ICHEP 2024 | PRAGUE

17–24 Jul 2024
Prague
Europe/Prague timezone

Status of Chiral Belle: The Beam Polarization Upgrade of SuperKEKB

J. Michael Roney

18 July 2024

On behalf of Belle II

and

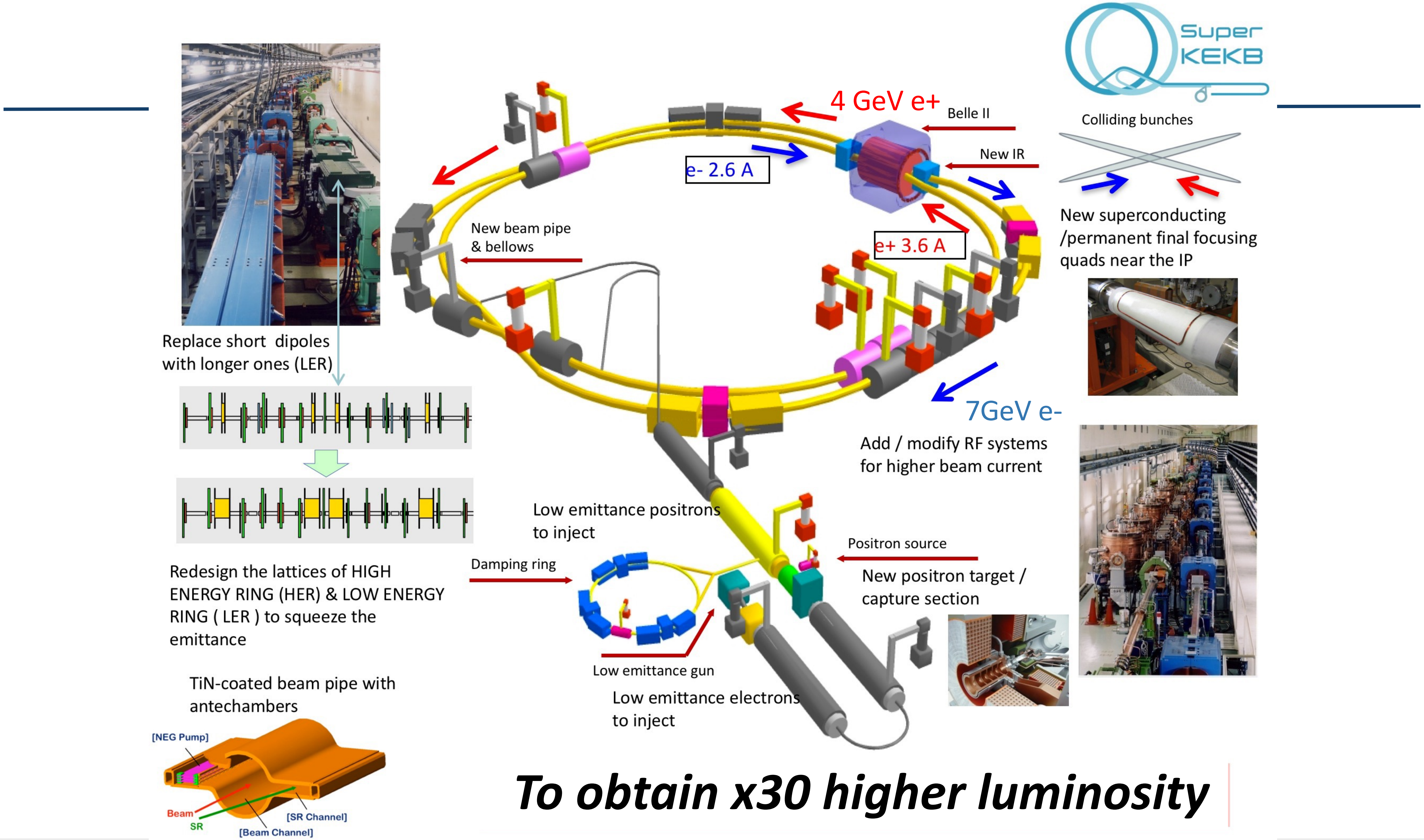
The BelleII/SuperKEKB Polarization Upgrade Working Group

University of Victoria

Upgrading SuperKEKB with polarized electrons Along with High Luminosity

Opens New Windows for Discovery with Belle II

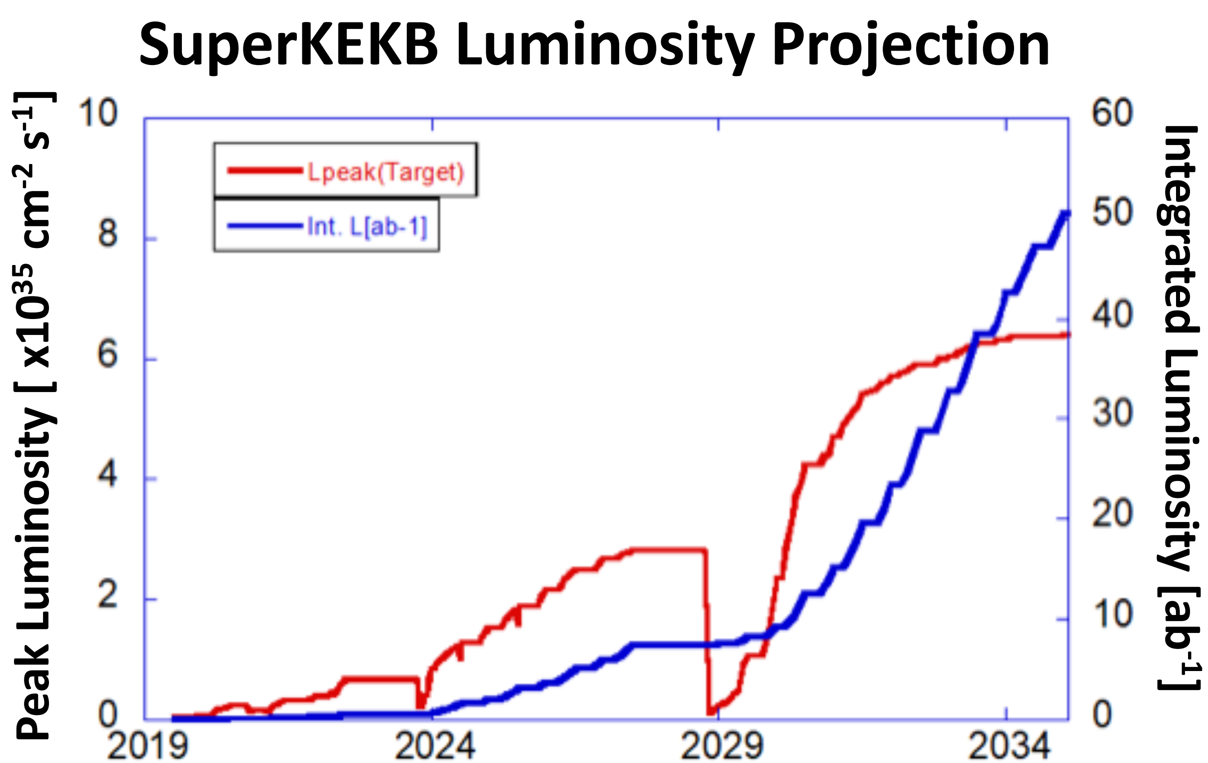
- Extremely rich and unique high precision electroweak program
- Unique Probe of Parity Violation in Dark Sector
- τ g-2
- τ EDM
- τ Michel Parameters
- Improved sensitivities for searches of $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$
- hadronic studies



To obtain x30 higher luminosity

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

getting to the design luminosity is our highest priority



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

getting to 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

getting to 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

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 program**

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

Left-Right Asymmetries ($A_{LR}=\frac{\sigma_L-\sigma_R}{\sigma_L+\sigma_R}$) 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

(see Appendix for Z_{dark} details)

as well as light quarks

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

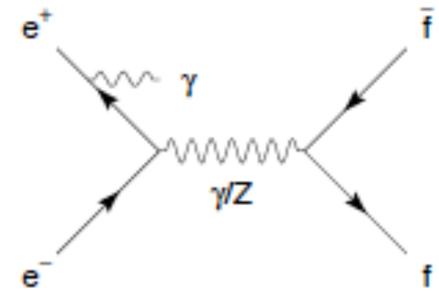
T_3 = -0.5 for charged leptons and Down-type quarks
+0.5 for neutrinos and Up-type quarks

‘Chiral Belle’ -> Left-Right Asymmetries

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

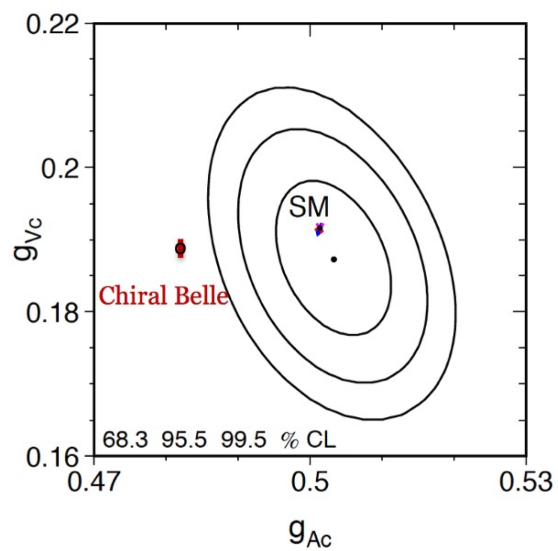
$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{4}{\sqrt{2}} \left(\frac{G_F s}{4\pi\alpha Q_f} \right) g_A^e g_V^f \langle Pol \rangle$$

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



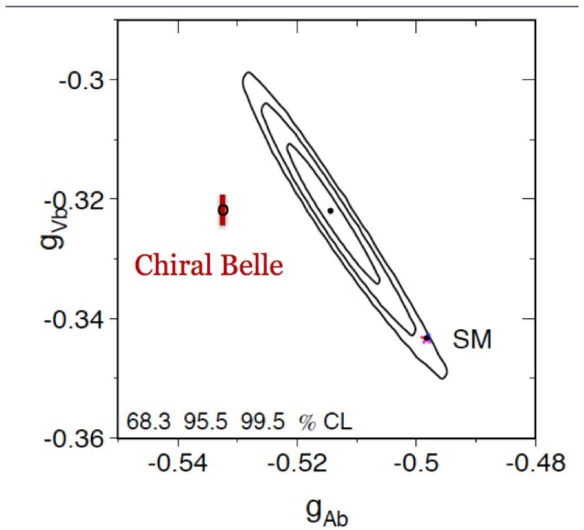
Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

c-quark:
Chiral Belle ~6 times more precise



b-quark:
Chiral Belle ~4 times more precise

with 20 ab^{-1}



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

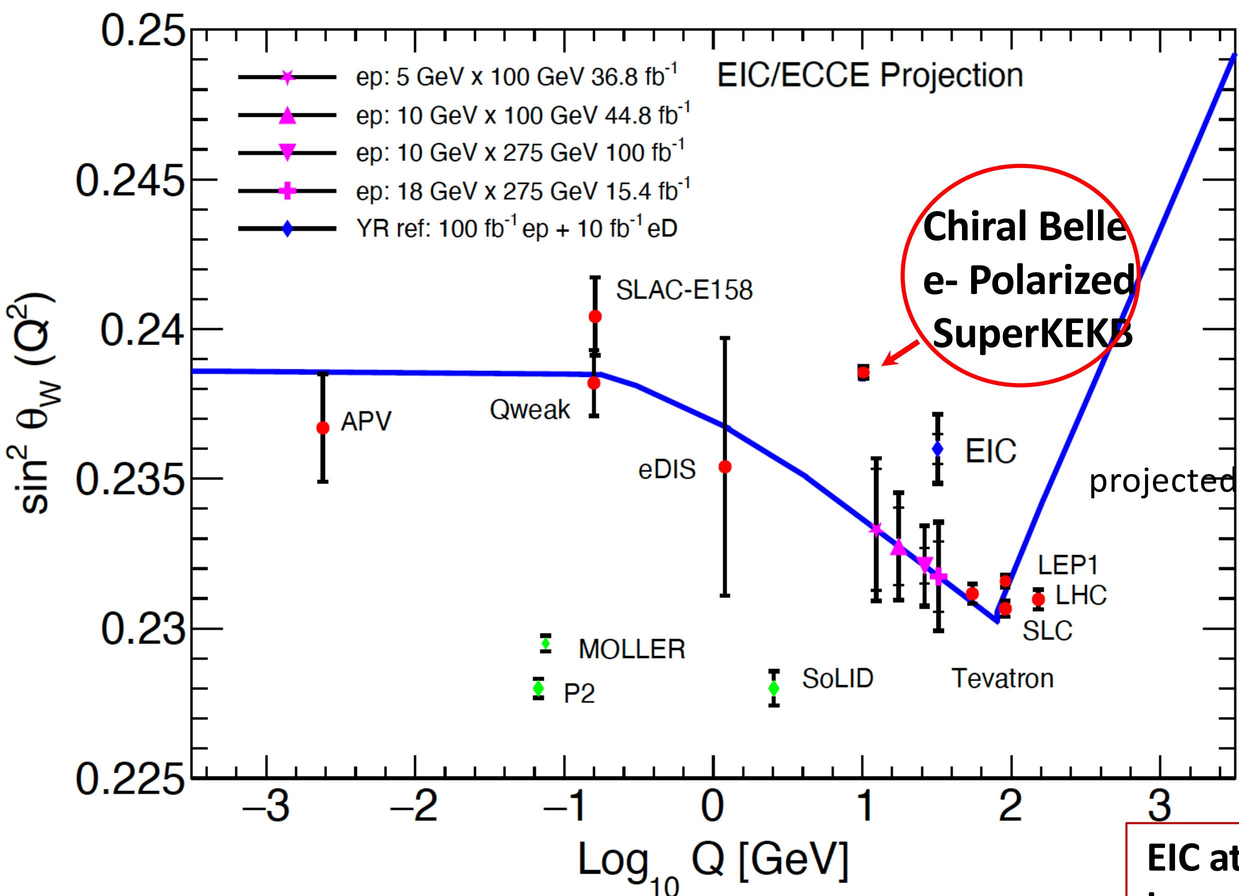


Figure Adapted from *Phys Rev D 106, 016006 (2022)*
(used in EIC Snowmass Whitepaper *arXiv:2203.13199v2)*
using data from PDG 2022 EW review (Erler&Freitas)

Chiral Belle:
$\sigma(\sin^2\theta_W) = 0.00018$ with $40ab^{-1}$
Using only clean leptonic states
(common <Pol> systematic included)
Comparable precision to Z^0 W.A.

- **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 $\sigma_{\sin2\theta W}$ (EIC) = 0.0012
***cf* 0.0002 @ Chiral Belle**

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 ab^{-1}	Chiral Belle $\sigma(g_V^f)$ 20 ab^{-1}	Chiral Belle $\sigma(g_V^f)$ 40 ab^{-1}	Chiral Belle σ $\sin^2\Theta_W$ 40 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	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667±0.0023	0.0031	0.0007 Improve x 3	0.0005	0.0003
Electron (17nb, eff=0.36)	-0.0371 ±.0003	-0.03816±0.00047	0.0039	0.0009	0.0006	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

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 the <Pol>, dominant systematic uncertainty
Produces VERY high precision evaluation of Standard Model predictions of the ratios

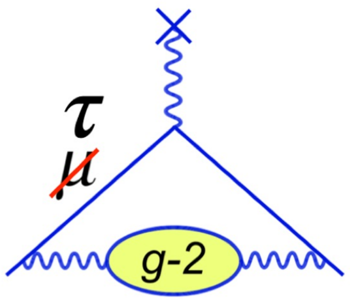
For example:

With only 10 ab^{-1} of data Chiral Belle achieves a
0.6% relative error for b-to-c ratio, *cf* 4.8% now
(40 ab^{-1} → 0.3% relative error for b-to-c ratio, *cf* 4.8% now, 14 fold improvement)

Chiral Belle physics broader program includes:

- Tau Lepton Magnetic Form factor F_2(10GeV) → τ g-2
- τ electric dipole moment (EDM)
- Improved precision measurements of τ Michel Parameters
- e^- beam polarization can be used to reduce backgrounds in $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$ – leading to improved sensitivities; also electron beam polarization and can be used to distinguish Left and Right handed New Physics currents.
- Polarized e+e- annihilation into a polarized Λ or a hadron pair experimentally probes dynamical mass generation in QCD

Magnetic dipole moment of τ lepton



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

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**

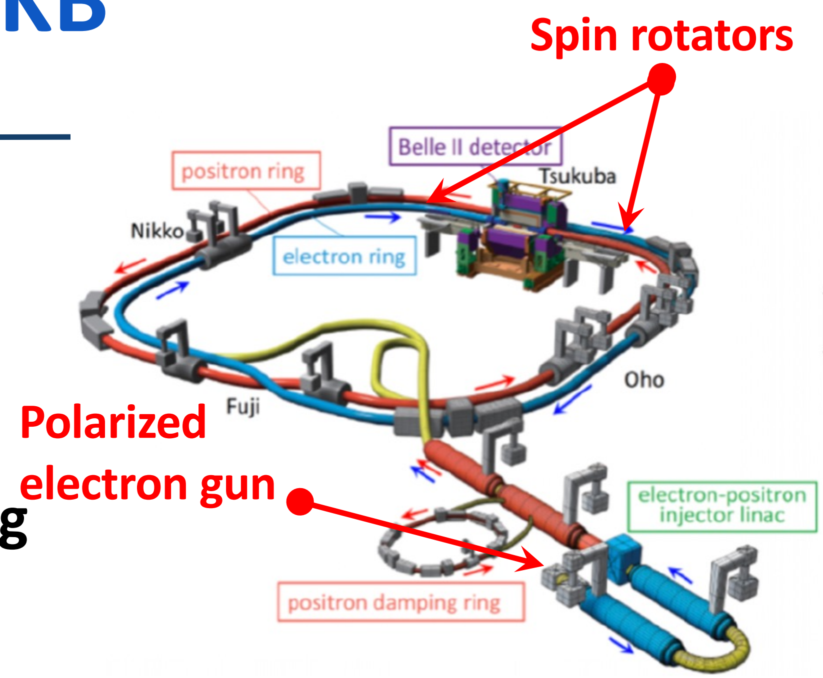
Contributions to $F_2(s)$ in units of 10^{-6}.

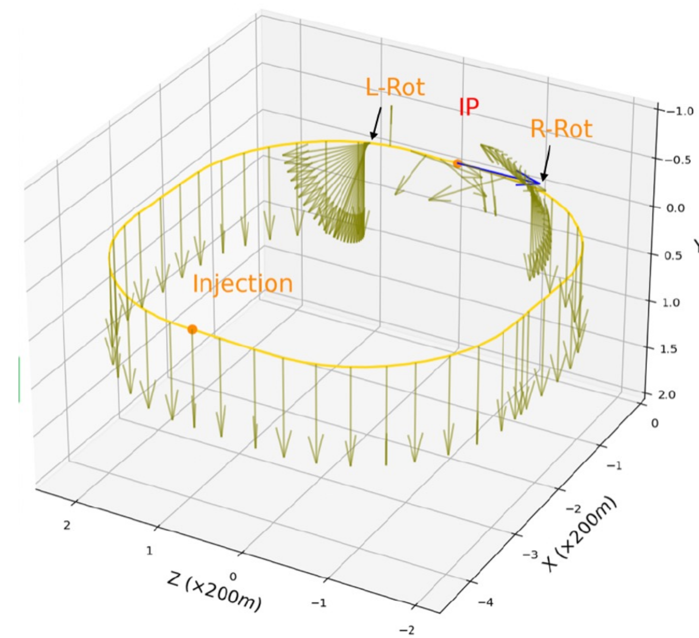
	$s=0$	$s=(10\,\mathrm{GeV})^2$
1-loop QED	1161.41	−265.90
e loop	10.92	−2.43
μ loop	1.95	−0.34
2-loop QED (mass independent)	−0.42	−0.24
HVP	3.33	−0.33
EW	0.47	0.47
total	1177.66	−268.77

- **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**
- **Approaches the precision regime in tau that starts to be sensitive to Minimal Flavour Violation equivalent of muon g-2 anomaly**

e- beam polarization in SuperKEKB

- Goal: 70% longitudinal polarization at Belle II from 80% polarization produced at source (note: SLC achieved 75% polarization @ SLD)
- Left-Right flip of electron helicity for trains of bunches by controlling the circular polarization of the source laser illuminating a GaAs photocathode (as in other experiments e.g. SLC, SLAC-E158, QWeak)
- 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 between Spin Rotator and IP to measure longitudinal polarization with 1% absolute precision in real-time
- Use tau decays to get absolute average polarization 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"

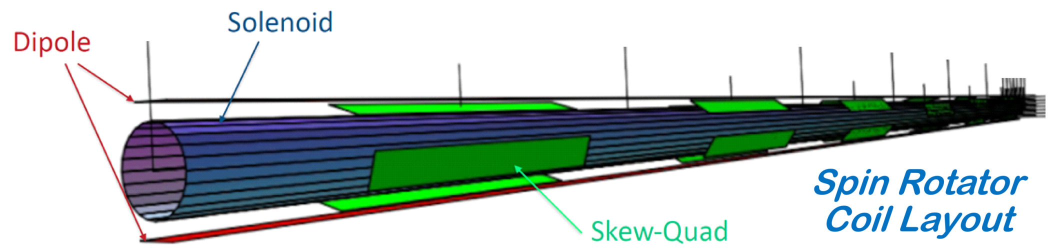
BABAR Collaboration, J.P. Lees et al

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**

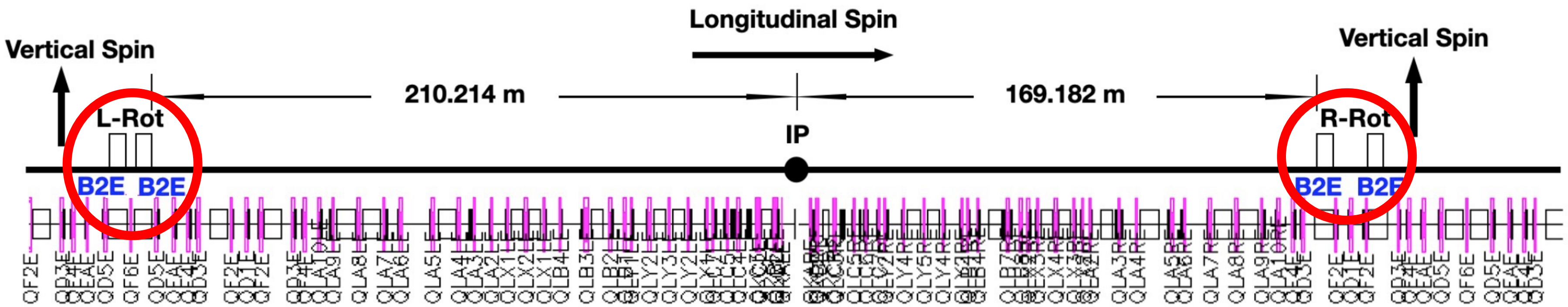
Original machine can be recovered by turning off solenoid and skew-quadrupole fields + retune with only the dipoles

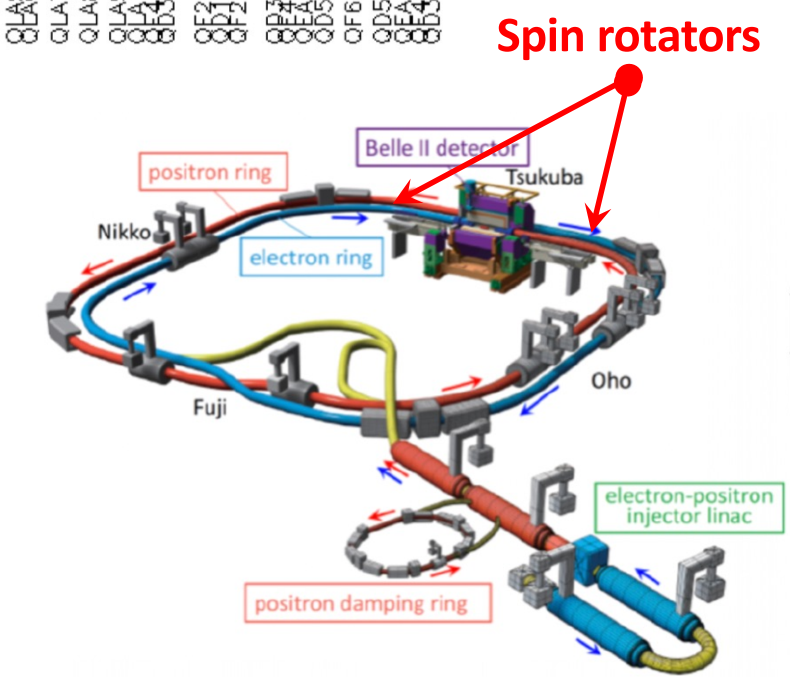
(BNL expertise in construction of direct wind magnets suitable for these magnets)

Compact spin rotator

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

Existing HER Lattice elements →

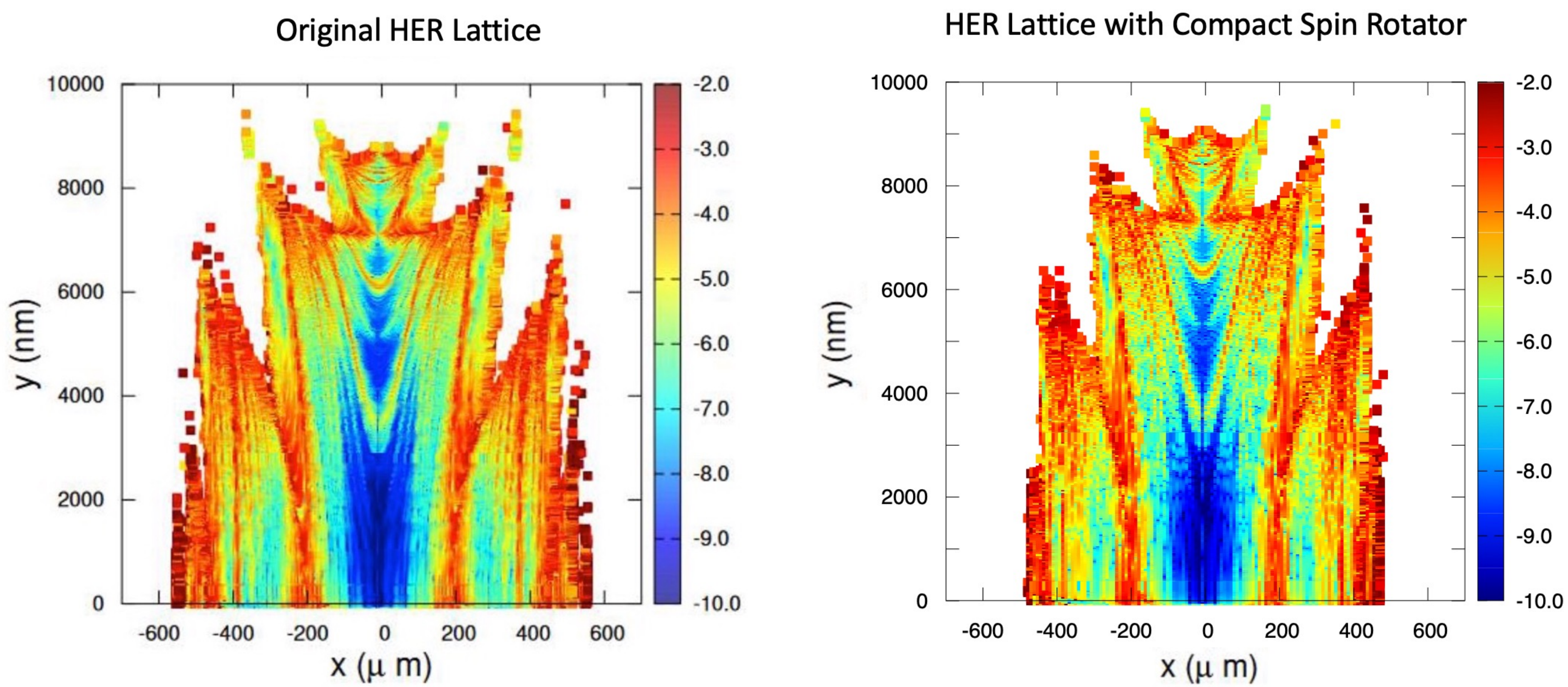




- Left Rotator (L-Rot) rotates the spin from the vertical to the horizontal plane
- Right Rotator (R-Rot) rotates the spin back to the vertical direction
- 4 **B2E** dipoles (using SAD lattice naming convention for HER) shown above to be replaced with the spin rotator magnets

Compact spin rotator

Frequency Map Analysis (FMA) dynamic aperture studies using Bmad accelerator modelling software – show no large changes. **Noah Tessema (UVic), D. Zhou (KEK), U. Wienands (ANL)**

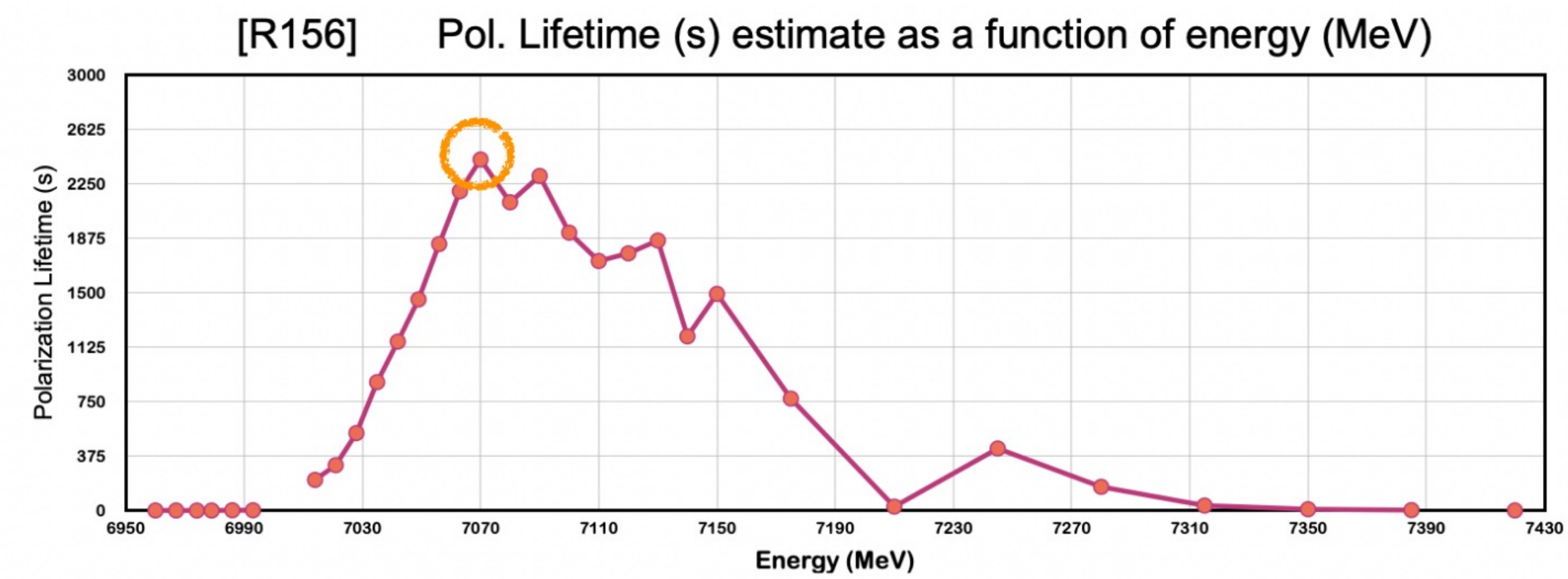


Bmad: A relativistic charged particle simulation library, D. Sagan, *Nucl.Instrum.Meth.A* 558 (2006) 356-359

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



Compact spin rotator

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

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

Conclusion:

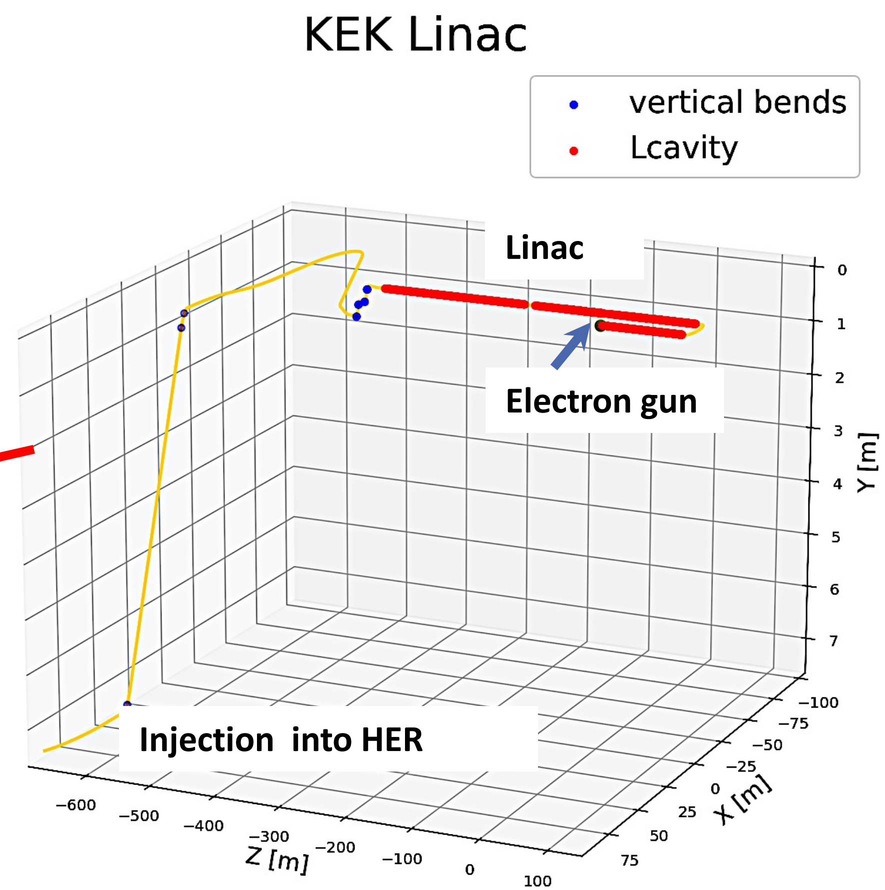
Beam is stable with compact spin rotators (5 million turns with 20 particles – no lost particles)

Good polarization lifetime (25 minutes ~10 top-up times) with HER energy of 7.05 GeV (~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

Next step: Propose to put LTT studies to the test with data in experiment with TRANSVERSE polarized beam to validate polarization lifetime

Inject transversely polarized beam at the HER injection point

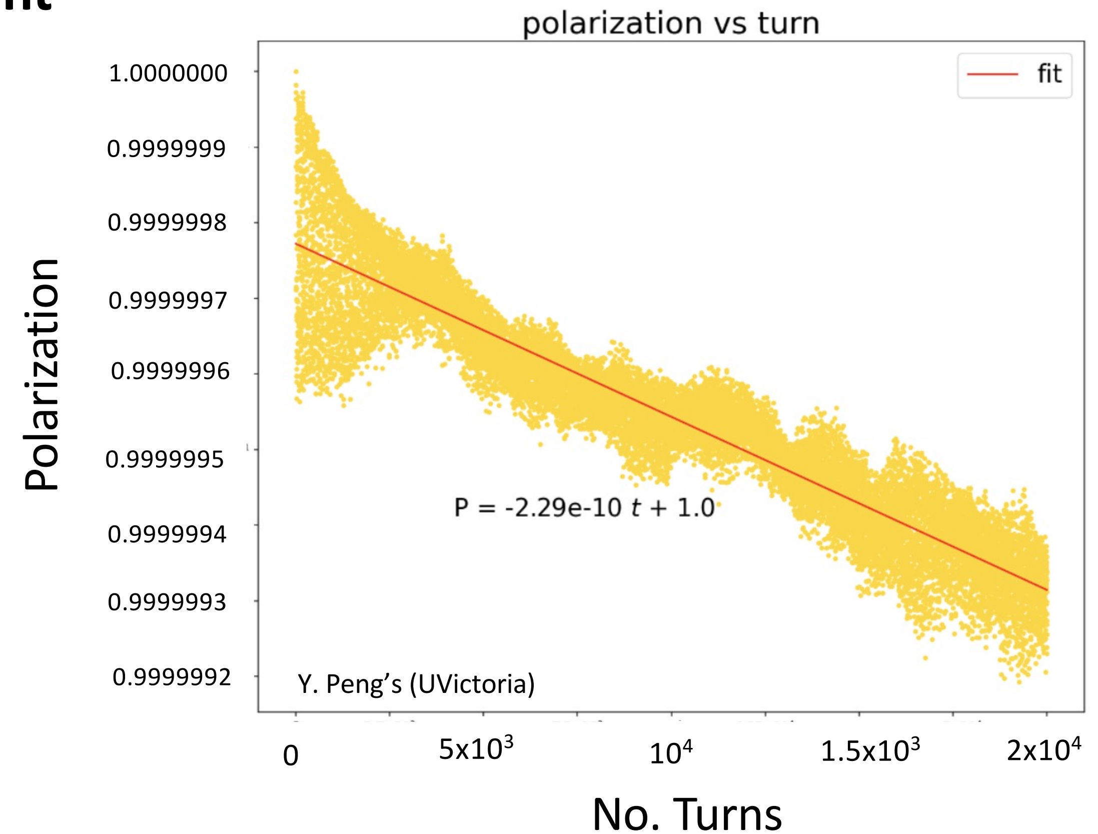


KEK Injection Linac polarization BMAD studies

KEK Injection Linac polarization Bmad studies

Inject transversely polarized beam at the HER injection point

Transverse polarization survival rate in HER



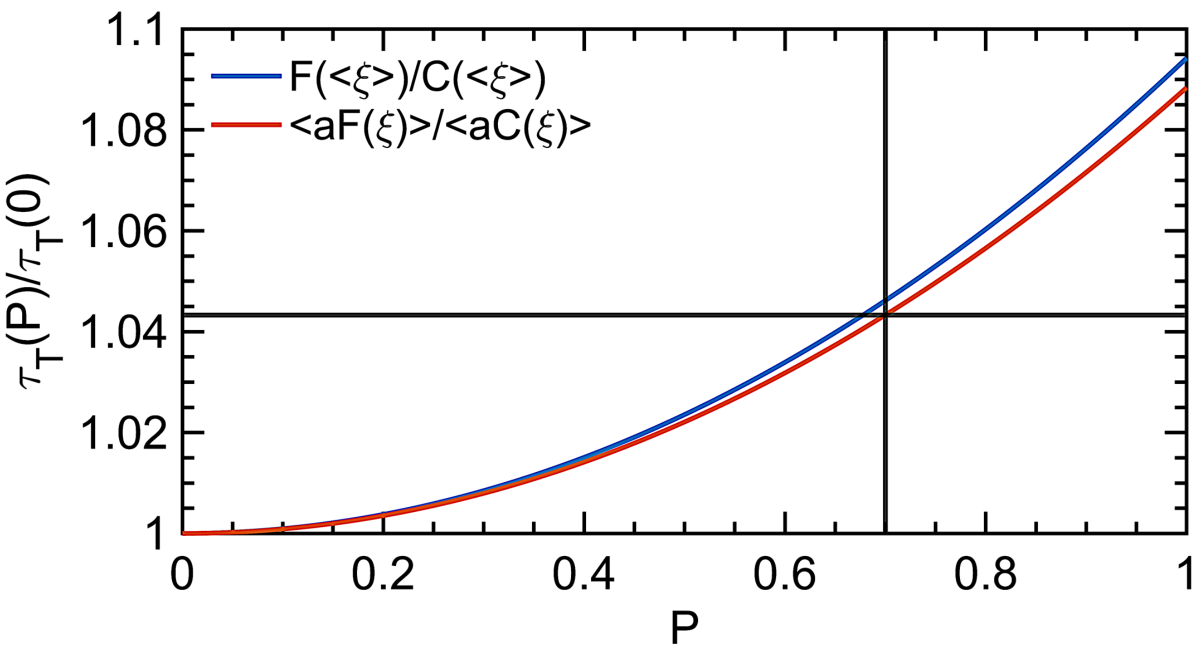
- **Tracking 100 particles for 20000 turns in the HER with BMAD**
- **This study estimates polarization lifetime > 10 hours**

History of Touschek lifetime being used to measure transverse polarization

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

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

For SuperKEKB



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

Touschek lifetime measurements already performed in HER with required precision

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 is being drafted

Feasible to plan for installation at end of this decade with collisions with polarization data starting while SuperKEKB completes its program of delivering $50ab^{-1}$ of data and continued beyond that program.

Summary

- e^- polarization upgrade at SuperKEKB coupled to high luminosity opens unique discovery windows with precision electroweak physics and broader program

- Feasible Technical Realization
  - Polarized source – synergies with e.g. EIC
  - Polarimetry at <0.5%
  - Spin Rotators transparent to rest of HER lattice

- Preparing for Touchek-Polarization lifetime experiment
  same approach to be used in FCC-ee

Thankyou for your attention…

…and consider joining the SuperKEKB electron beam polarization project!

Many areas where new people can have an impact! Additional accelerator physicists, experimentalist and theorists very welcome

- Beam dynamics and spin tracking
- Spin rotator design
- Compton polarimetry – detector expertise
- Polarized low emittance source
- Tau decay polarimetry – use as many decay channels as possible
- Tau Michel parameter, EDM and F_2 studies
- Detailed physics MC studies with final-state fermion selection optimizing signal to background: b, c, tau, mu and e, as well as light quarks
- Precision EW theoretical calculations
- Bhabha MC generator with polarized beams -> now have ReneSANCe

Additional Information

'Chiral Belle' Left-Right Asymmetries

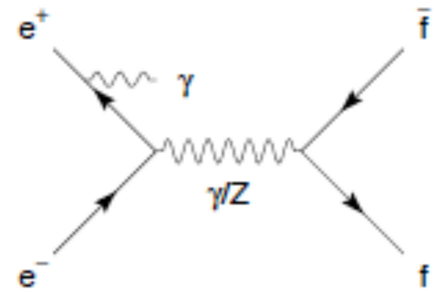
Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.

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

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

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

(for s-channel Born)



Source generates mainly right-handed electrons

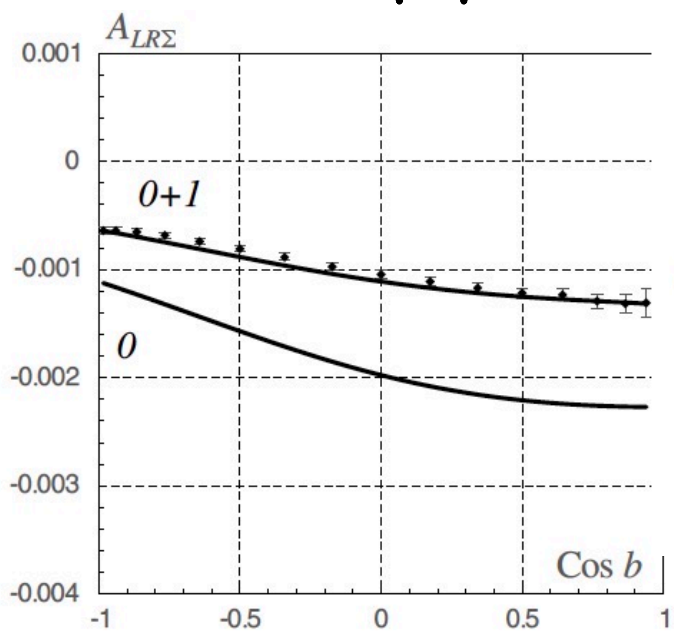
Source generates mainly left-handed electrons

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

➤ SM Electroweak calculations:

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

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

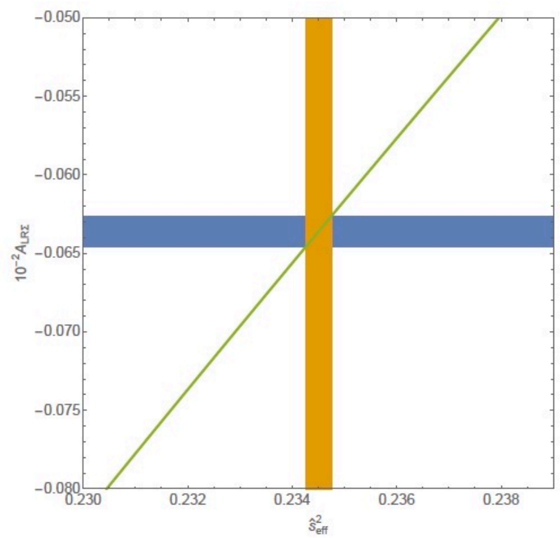


$$\Sigma_L^C = \int_{\cos b}^{\cos a} \sigma_L^C \cdot d(\cos\theta), \quad \Sigma_R^C = \int_{\cos b}^{\cos a} \sigma_R^C \cdot d(\cos\theta)$$

a=10° & energy of photons < 2GeV

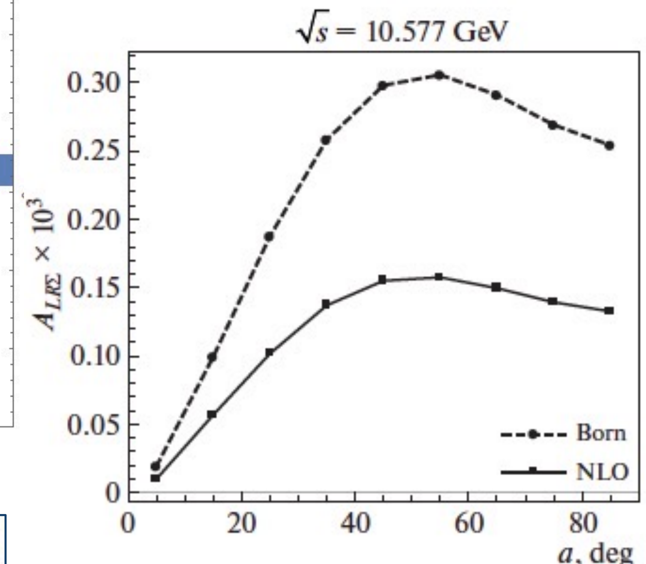
Phys.Rev. D101 (2020) no.5, 053003

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



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

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



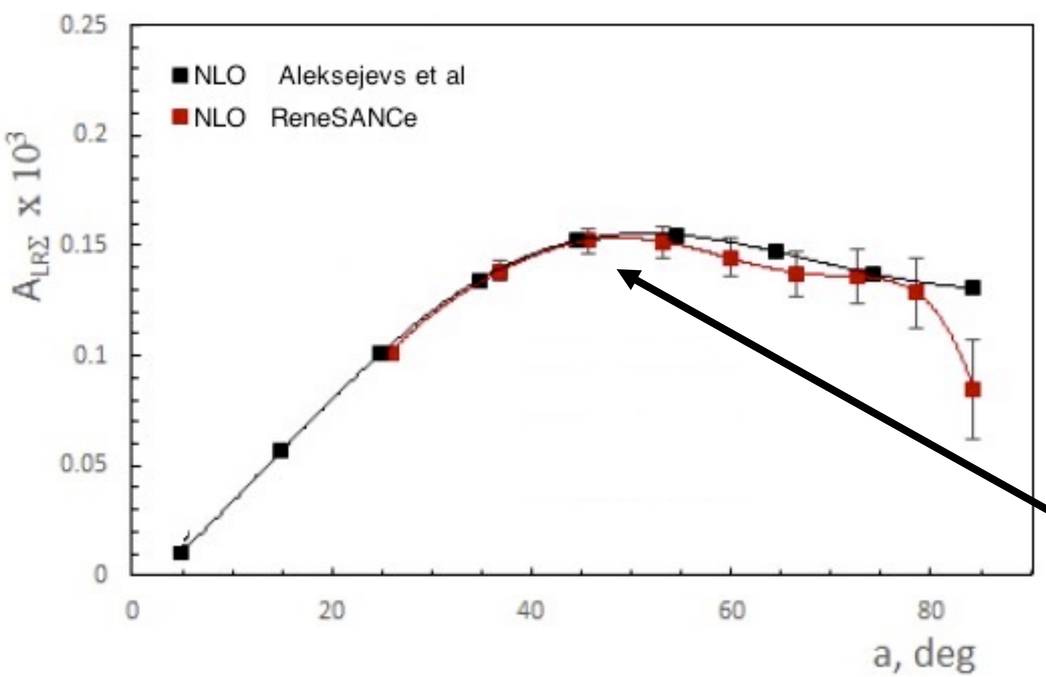
$$\Sigma_L^C = \int_{-\cos a}^{\cos a} \frac{d\sigma_{L0}^C}{dc} \cdot dc, \quad \Sigma_R^C = \int_{-\cos a}^{\cos a} \frac{d\sigma_{R0}^C}{dc} \cdot dc.$$

PHYSICS OF ATOMIC NUCLEI Vol. 83 No. 3 2020

$e^+e^- \rightarrow e^+e^-$ NLO Generator: ReneSANCe

Renat Sadykov (JINR,Dubna) and Vitaly Yermolchyk (JINR Dubna&INP,Misnk), "Polarized NLO EW e+e− → e+e− cross section calculations with ReneSANCe-v1.0.0", *Comput.Phys.Commun.* 256 (2020) 107445; 2001.10755 [hep-ph]

Relatively recently developed generator capable of producing Bhabhas with single beam polarization



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

Belle II published luminosity paper with Bhabha acceptance in central part of detector:
F. Abudinén et al, Belle II Collaboration, Chin.Phys.C 44 (2020) 2, 021001
Reports: Cross-section = 17.4nb, efficiency=36%

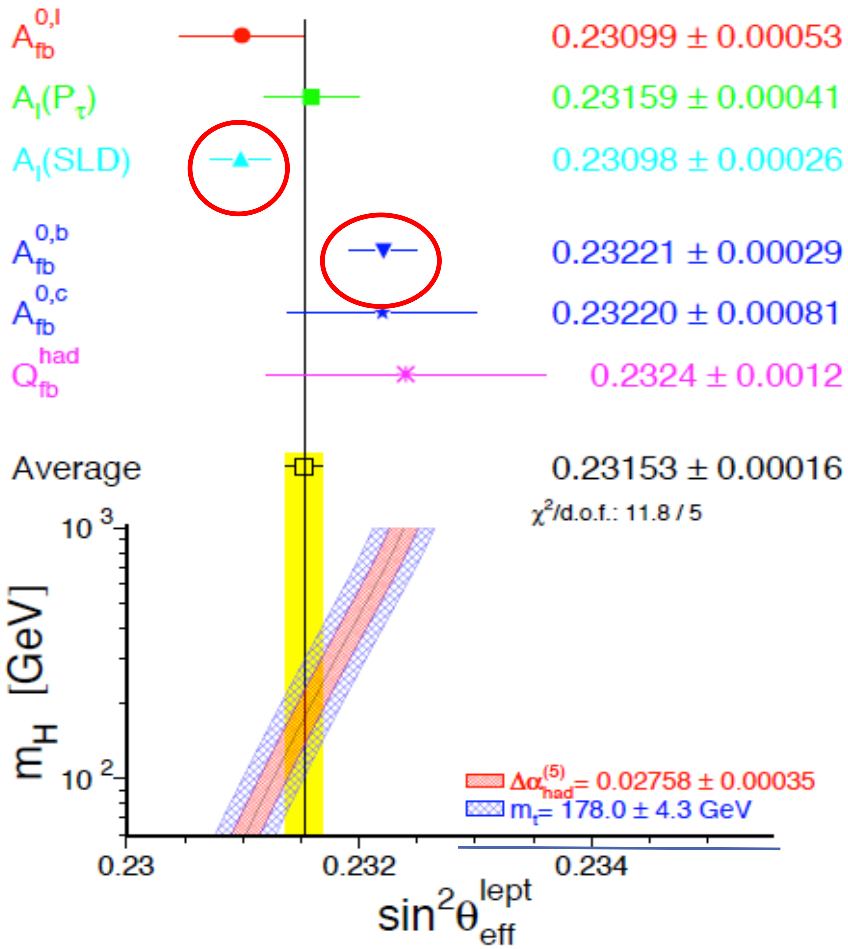
With 70% polarized electron beam get unprecedented precision for neutral current vector couplings

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 ±.000015	2.4%
muon (eff. = 0.5)	-0.00064 ±.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

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 $Z \rightarrow$ b-quark pairs (Physics Report 2006)

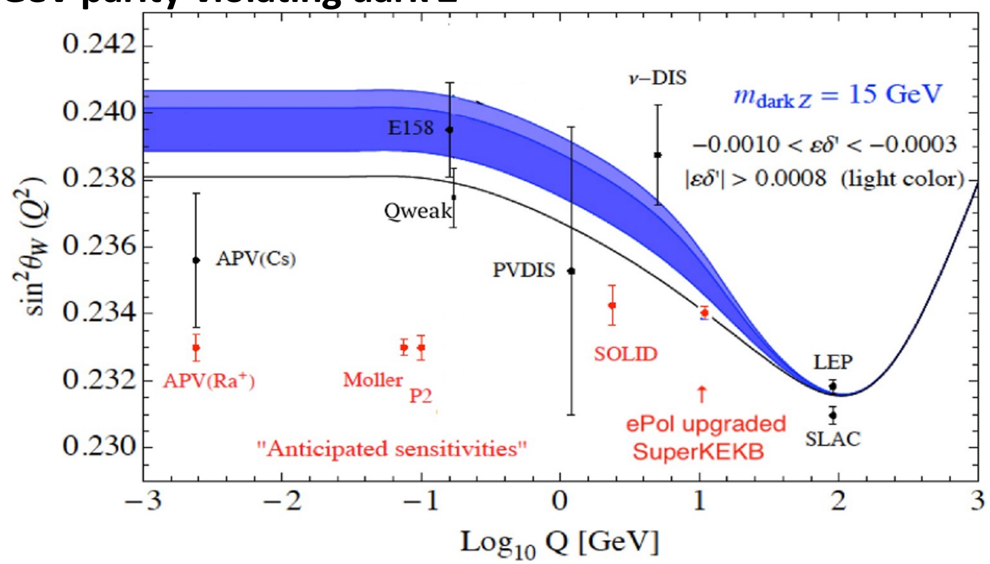
Chiral Belle is at B-meson pair production threshold, so not limited by this

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

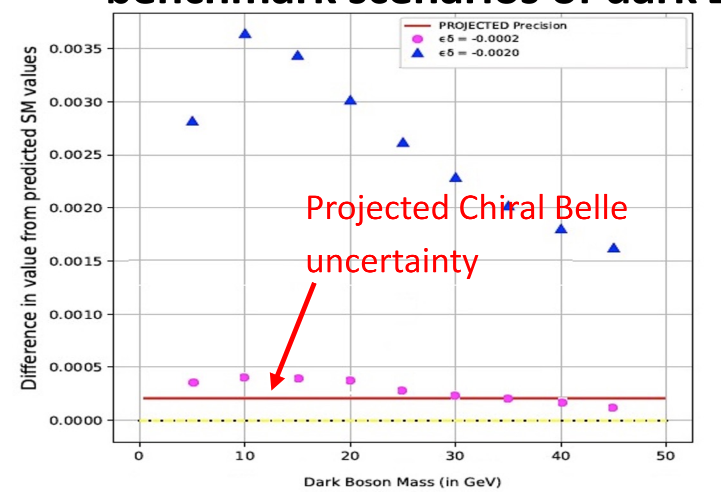
Upgrading SuperKEKB with e- Polarized Beams: Chiral Belle → unique probe of Dark Sector

Running of $\sin^2\Theta_W$: PV 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



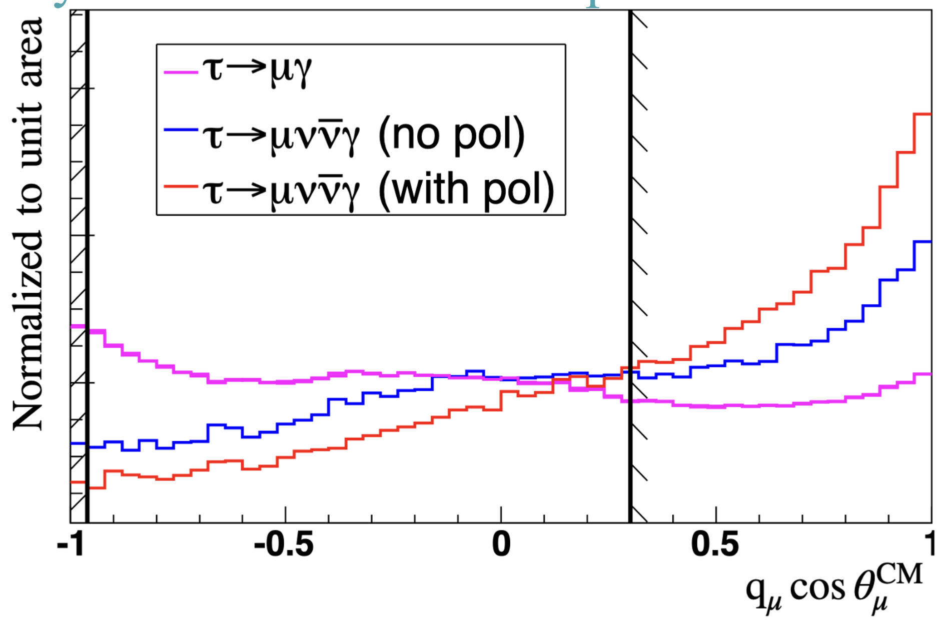
Differences between SM and two benchmark scenarios of dark Z



- **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**

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

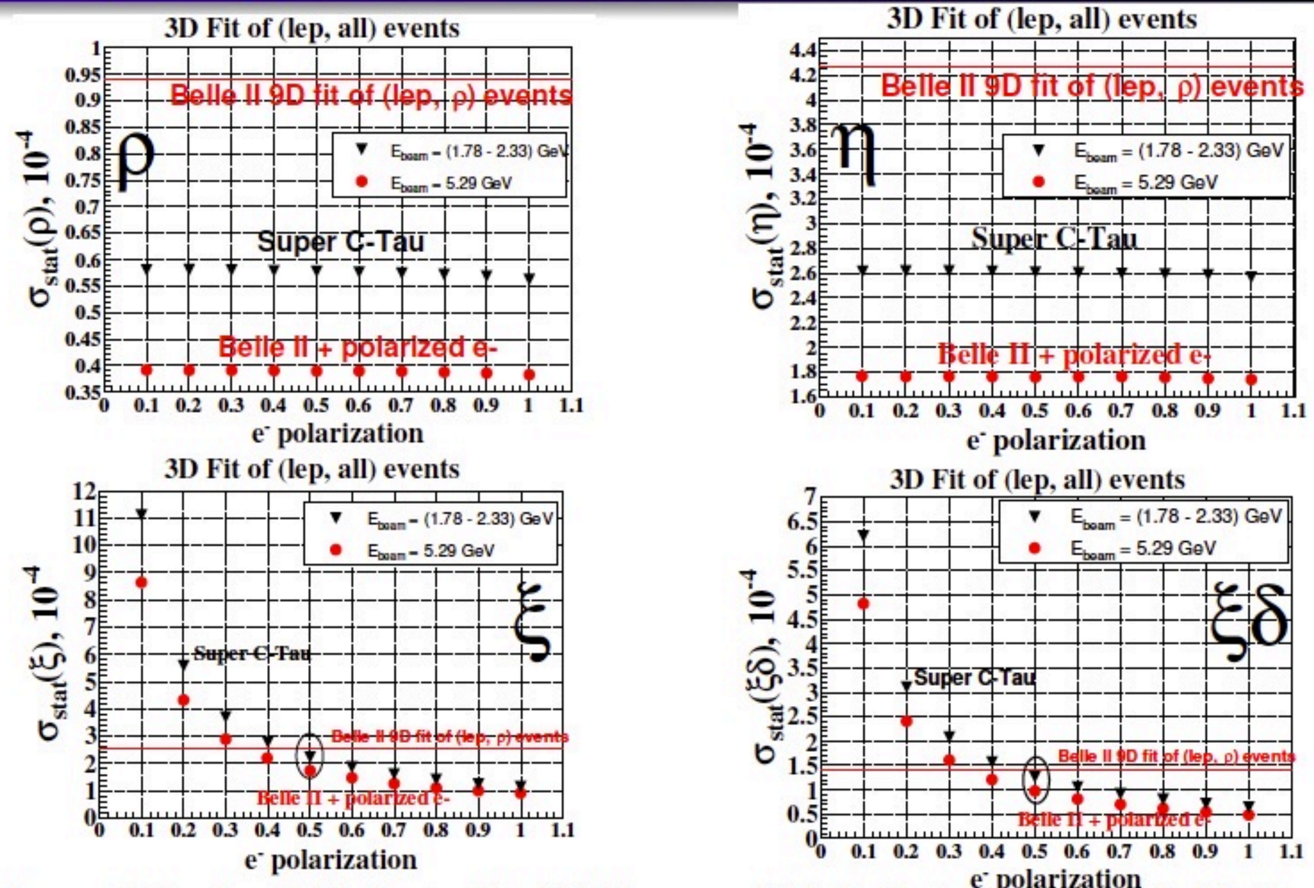


- Possible to disentangle helicity structure of LFV in $\tau \rightarrow \ell\ell\ell$ from Dalitz plots

τ Michel Parameter with polarized e- beam

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

Fit of $(\ell,\ \text{all})$ 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

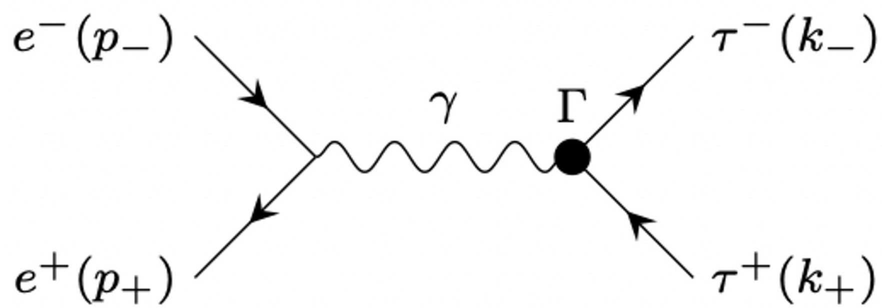
50/ab of polarized Belle II data assumed in these studies

Masanori Satoh, KEK (June 2020)

Machine Parameters for KEKB/SuperKEKB

Stage	KEKB (final)		Phase-I		Phase-II		Phase-III (interim)		Phase-III (final)	
Beam	e+	e–	e+	e–	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1.0 A	1.0 A	–	–	1.8 A	1.3 A	3.6 A	2.6 A
Life time (min.)	150	200	100	100	–	–	–	–	6	6
Bunch charge (nC)	primary e- 10 → 1	1	primary e- 8 → 0.4	1	0.5	1	2	2	primary e- 10 → **4**	**4**
Norm. Emittance (γβε) (μmrad)	1400	310	1000	130	200/40 (Hor./Ver.)	150	150/30 (Hor./Ver.)	100/40 (Hor./Ver.)	**100/15** (Hor./Ver.)	**40/20** (Hor./Ver.)
Energy spread	0.13%	0.13%	0.50%	0.50%	0.16%	0.10%	0.16%	0.10%	0.16%	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 Hz		25 Hz		50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Partially		4+1 rings (LER, HER, DR, PF, PF-AR)		4+1 rings (LER, HER, DR, PF, PF-AR)	

Effective field theory approach to τ-pair production



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

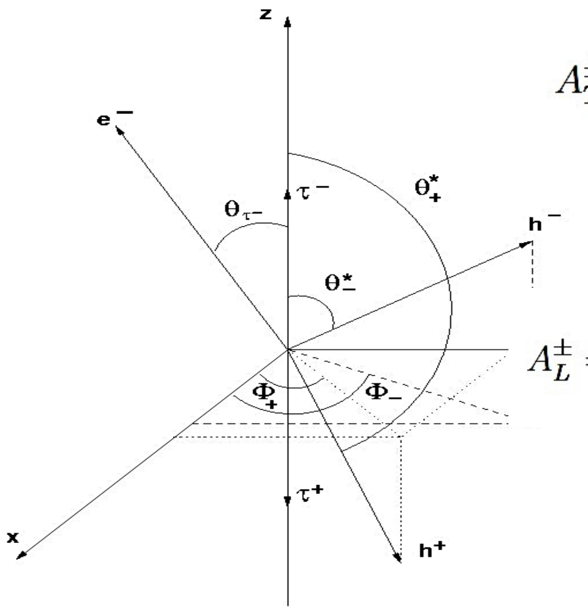
- $F_1\left(q^2\right)$, $F_2\left(q^2\right)$ are called the Dirac and Pauli; $F_1(0) = 1$; $F_2(0) = a_\tau$
- $g = 2 \cdot [F_1(0) + F_2(0)] = 2 + 2F_2(0)$ $\quad d_\tau^\gamma = \frac{e}{2m_\tau} \cdot F_3(0)$

Leading term:

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

”Schwinger term”

Magnetic dipole moment of τ lepton



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

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

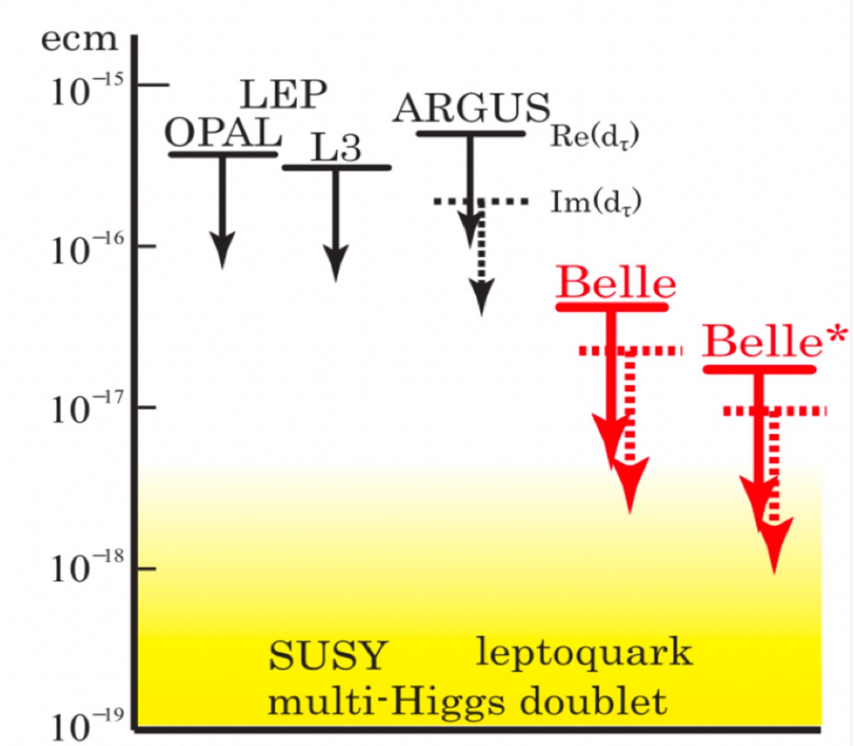
$$A_{RL} = \frac{d^2\sigma^{R_e}}{dz_\pm^* dz} - \frac{d^2\sigma^{L_e}}{dz_\pm^* dz}$$

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

requires precision E_{cm} & m_τ 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

Electric dipole moments of τ lepton



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

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

– 95% confidence intervals

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

- 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

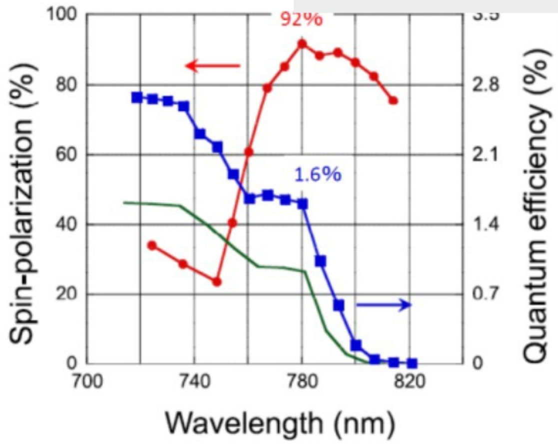
➢ **With 50 ab^{-1} data at Belle II: Re(d_τ) ~ 8 x 10^{-19}, Im(d_τ) ~ 4 x 10^{-19}**

➢ Further improvement expected from proposed upgrade of polarized e- beams.

Polarization in SuperKEKB

Polarized Source Development

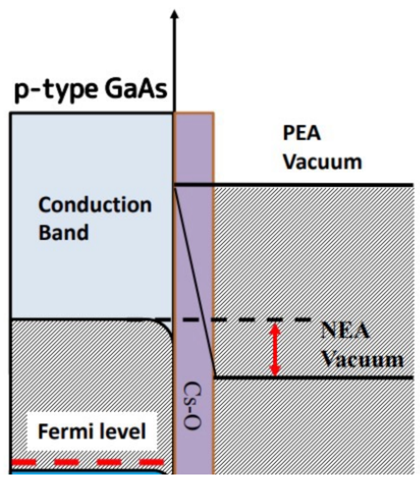
From Zachary J. Liptak (Hiroshima U.)

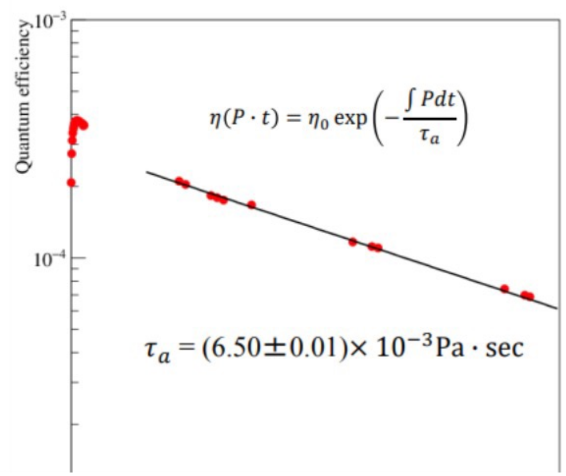


GaAs cathodes can produce beams with >90% polarization and ~1.6% QE, but due to a wide band gap accelerating electrons is difficult

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.





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"

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

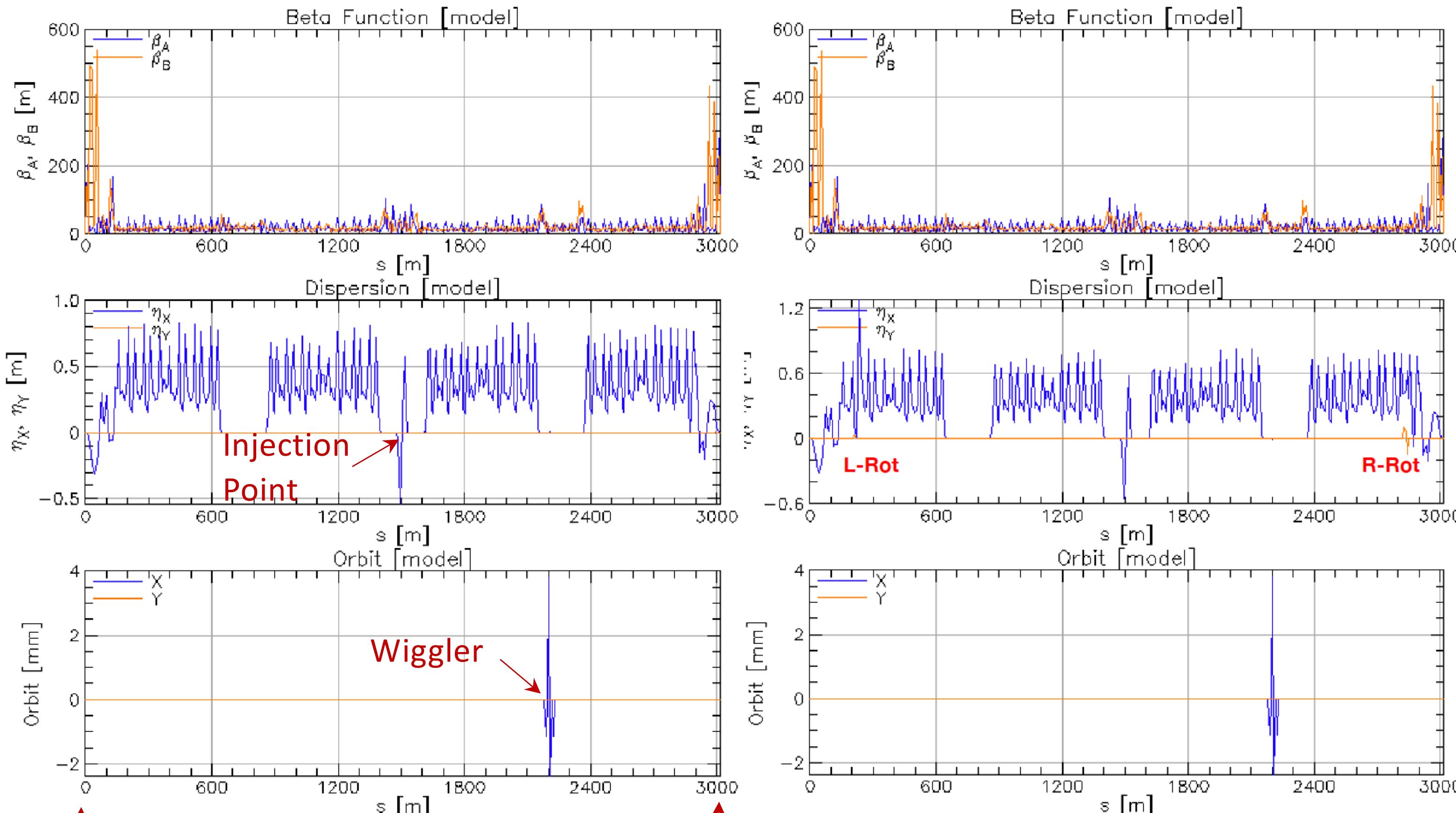
Compact spin rotator

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

Beta
x & y

Diffusion
x & y

Orbit



Original Ring

Rotator Ring

Interaction Point

Interaction Point

Y. Peng's (UVictoria)

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

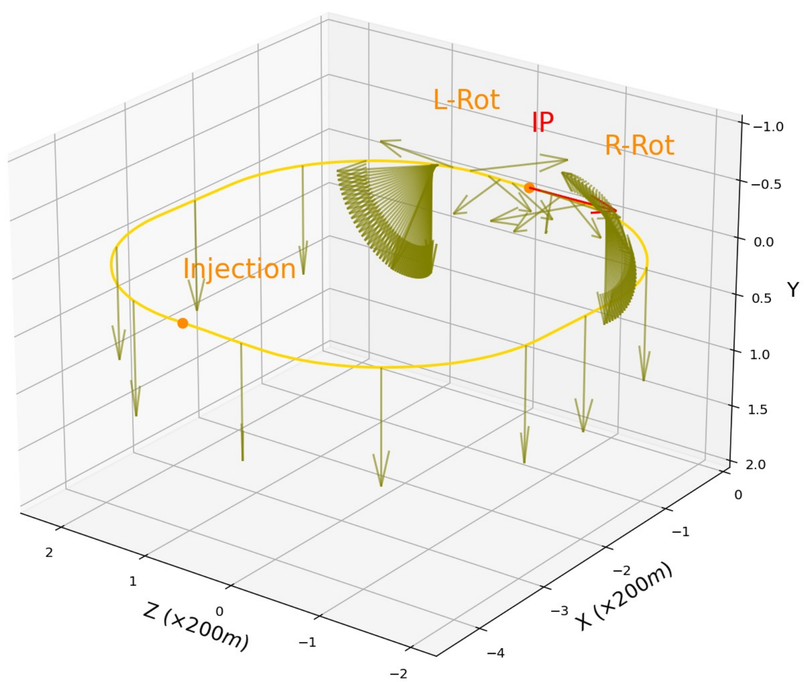
Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}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

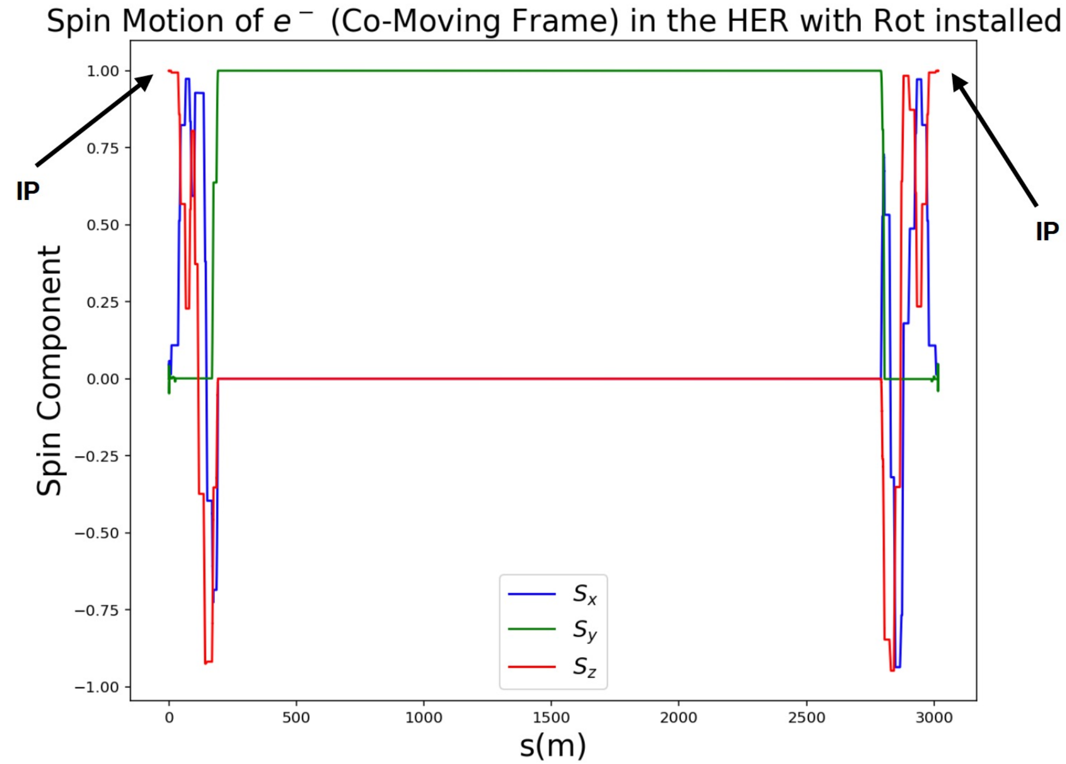
Compact spin rotator

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





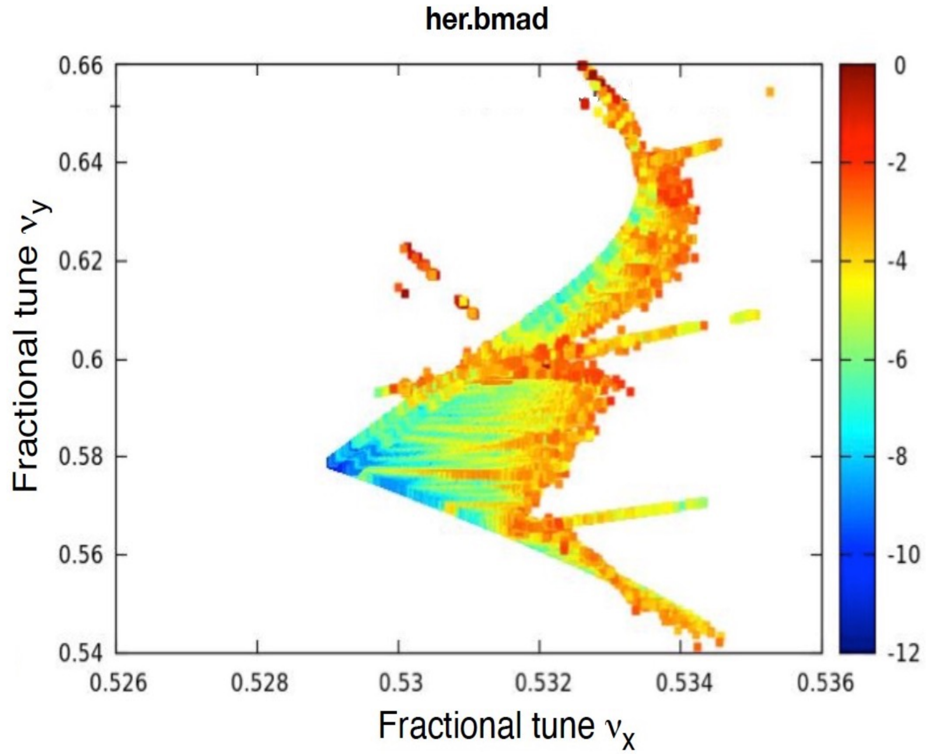
Compact spin rotator

Frequency Map Analysis (FMA)

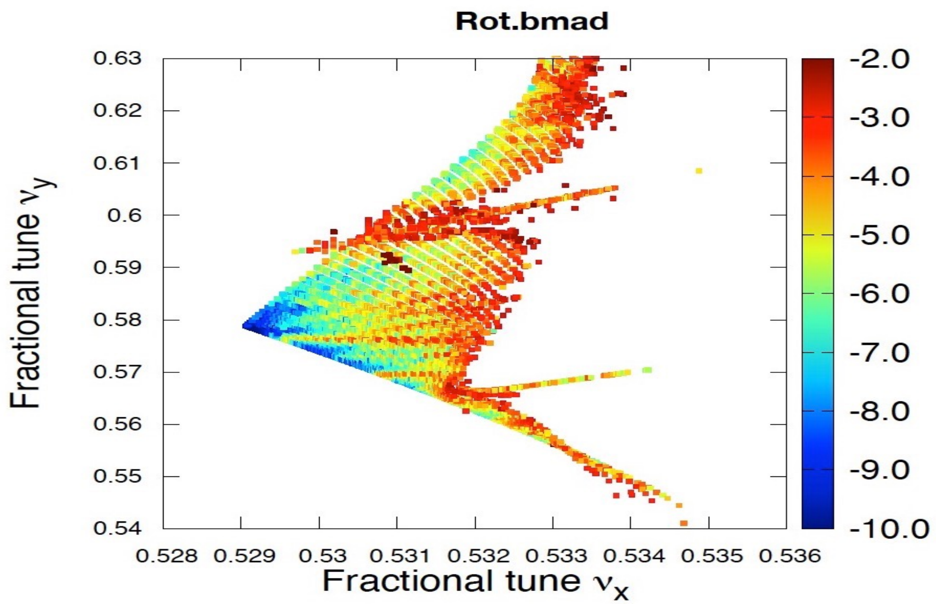
dynamic aperture studies using BMAD – show no large changes

work by D. Zhou (KEK) & Noah Tessema (UVictoria)

Original HER Lattice

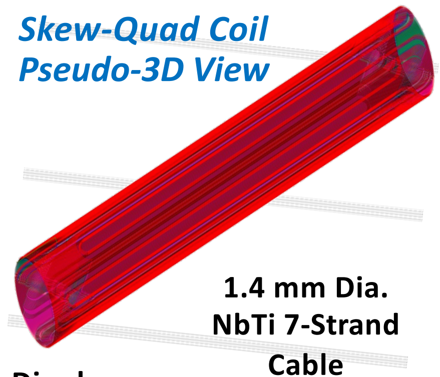


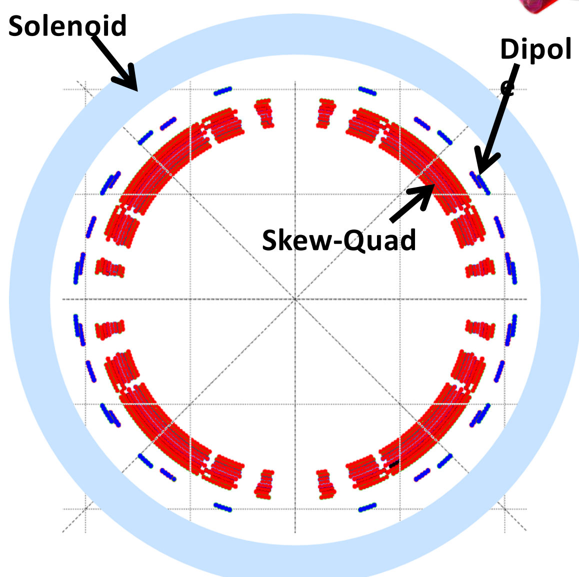
HER Lattice with spin rotator



Compact Spin Rotator – Coil Feasibility

Brett Parker (BNL)





Coil Cross Section at Skew-Quad Center

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

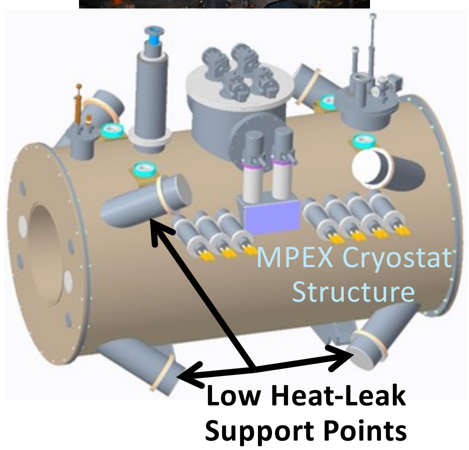
Combined Field @ Skew-Quad is 6.15 T
I_{op} = 729 A
I_q = 1050 A
for 69% Short Sample

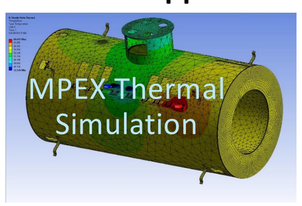
- **We plan to use BNL Direct Wind coil production technique to fabricate the nested coil structure.**
- **Results from first pass NbTi coil structure shown here yield desired operating margin at 4.22 K.**
- **Final coil layout requires careful optimization balancing warm-bore, intermediate heat shield, 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.**

48

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

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.

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

2023 JINST 18 P10014

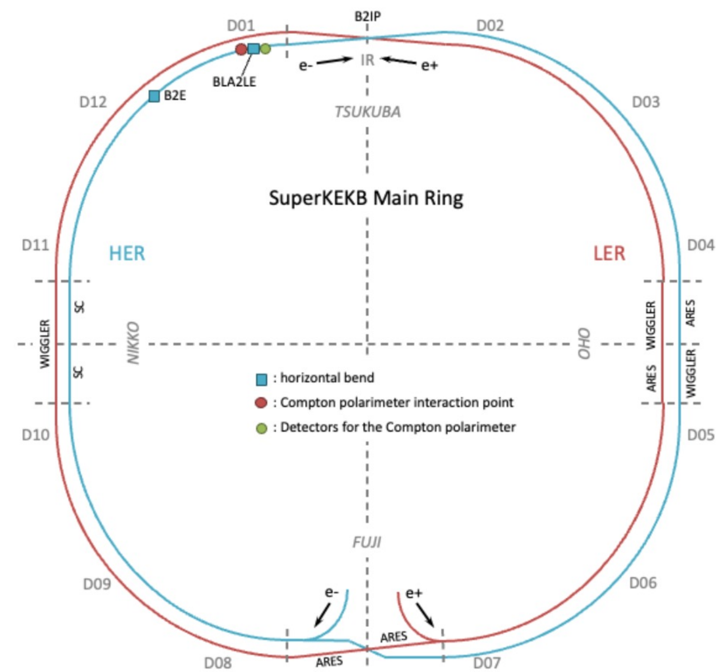


Figure 1. Schematic drawing of the main SuperKEKB ring, where the current B2E dipole to be replaced by spin rotators is identified. The location of the Compton polarimeter is also shown as well as Belle II interaction point.

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

2023 JINST 18 P10014

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.

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

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

2023 JINST 18 P10014

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.

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

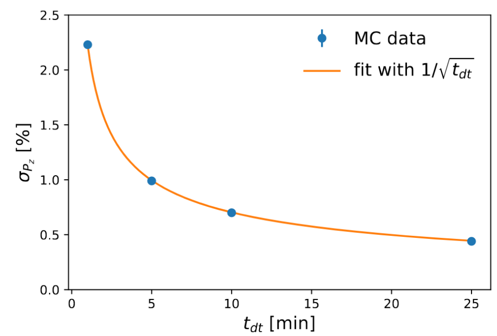


Figure 7. Statistical precision of the Compton polarimeter as a function of the duration of the data taking t_{dt} for a single bunch. For 25 minutes of data taking, a 0.5% statistical precision is obtained. Monte Carlo uncertainties on the points are negligible and smaller than the size of the points. 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.

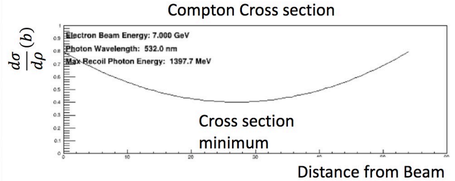
Version 8 at UofM

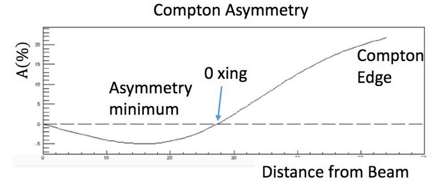
The chip is primarily developed by groups at the U. of Heidelberg and the Karlsruhe Institute of Technology, and intended for various experiments:

- ATLAS
- Mu3e
- PANDA
- P2
- MOLLER

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

Calculations/Simulations





Tau Polarization as Beam Polarimeter

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

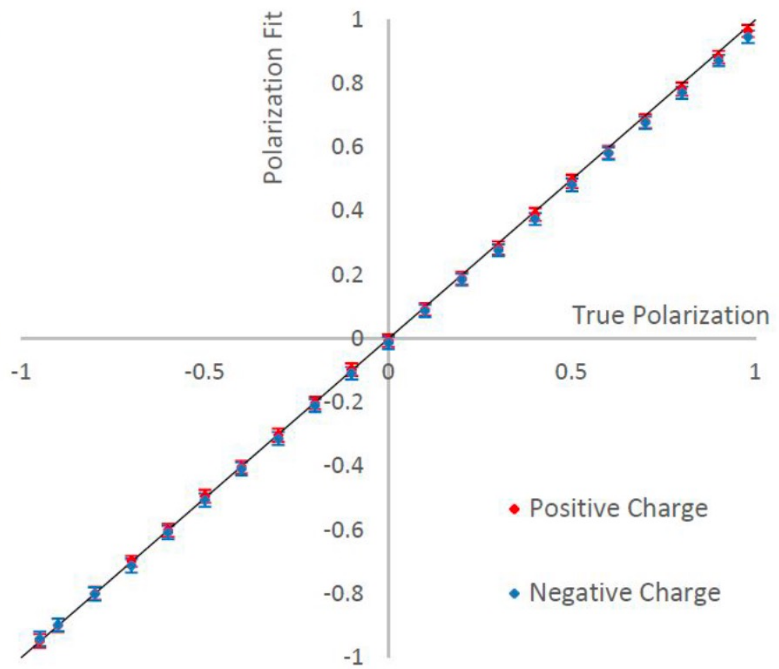
- Dominant term is the polarization forward-backward asymmetry (A^{pol}_{FB}) whose coefficient is the beam polarization
- Measure tau polarization as a function of θ for the separately tagged beam polarization states
- Gives <0.5% absolute precision of the polarization at the interaction point – includes 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

Considering Chiral Belle Project Staging Options

One option:

Stage 1: implement transversely polarized e- beams

- Confirm large transverse polarization is transferred to HER
- Measure spin lifetime with transverse Compton polarimeter and validate calculations of long spin lifetime
- Consider possible physics measurements
  - Energy calibration of HER e- beam with resonant depolarization - perform at Y(1S) where CM is precisely known to also calibrate LER e+ energy; would provide precision CM energies above the Y(4S)

Stage 2: implement spin rotators and longitudinal Compton polarimeters

- Initially with dedicated polarization runs and start Chiral Belle electroweak physics program

Stage 3: Collect High integrated luminosity polarization data set

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