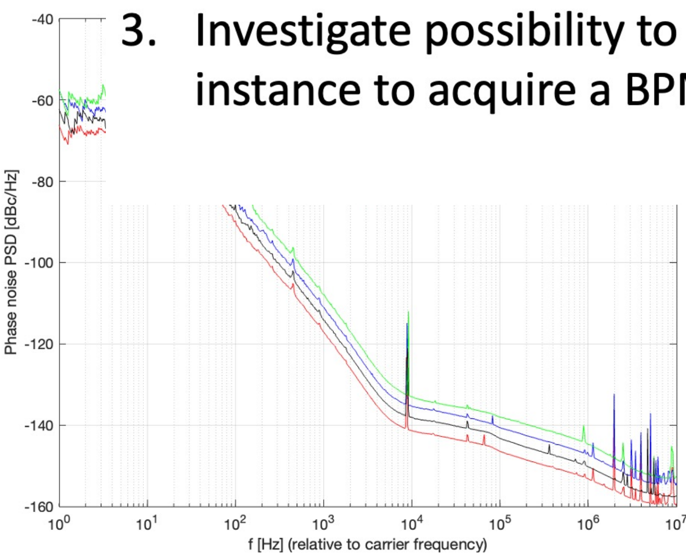
Synchronization Studies

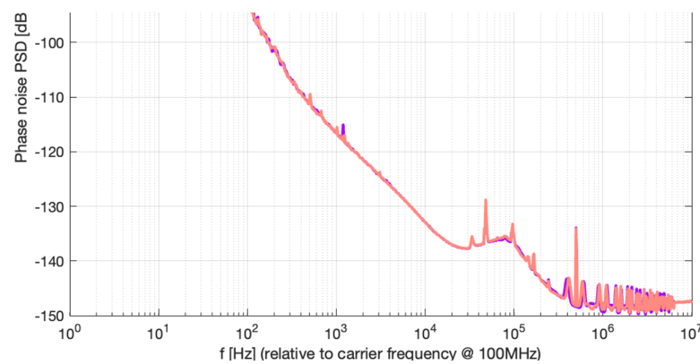
(A. Martens)

Further plans at KEK

1. ATF measurement of beam stability while PC laser is sync-ed with or without IDROGEN. → to be planned still.
2. Absolute phase repeatibility validation → to be done at IJCLab
3. Investigate possibility to make test with board inside accelerator tunnel (ATF?), for instance to acquire a BPM. To be discussed and planned.

Phas



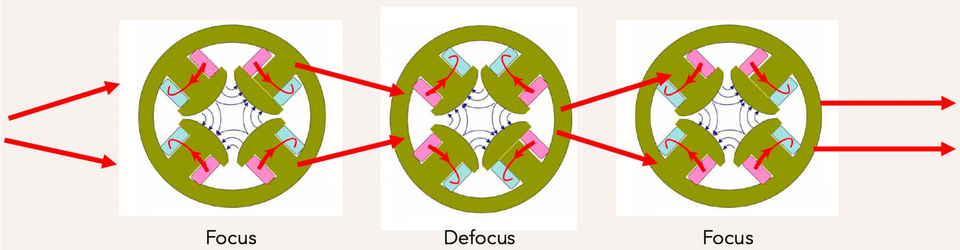


Merge Line - option for Touschek Polarization Experiment

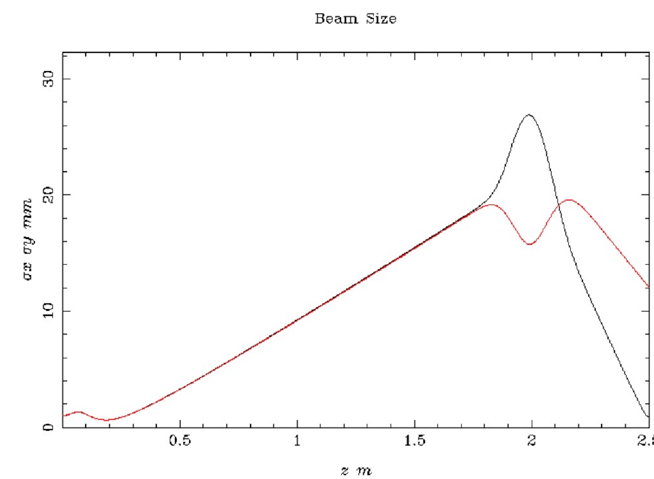
Z. Liptak presented studies adding quadrupoles before the merge point to reduce the beam spot size.

- Singlet may be sufficient, but a triplet (FDF) can provide better focusing in both directions
- Beam size/spread depends strongly on the bunch charge.

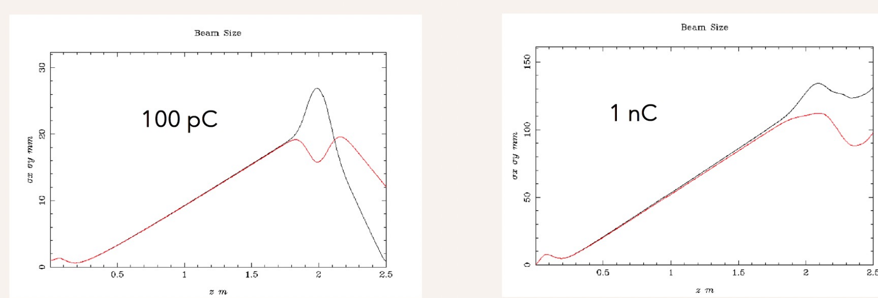
Quadrupole Optimization – Quad triplet



With the triplet, we can get small spot size in X or Y and OK spot size in the opposite dimension.
Assuming horizontal is the more important DOF, we can get sub-mm in X,

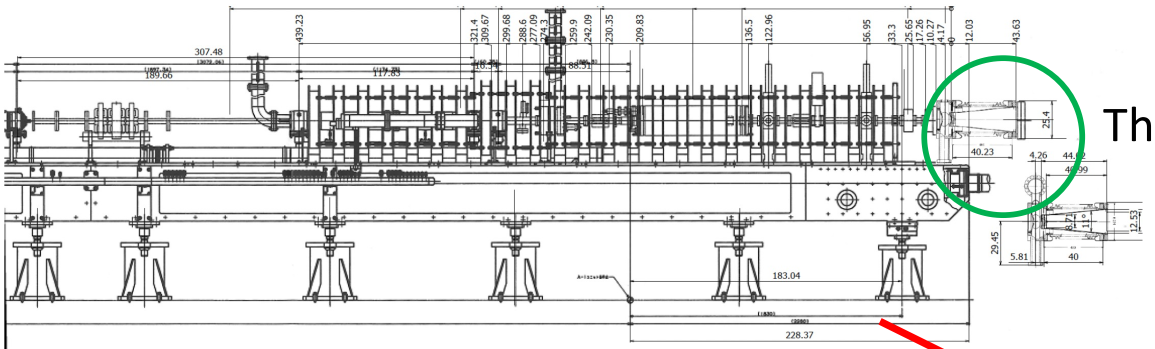


Bunch charge effects

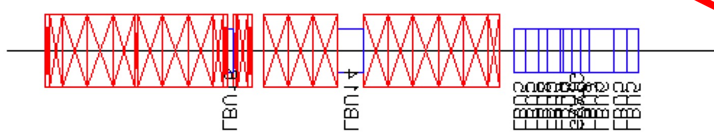


Z. Liptak

Merge Line - option for Touschek Polarization Experiment

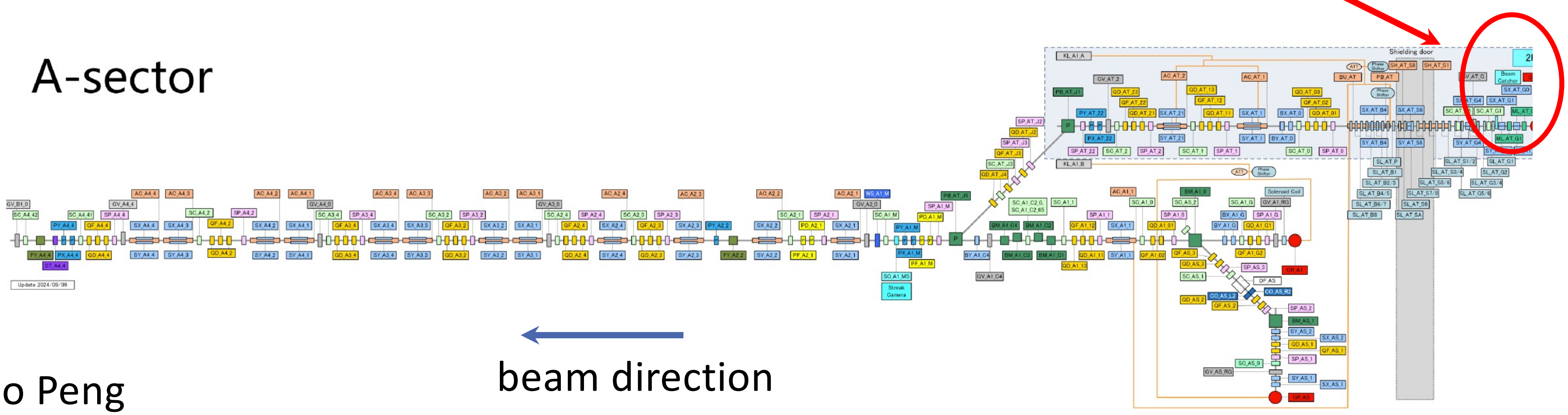


Thermionic source



KEK Linac A-sector

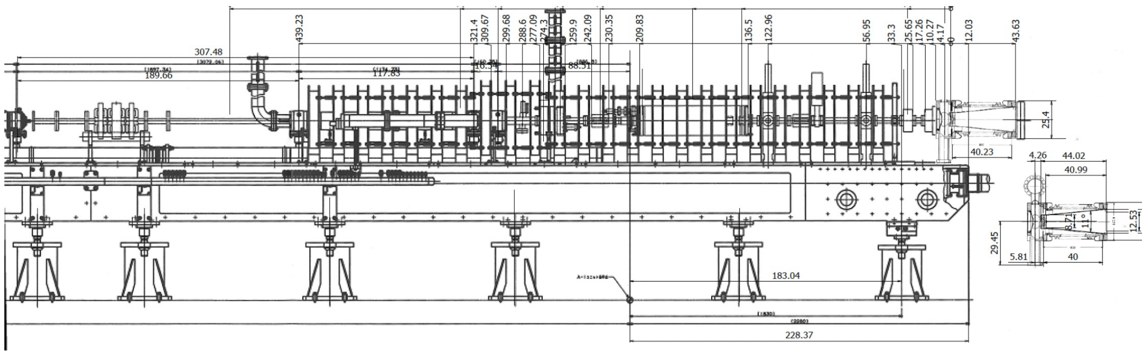
A-sector

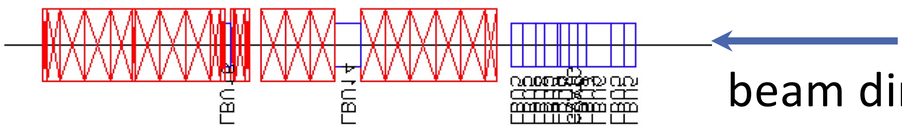


beam direction

Yuhao Peng

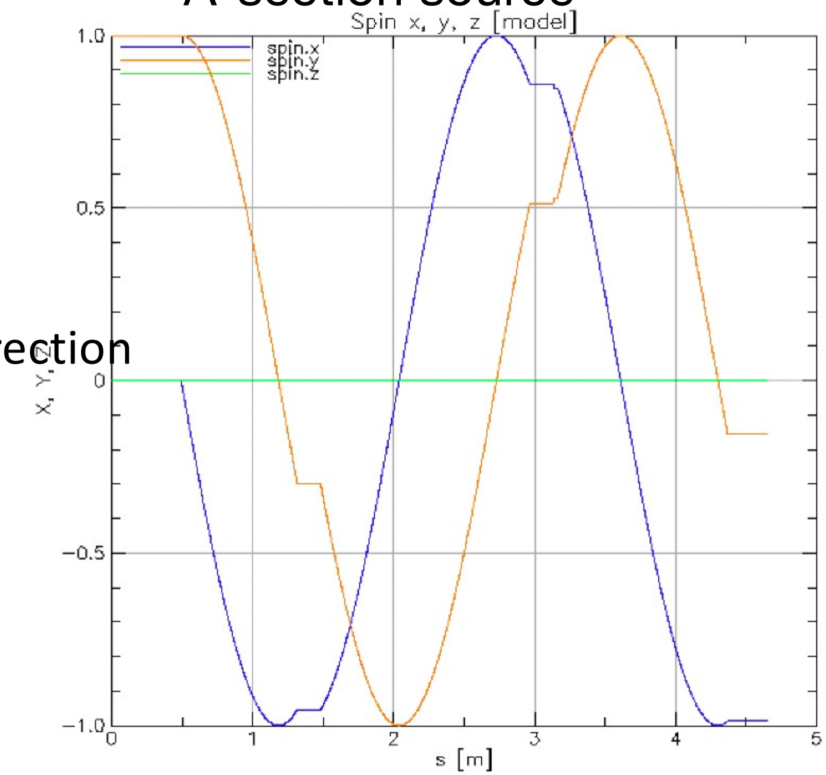
Merge Line - option for Touschek Polarization Experiment





beam direction

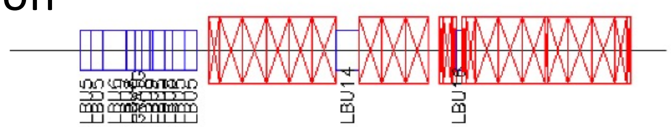
Bmad spin tracking in the A-section source



Plan would be to fill HER with polarized electrons with solenoids off to avoid spin rotations in this sector

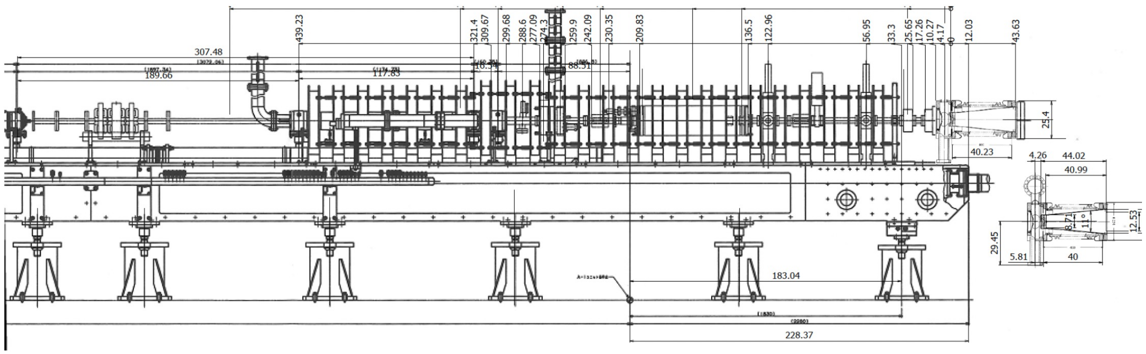
Interleave with LER fill, which uses thermionic gun and would have solenoids on

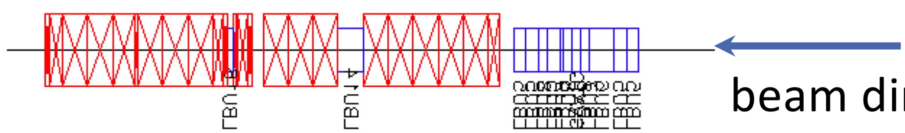
beam direction



Yuhao Peng

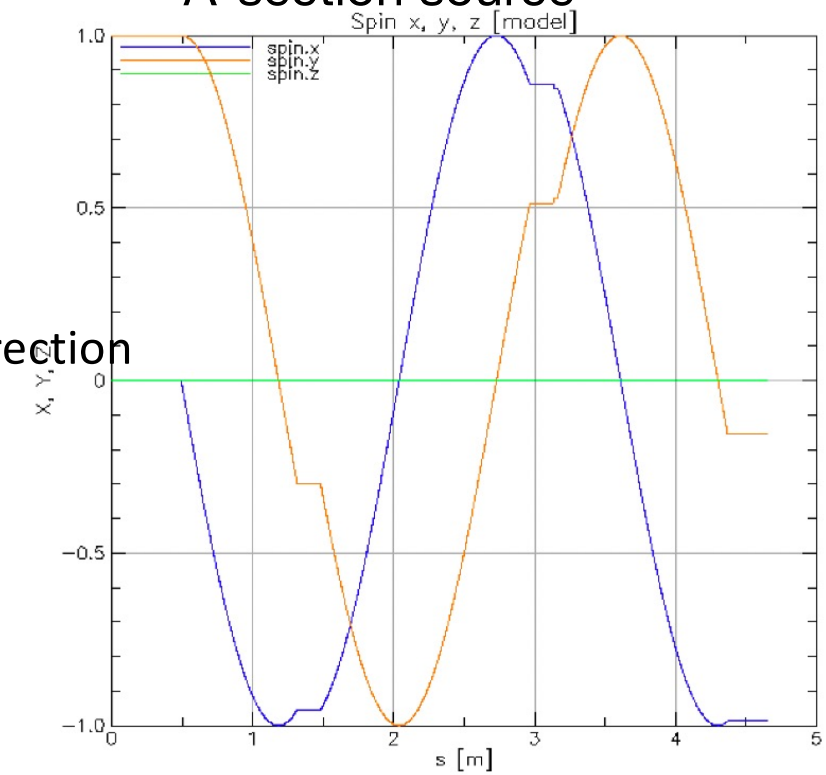
Merge Line - option for Touschek Polarization Experiment





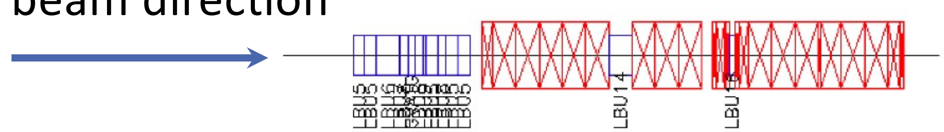
beam direction

Bmad spin tracking in the A-section source



Yoshida-san has started to consider alternative merge option that avoids the solenoids

beam direction



Yuhao Peng