Hiroshima Workshop on Beam Polarization 8–10 Feb 2023

Overview of Chiral Belle

J. Michael Roney

University of Victoria

9 February 2023

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

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Snowmass 2021 White Paper
Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation
arXiv:2205.12847

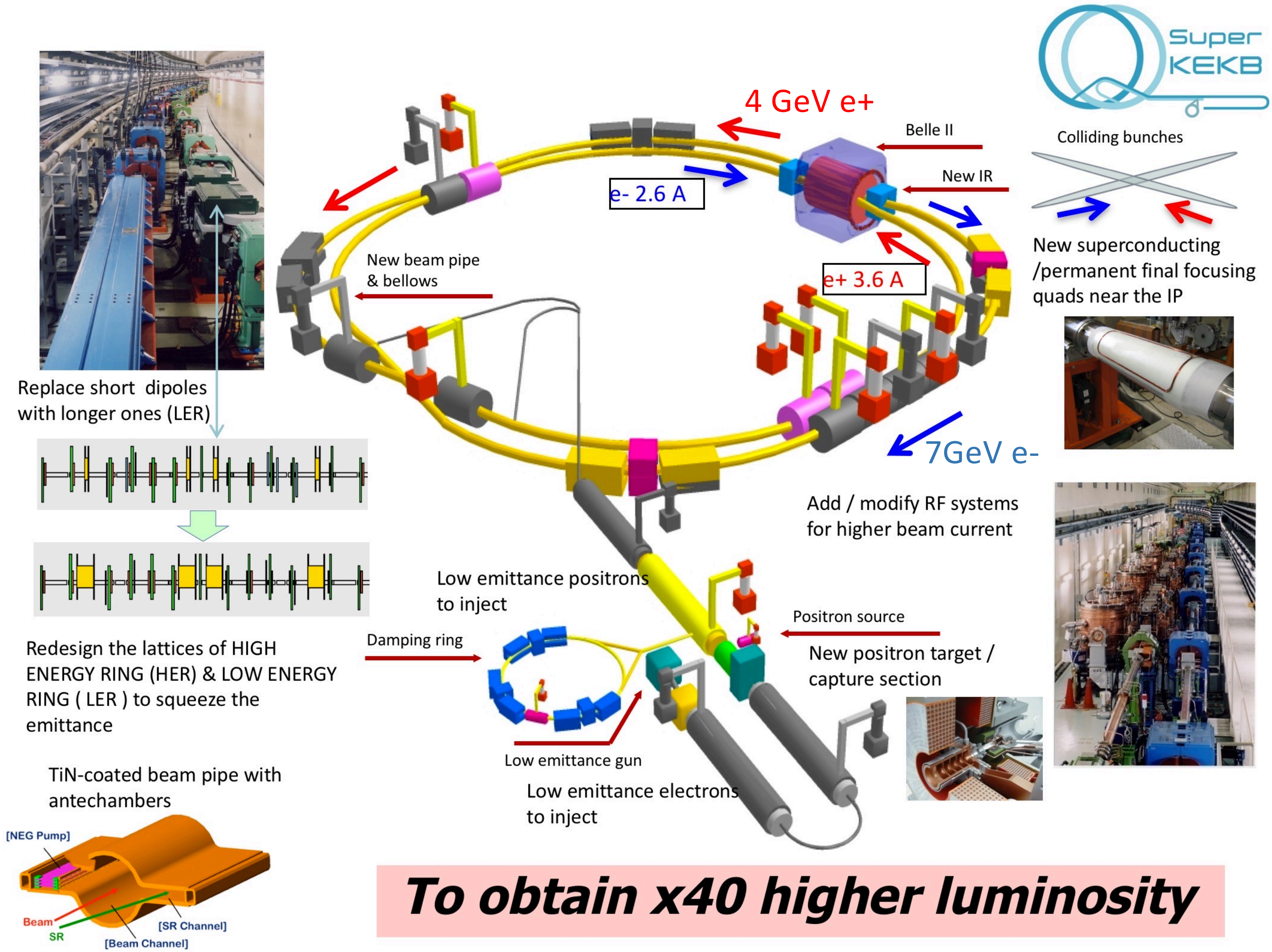
On behalf of the Belle II/SuperKEKB e- Polarization Upgrade Working Group

University of Victoria

Upgrading SuperKEKB with polarized electrons

Opens New Windows for Discovery with Belle II

- Extremely rich and unique high precision electroweak program
- Probe of Dark Sector
- Tau Lepton Magnetic Form factor F_2(10GeV) → τ g-2
- Polarized Beam also provides:
  - Improved precision measurements of τ Michel Parameters, electric dipole moment (EDM)
  - Reduces backgrounds in $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$ precision leading to significantly improved sensitivities
- hadronic studies


Super KEKB
4 GeV e+
Belle II
New IR
Colliding bunches
e- 2.6 A
e+ 3.6 A
New beam pipe
& bellows
New superconducting
/permanent final focusing
quads near the IP
Replace short dipoles
with longer ones (LER)
7GeV e-
Add / modify RF systems
for higher beam current
Low emittance positrons
to inject
Positron source
Damping ring
New positron target /
capture section
Redesign the lattices of HIGH
ENERGY RING (HER) & LOW ENERGY
RING (LER) to squeeze the
emittance
Low emittance gun
Low emittance electrons
to inject
TiN-coated beam pipe with
antechambers
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
To obtain x40 higher luminosity

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

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

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

as well as light quarks

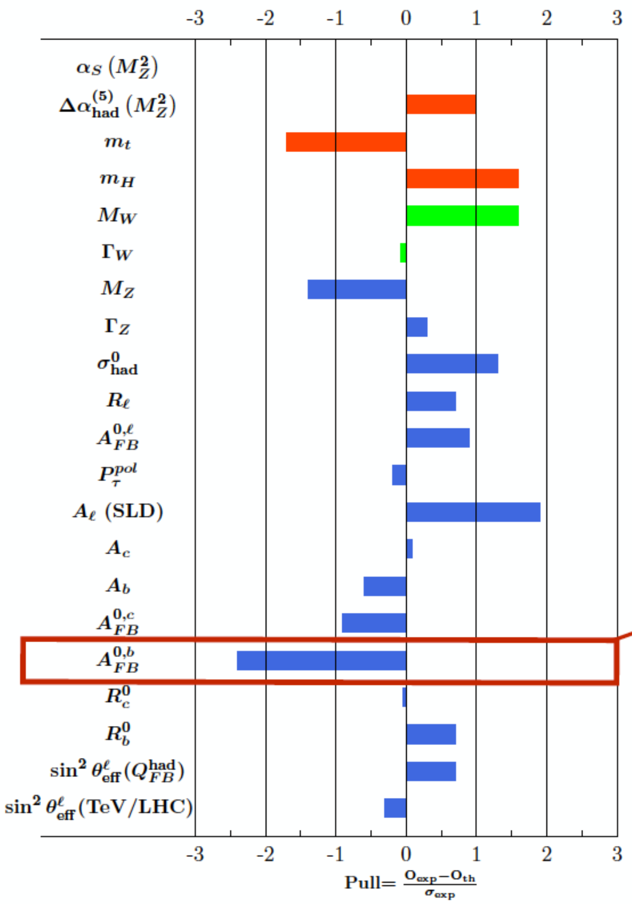
T_3 = -0.5 for charged leptons and D-type quarks
+05 for neutrinos and U-type quarks

From Jorge de Blas's talk this morning on EW Parameter Fits:

The Standard Model Electroweak fit

SM fit results: Predictions for EWPO

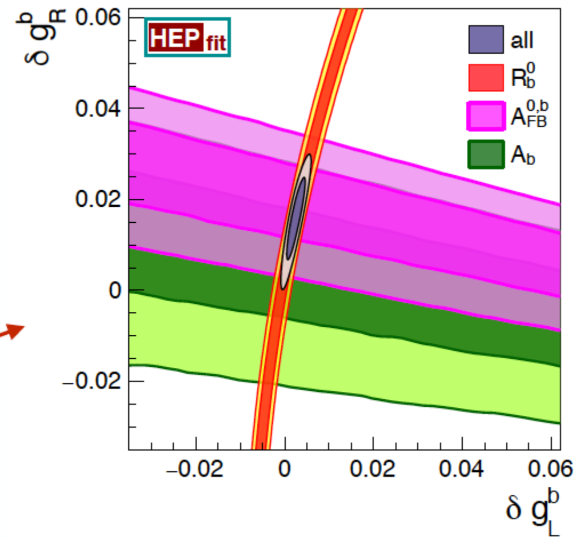
Also good agreement between indirect determination of EWPO and experimental measurements, with one notable exception



~2.5 σ discrepancy in forward-fackward asymmetry of the b quark

Requires modifications of (right-handed) *Zbb* couplings

$$g^b_{L,R} = g^{b\,SM}_{L,R} + \delta g^b_{L,R}$$



	Fit result	Correlations	
δg^b_R	0.017±0.007	1.00	
δg^b_L	0.003±0.001	0.89	1.00

'Chiral Belle' -> Left-Right Asymmetries

- Measure difference between cross-sections with left-handed beam electrons and right-handed beam electrons
- Same technique as SLD A_{LR} measurement at the Z-pole giving single most precise measurement of :

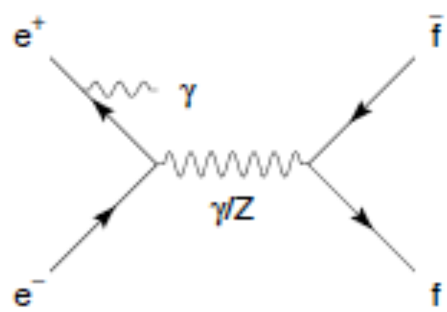
$$\sin^2\theta_{eff}^{lepton} = 0.23098 \pm 0.00026$$

- At 10.58 GeV, polarized e^- beam yields product of the neutral axial-vector coupling of the electron and vector coupling of the final-state fermion via Z-γ interference:

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

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

(for s-channel Born)



‘Chiral Belle’ Left-Right Asymmetries

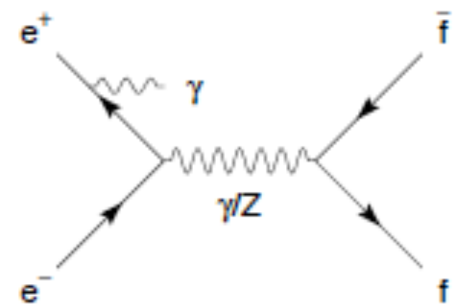
Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.

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

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

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

(for s-channel Born)

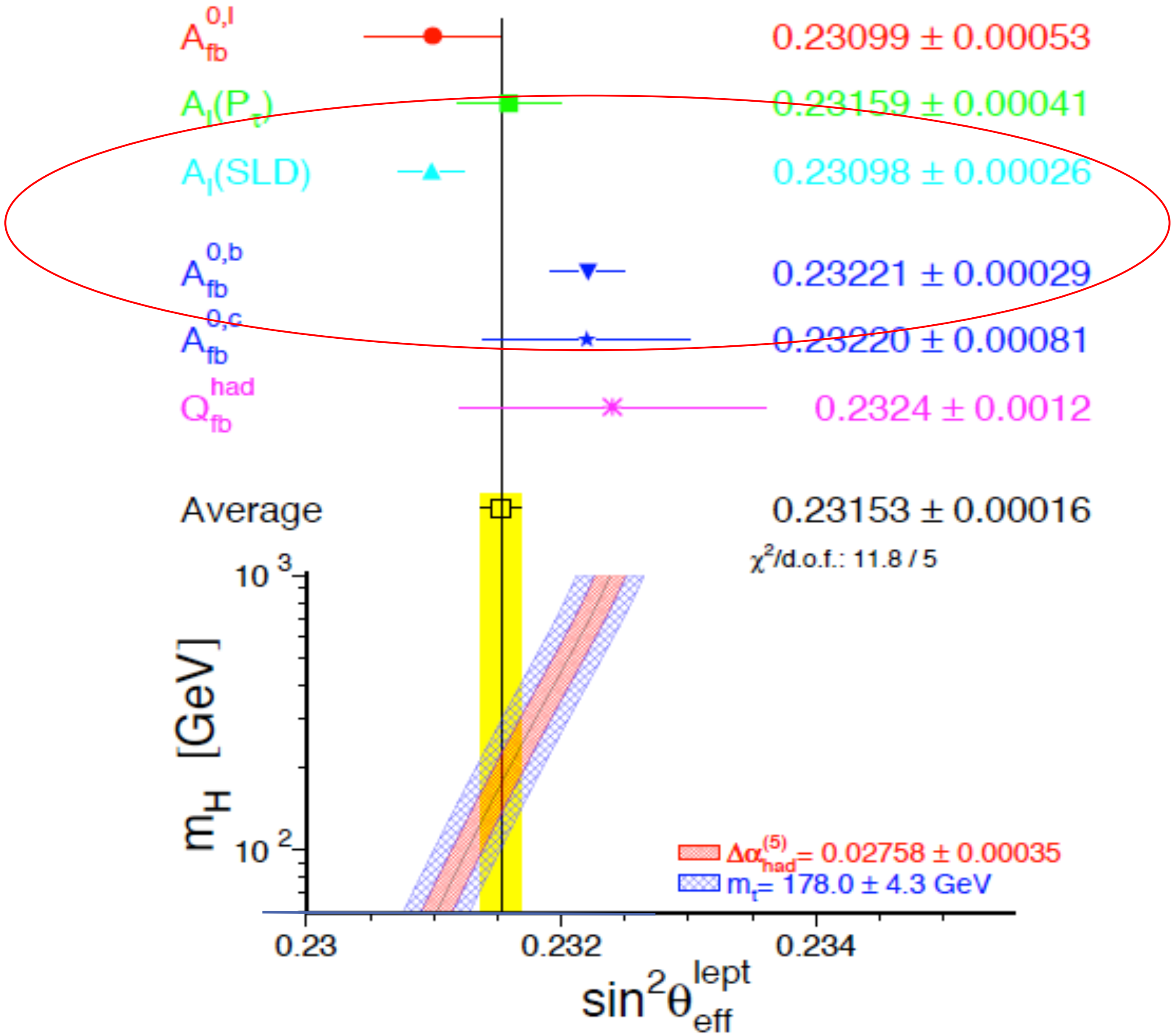


Source generates mainly right-handed electrons

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

Existing tension in data on the Z-Pole:



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

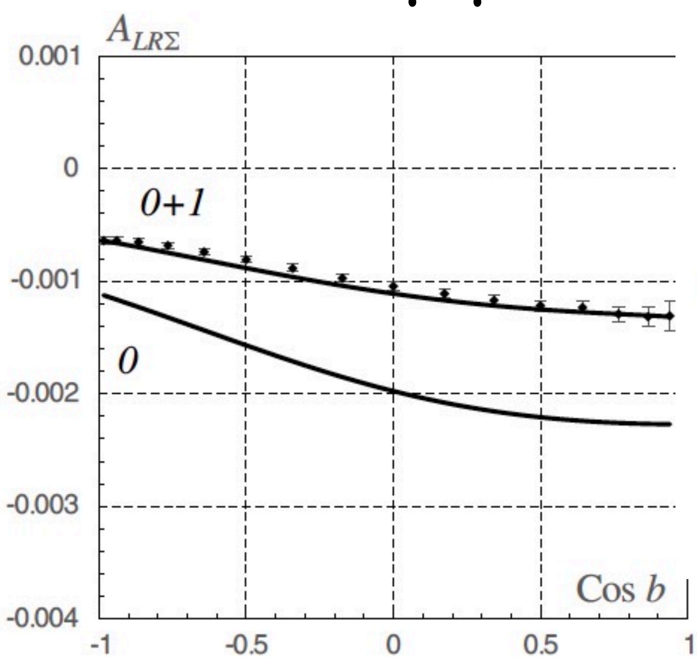
3.2σ comparing only A_{LR} (SLC) and $A^{0,b}_{fb}$(LEP)

International collaboration of Accelerator and Particle Physicists

➤ **Theorists currently working on SM Electroweak calculations:**

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

$e^+e^- \rightarrow \mu^+\mu^-$

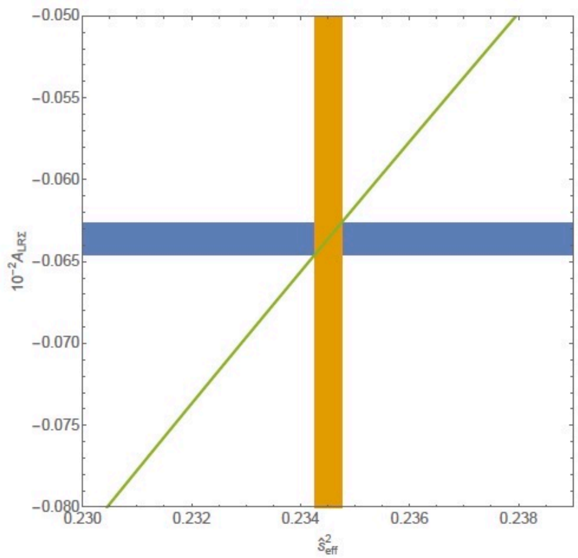


$$\Sigma_L^C = \int_{\cos b}^{\cos a} \sigma_L^C \cdot d(\cos\theta), \quad \Sigma_R^C = \int_{\cos b}^{\cos a} \sigma_R^C \cdot d(\cos\theta)$$

a=10° & energy of photons < 2GeV

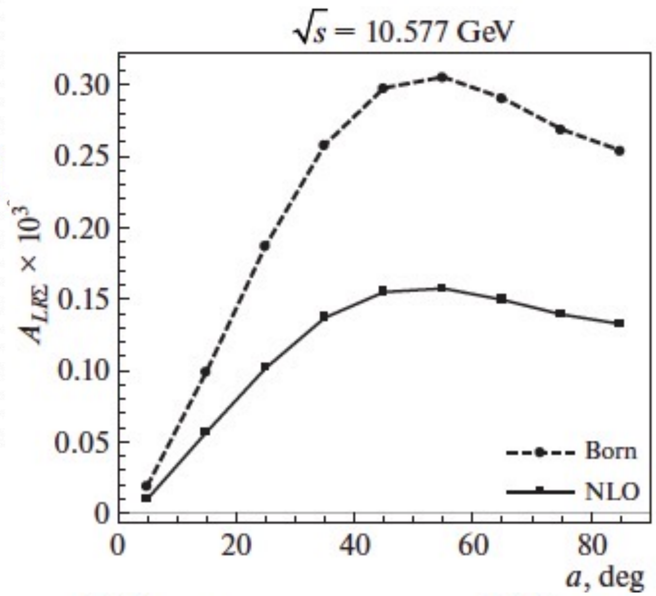
Phys.Rev. D101 (2020) no.5, 053003

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



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

$e^+e^- \rightarrow e^+e^-$



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

PHYSICS OF ATOMIC NUCLEI Vol. 83 No. 3 2020

Recent 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]

Recently released generator with beam polarization capable of producing Bhabhas.

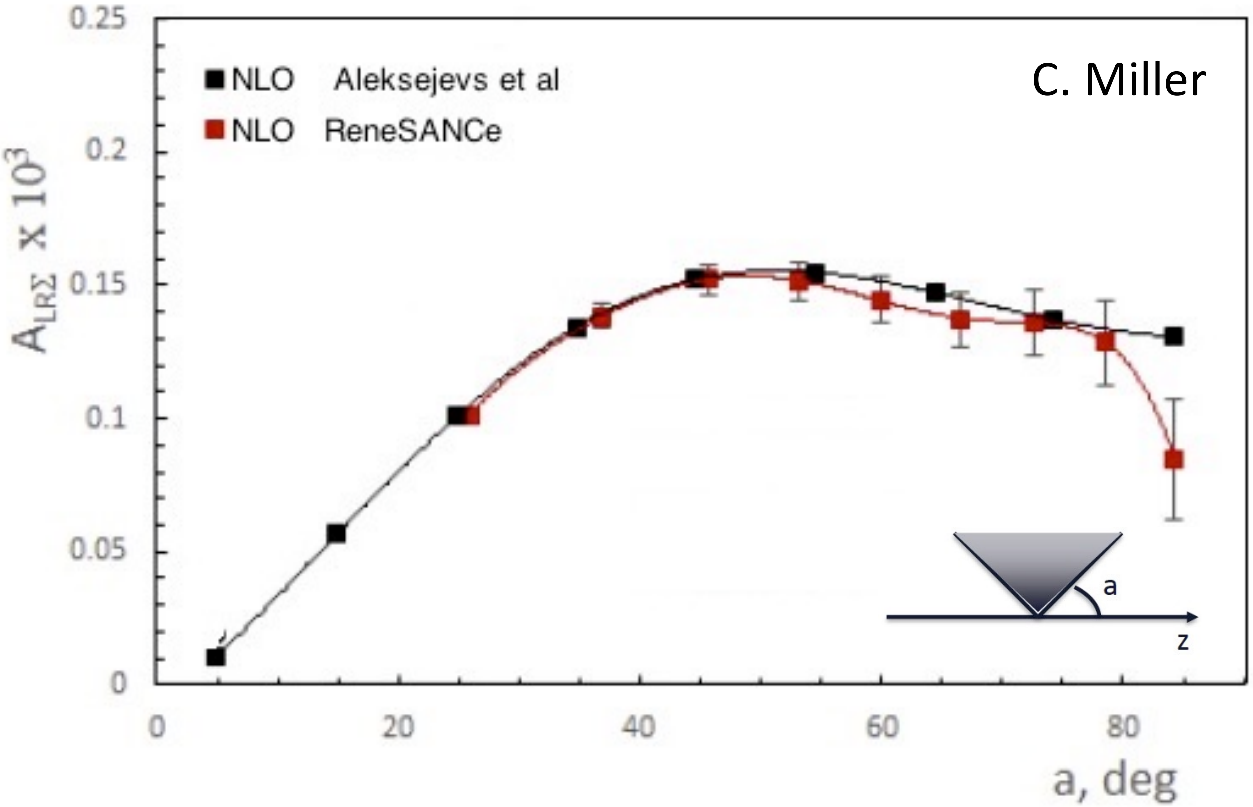
Polarization in each beam and special mode to efficiently calculate A_{LR} without event generation output.

Caleb Miller (Victoria) has worked with authors on use of ReneSANCe for 10.58GeV SuperKEKB polarization application. Now has single beam polarization.

Comparing ReneSANCe with results published in:

A. G. Aleksejevs (Memorial U, Canada), S.G.Barkanova (Memorial U, Canada), Yu.M.Bystritskiy (JINR, Dubna), and V. A. Zykunov (JINR, Dubna& Gomel), "Electroweak Corrections with Allowance for Hard Bremsstrahlung in Polarized Bhabha Scattering", Physics of Atomic Nuclei, 2020, Vol. 83, No. 3, pp. 463–479

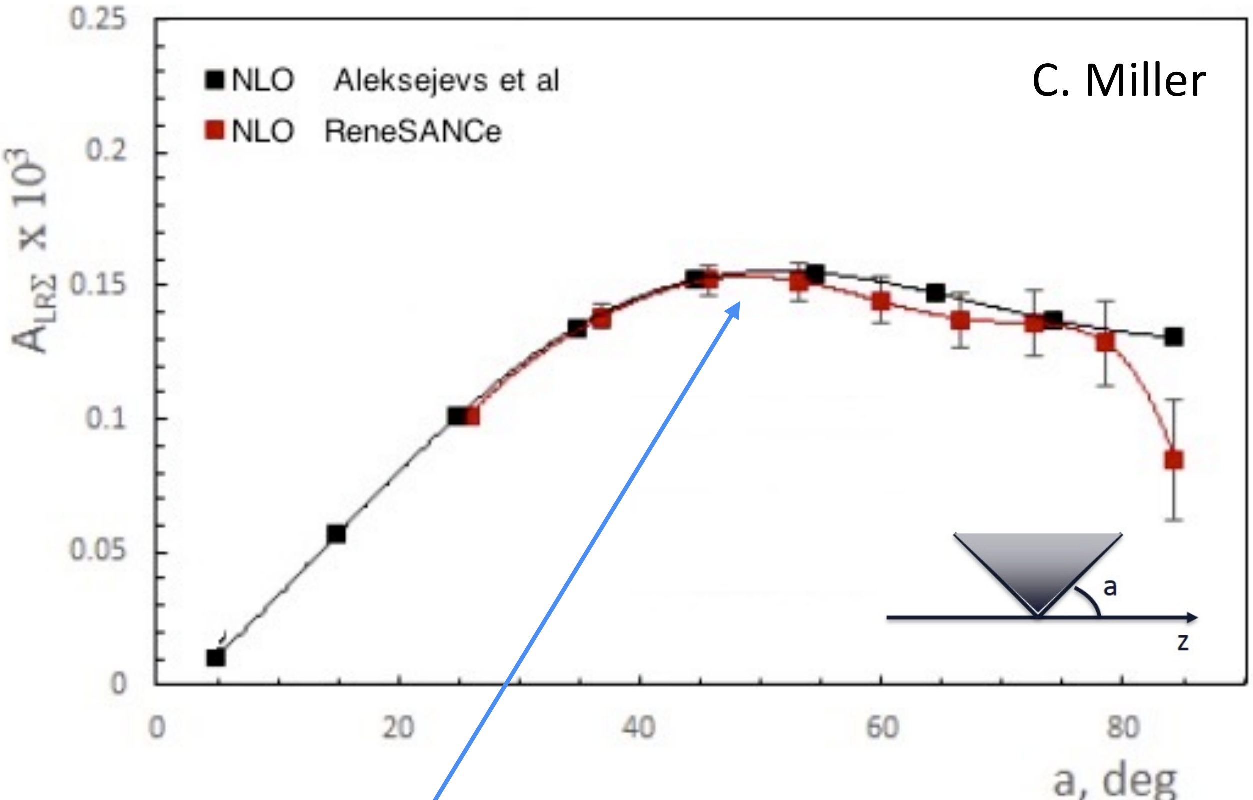
ReneSANCe *cf* Aleksejevs *et al*



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

Using M_W variations with ReneSANCe, can find $\delta \sin^2 \theta_W$ / δA_{LR}

ReneSANCe *cf* Aleksejevs *et al*



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

Using M_W variations with ReneSANCe, can find $\delta \sin^2 \theta_W$ / δA_{LR}

Belle II has published a luminosity paper with Bhabha acceptance in the central part of the 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	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

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 σ 20 ab^{-1}	Chiral Belle σ 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)	0.002 Improve x4	0.002	0.003
c-quark (eff. = 0.3)	+0.1920 ±.0002	+0.1873 ± 0.0070	0.001 Improve x7	0.001	0.0008
Tau (eff. = 0.25)	-0.0371 ±.0003	-0.0366 ± 0.0010	0.001 (similar)	0.0008	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667±0.0023	0.0007 Improve x 3	0.0005	0.0003
Electron (17nb, eff=0.36)	-0.0371 ±.0003	-0.03816 ±0.00047	0.0009	0.0006	0.0003

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

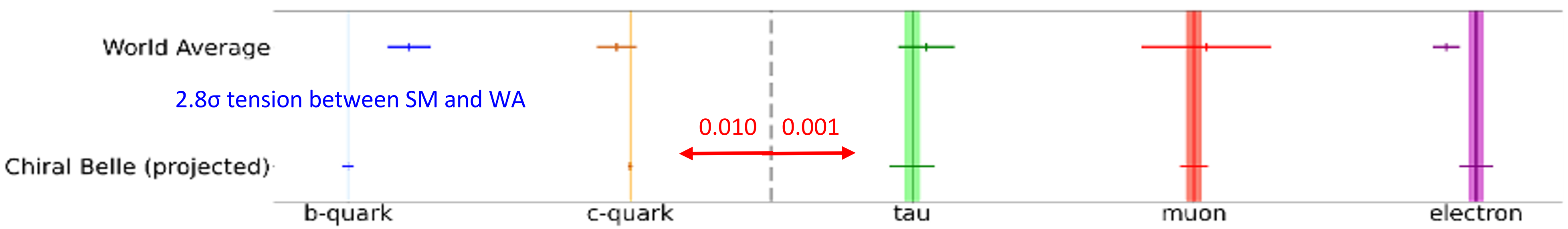
$\sin^2\Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016

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

Precision electroweak measurements

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

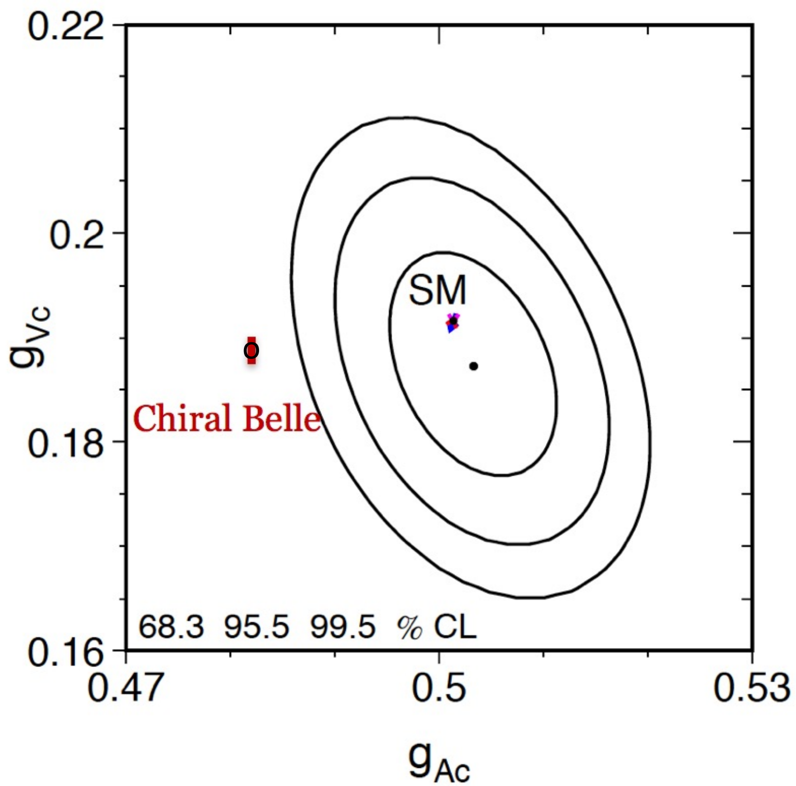
Combined analysis (assuming universality) : $\sigma(g_V^f)$ = $0.00033_{stat} \pm 0.00018_{sys}$ [*cf.* SM error of ±0.0003]



Chiral Belle probes both high and low energy scales

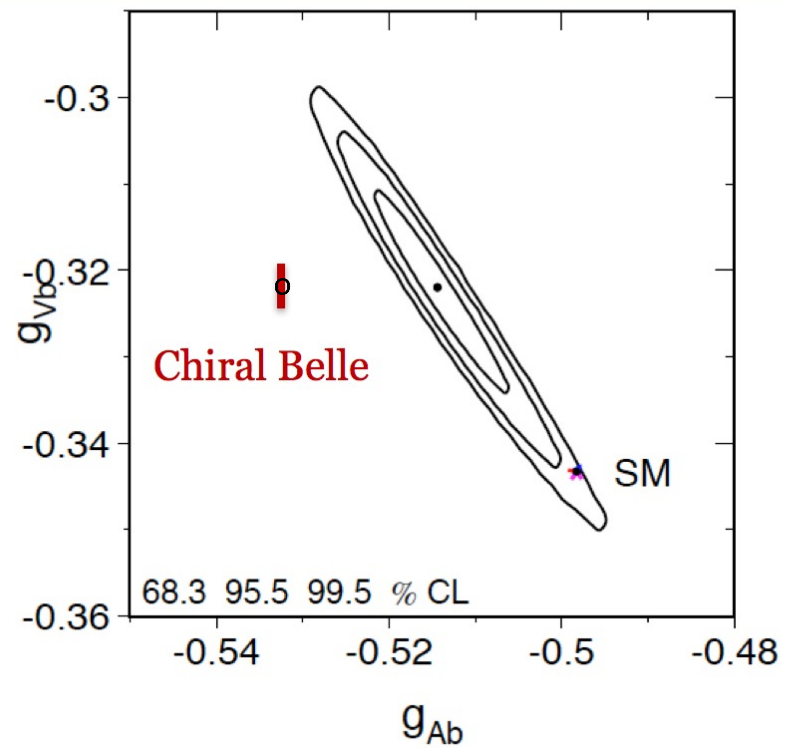
Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

c-quark:
Chiral Belle ~7 times more precise



b-quark:
Chiral Belle ~4 times more precise

with 20 ab^{-1}



Chiral Belle probes both high and low energy scales

Universality of the Couplings to the Z^0

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

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

We'll measure A_{LR} for all three leptons and b-quark and c-quark
Taking the ratio of pairs of these cancels the <Pol> term, which dominates the systematic uncertainty for the quarks.
Produces VERY high precision evaluation of Standard Model predictions of the ratios (e.g. < 0.3% relative error for b-to-c ratio, *cf* 4% now)

Chiral Belle probes both high and low energy scales

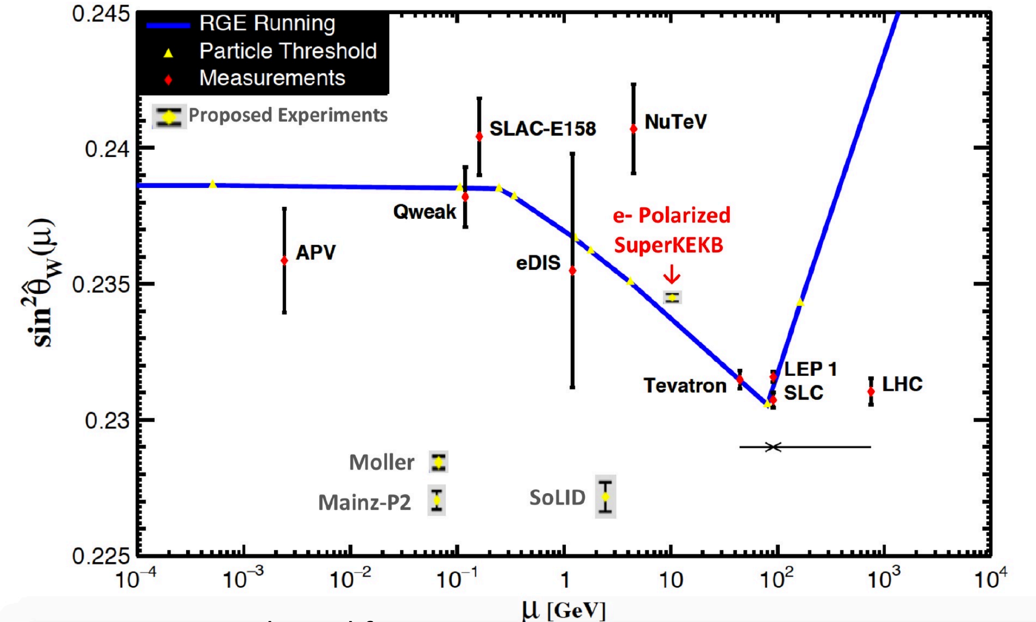


Figure Adapted from
J. Erler and A. Freitas, (PDG) Phys. Rev. D98 , 030001 (2018)

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

- **Precision probe of running of the weak mixing angle**
- **Being away from Z-pole opens NP sensitivities not available at the pole**

- Measurements of $\sin^2\theta_{eff}^{lepton}$ of using lepton pairs of comparable precision to that obtained by LEP/SLD, except at 10.58GeV
  - sensitive to Z' > TeV scale; can probe purely Z' that only couple to leptons: complementary to direct Z' searches at LHC which couple to both quarks and leptons
- highest precision test neutral current vector coupling universality where beam polarization error cancels (< 0.3% relative error for b-to-c, *cf* 4% now)
- Most precise measurements for charm and beauty
  - probes both heavy quark phenomenology and Up vs Down

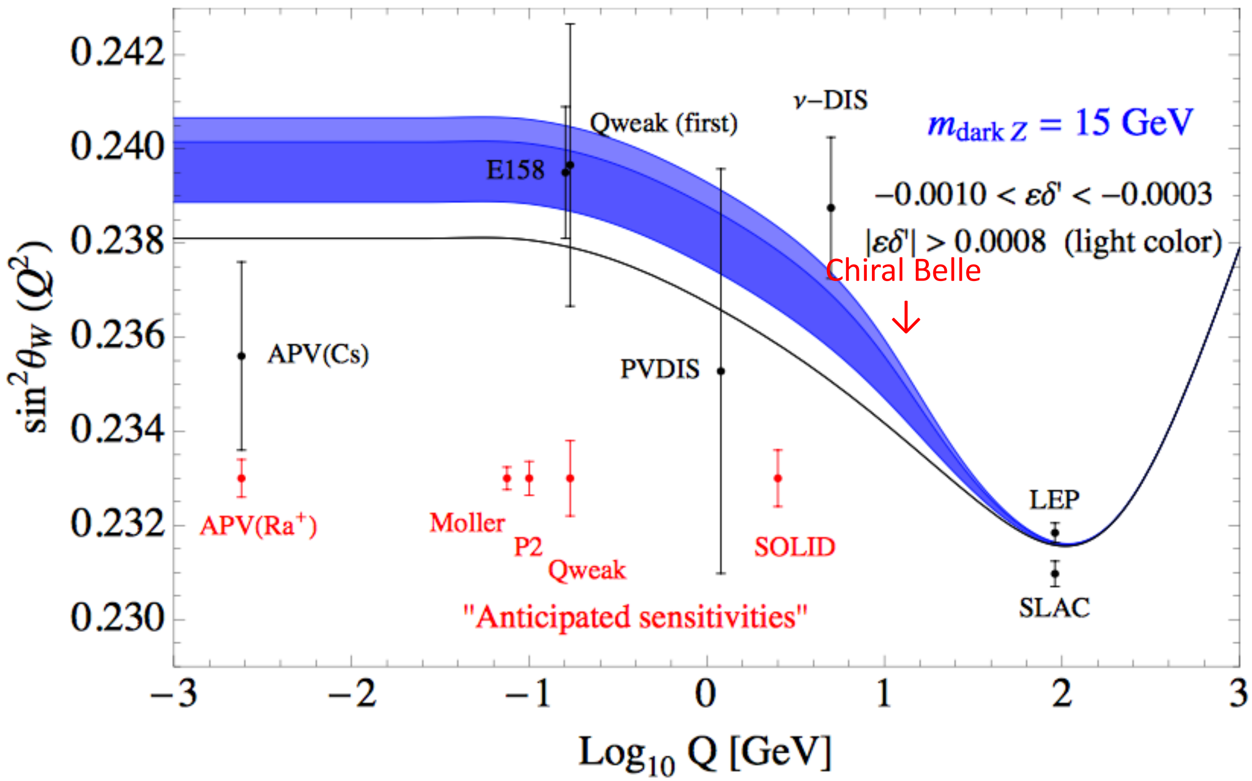
Chiral Belle probes both high and low energy scales

Global interest in this EW physics:

- LHC experiments
- APV measurements at lower energy scales
- Moller Experiment at Jefferson Lab which will measure $\sin^2\theta_{eff}^{electron}$ below 100MeV with similar precision (note: Moller is only sensitive to electron couplings.)
- EIC can measure $\sin^2\theta_{eff}$ in similar kinematic region, but with less precision
- Next generation high energy e+e- colliders: ILC (where polarization is planned) & FCC-ee

Chiral Belle probes both high and low energy scales

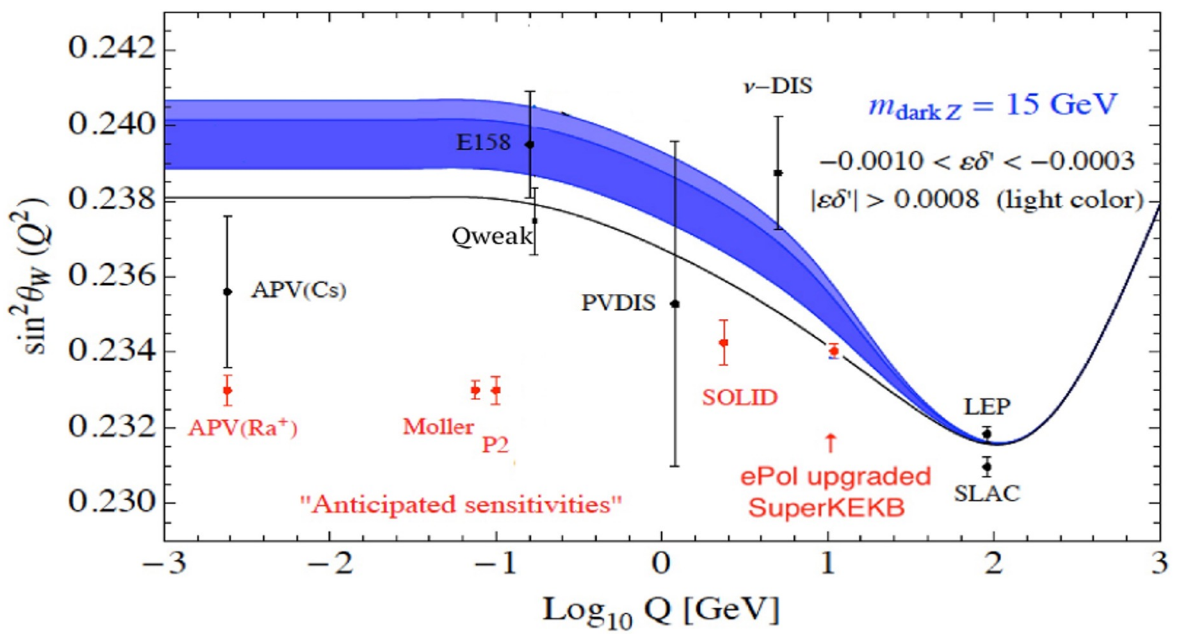
- Unique sensitivity to Dark Sector parity violating light neutral gauge bosons – especially when Z_{dark} is off-shell or couples more to 3rd generation
  - Because couplings are small, this sector would have been hidden
  - See e.g. H. Davoudiasl, H. S. Lee and W. J. Marciano, Phys.Rev. D 92, no. 5, 055005 (2015)

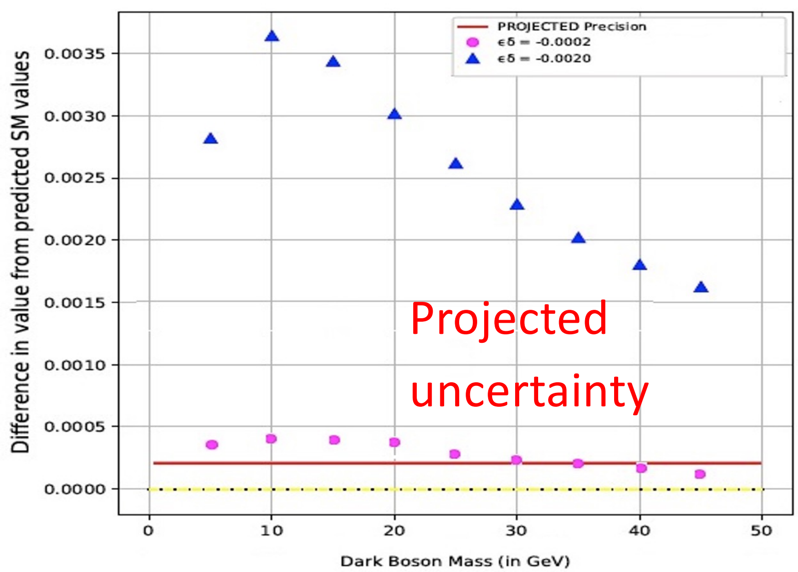


Running of $\sin^2 \theta_W(Q^2)$ window to the Dark Sector

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

Differences between SM and 2 benchmark scenarios of dark Z





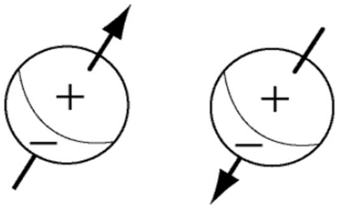
- Adapted from Fig. 3 of H. Davoudiasl, H.S. Lee and W.J. Marciano, Phys.Rev.D 92(5),2015.
- Red bars shows expected ±1 sigma uncertainty = 0.0002 with 40 ab^{-1} at Chiral Belle [placed at arbitrary positions].
- Also sensitive to parity violation induced by exchange of heavy particles e.g. a hypothetical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

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

Electric and magnetic moments of τ lepton

Charge asymmetry along spin direction: EDM ≠ 0 ⇒ CP violation
SM expectation $\mathcal{O}(10^{-37})$ e.cm far below experimental sensitivity
New physics in loops can enhance EDM of τ lepton ~ $\mathcal{O}(10^{-19})$ e.cm

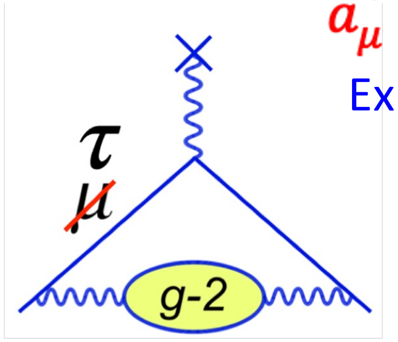


W. Bernreuther et. al. Phys. Lett. B 391, 413 (1997); T. Huang et. al. Phys. Rev. D 55, 1643 (1997).

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

Large deviation in anomalous magnetic moment of muon:

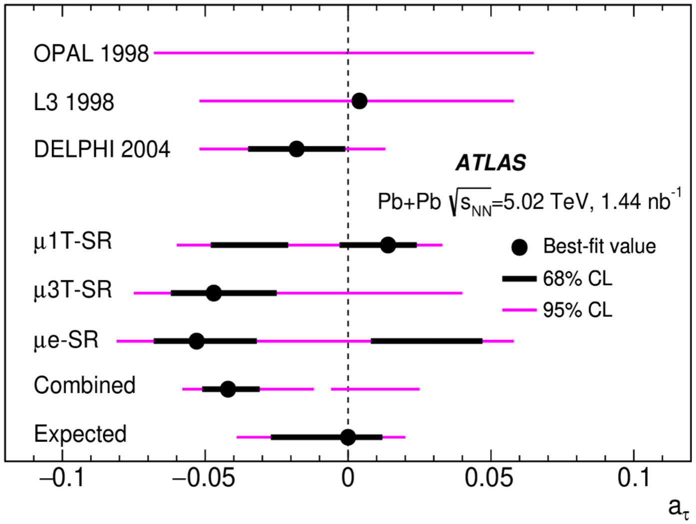
$$a_\mu^{\rm exp} - a_\mu^{\rm SM} = (251 \pm 59)\times 10^{-11}[4.2\sigma]$$



Expectation from Minimal flavor violation:

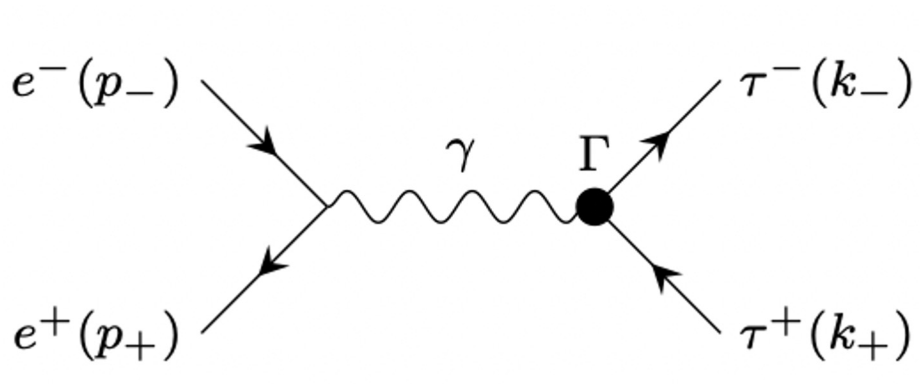
$$a_\tau^{\rm BSM} \sim a_\mu^{\rm BSM}\left(\frac{m_\tau}{m_\mu}\right)^2 \sim 10^{-6}$$

Current bound in tau ~ $\mathcal{O}(10^{-2})$
Chiral Belle reach ~ $\mathcal{O}(10^{-5})$ with 50ab^{-1}



e-Print: 2204.13478 [hep-ex]
ATLAS Collaboration

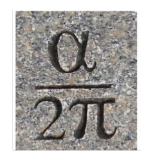
Effective field theory approach to τ-pair production



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

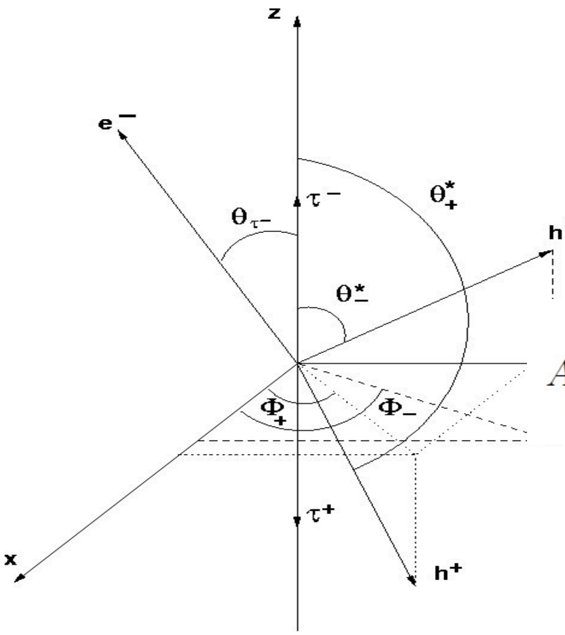
- $F_1\left(q^2\right)$, $F_2\left(q^2\right)$ are called the Dirac and Pauli; $F_1(0) = 1$; $F_2(0) = a_\tau$
- $g = 2\cdot[F_1(0) + F_2(0)] = 2 + 2F_2(0)$ $\quad d_\tau^\gamma = \frac{e}{2m_\tau}\cdot F_3(0)$

Leading term



$\approx 0.001\,161\,4$

Magnetic dipole moments 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
F_1 cancellation

Magnetic dipole moments of τ lepton

Andreas Crivellin, Martin Hoferichter, J. Michael Roney arXiv:2111.10378 **[hep-ph]**

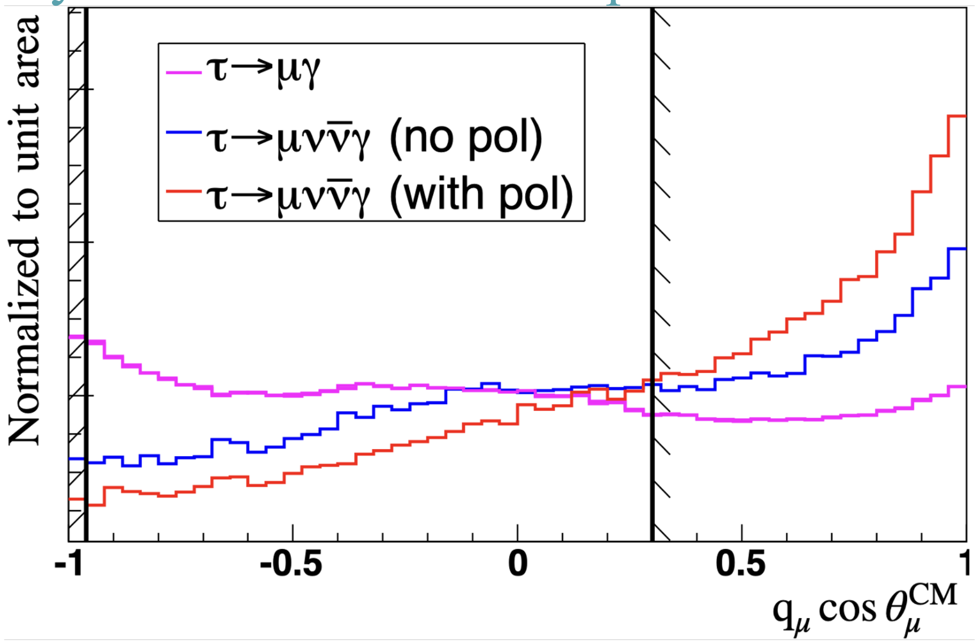
Contributions to $F_2(s)$ in units of 10^{-6}.

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

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

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 $\tau \to \ell\gamma$ sensitivity

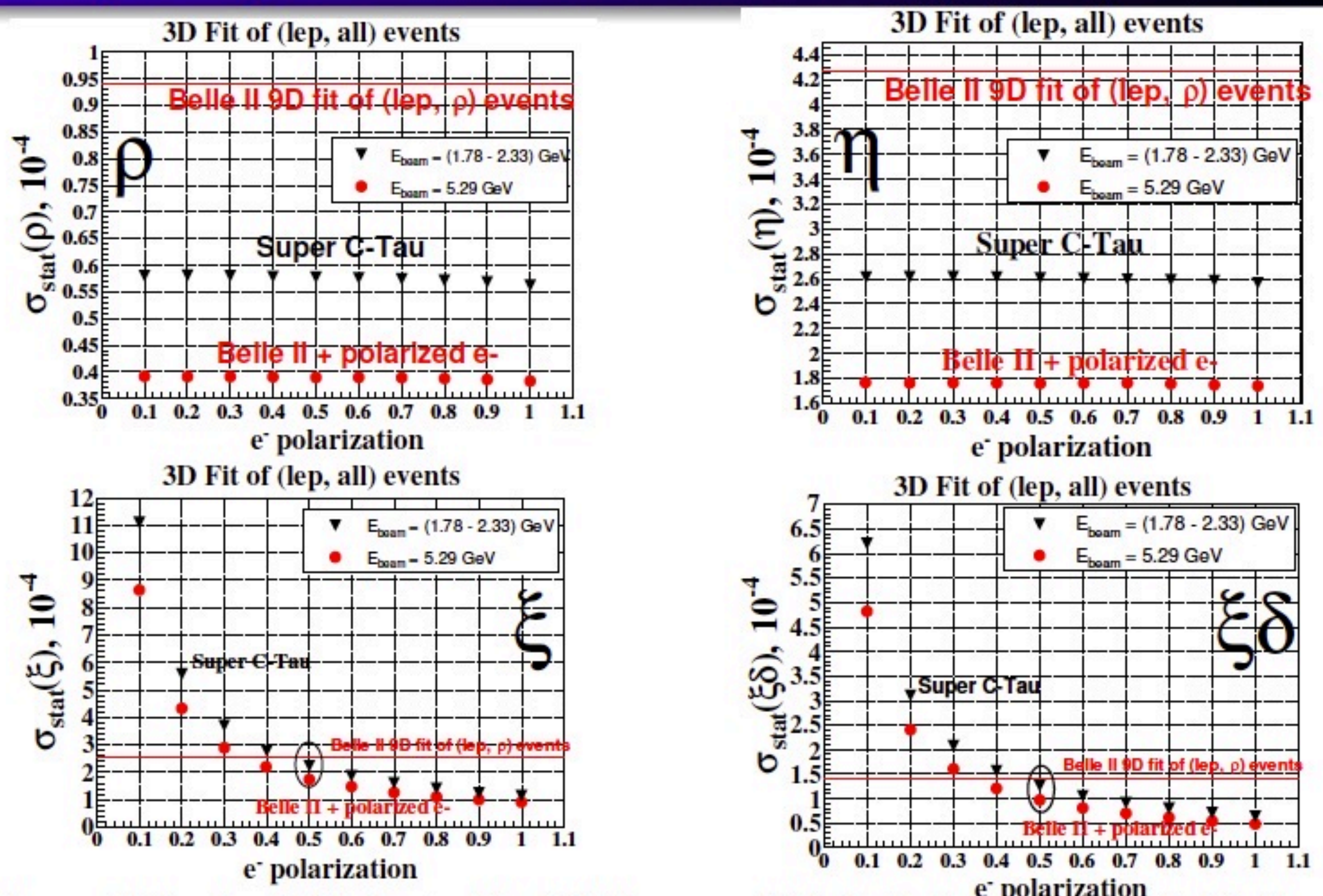


- Possible to disentangle helicity structure of LFV in $\tau \to \ell\ell\ell$ from Dalitz plots

τ Michel Parameter with polarized e- beam

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

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



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

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

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

Polarization in SuperKEKB

- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject vertically polarized electrons into the High Energy Ring (HER) - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before Interaction Point, and then back to vertical after IP using solenoidal and dipole fields
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry
- Use tau decays to get absolute average polarization at Interaction Point

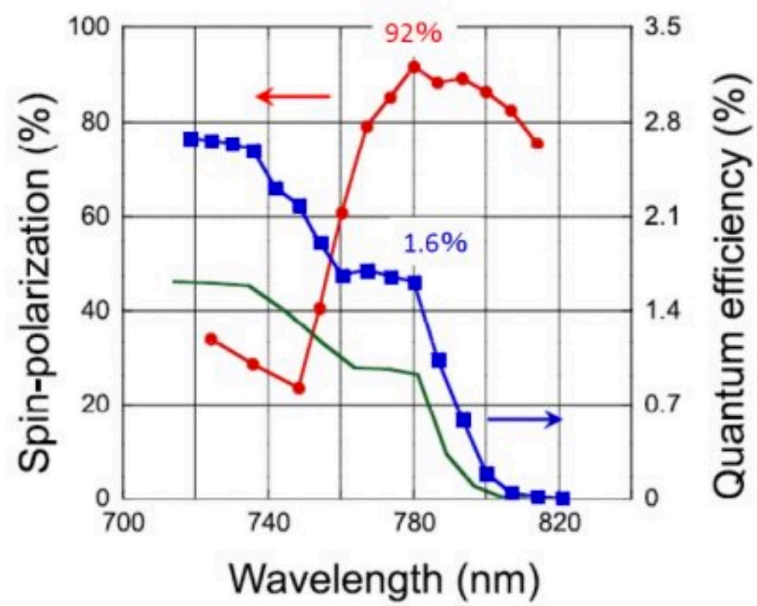
Polarization in SuperKEKB

- These electroweak measurements require highest luminosity possible
- Polarized source not expected to reduce luminosity
- Spin rotators might affect luminosity if not carefully designed to minimize couplings between vertical and horizontal planes
  - Higher order and chromatic effects have to be considered in the design to ensure luminosity is not degraded

Polarization in SuperKEKB

Hardware needs

1. **Low emittance polarized Source**
2. Spin rotators
3. Compton polarimeter



Z. Liptak and M. Kuriki (Hiroshima)

Design source photo-cathode

With 4 nC/bunch

20 mm-mrad vertical emittance

50 mm-mrad horizontal emittance

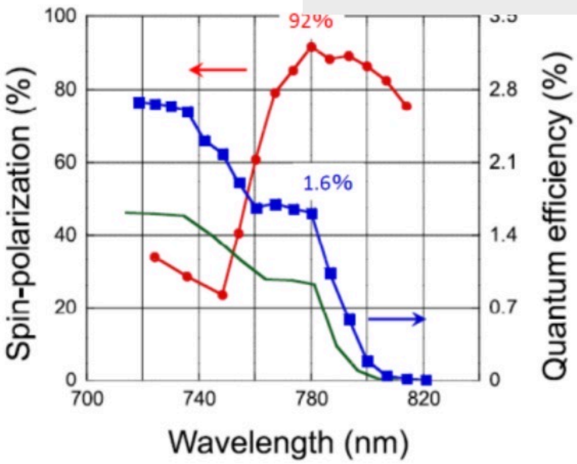
Current focus is on developing GaAs cathode with a thin Negative Electron Affinity (NEA) surface.

KEK and Hiroshima Groups - work on ILC sources leveraged

Polarization in SuperKEKB

Polarized Source Development

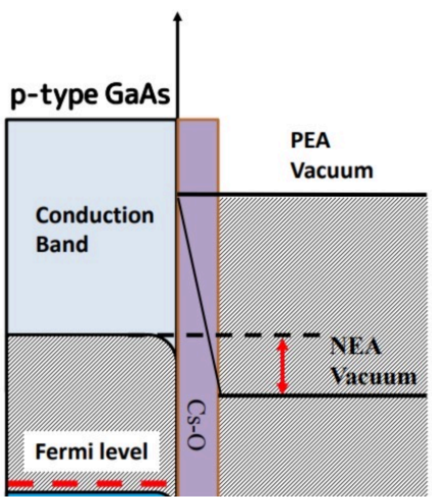
From Zachary J. Liptak (Hiroshima U.)

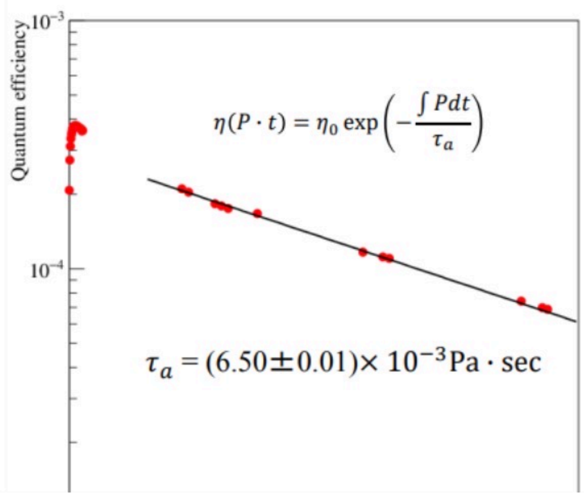


GaAs cathodes can produce beams with >90% polarization and ~1.6% QE, but due to a wide band gap accelerating electrons is difficult

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.





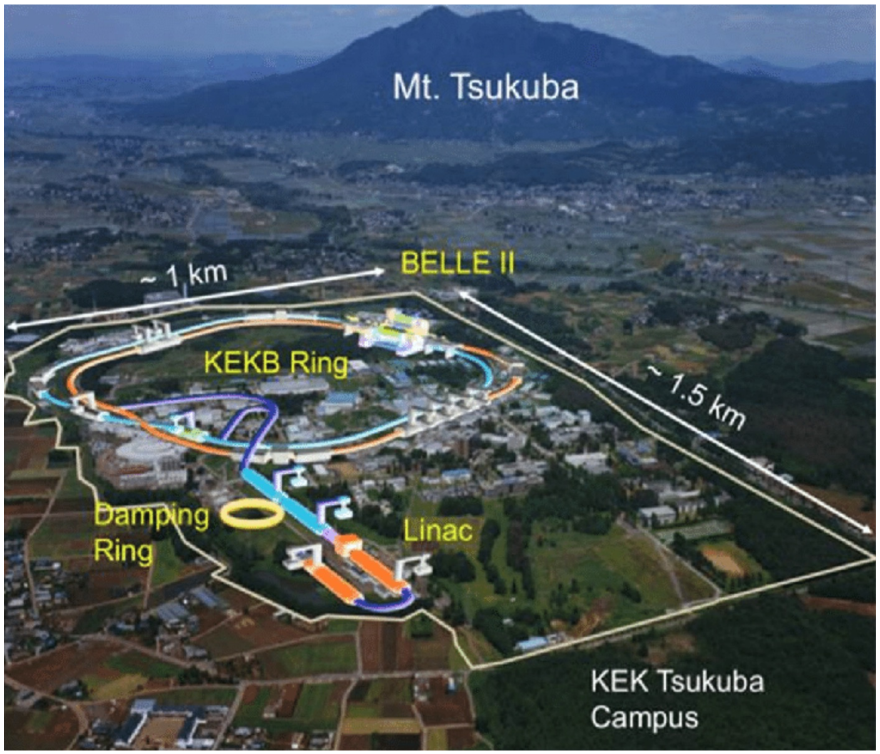
Cathodes	Lifetime τ_a [10^{-3}Pa · sec]
CsKTe/GaAs	6.50±0.01
Cs-O/GaAs	0.29±0.03 [1]
Cs-O/GaAs	0.40±0.02 [2]

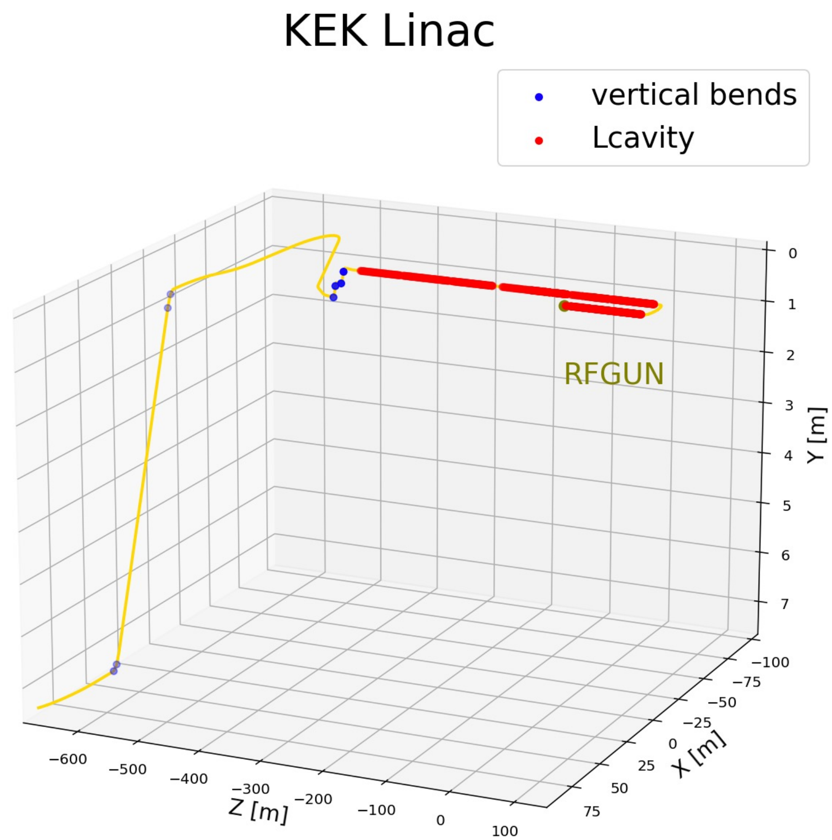
[1]K. Miyoshi, M. Thesis, Hiroshima U. (2013)
[2]G. Lei, M. Thesis, Hiroshima U. (2014)

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

KEK Injection Linac polarization BMAD studies

Y. Peng's (UVictoria)

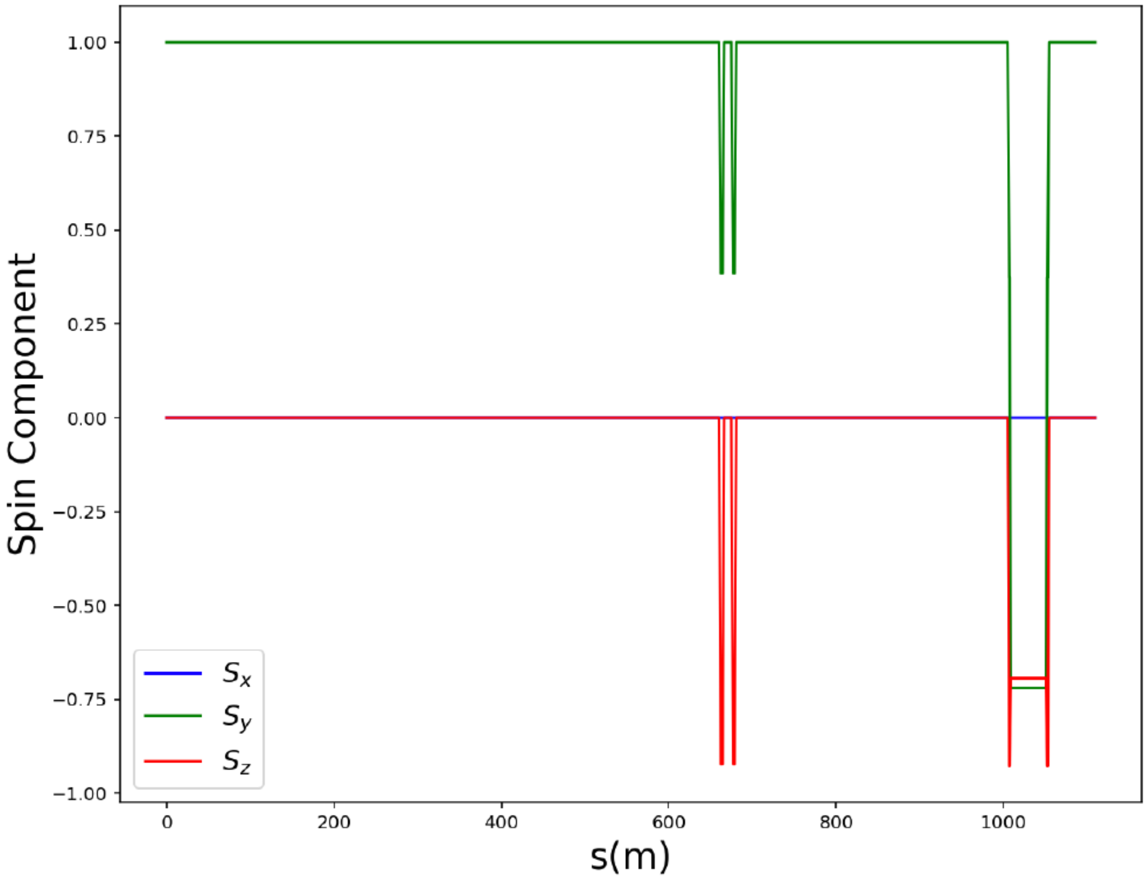




Need transversely polarized beam at the injection point of the e- storage ring (High Energy Ring -HER)

Spin motion in the KEK Injection Linac

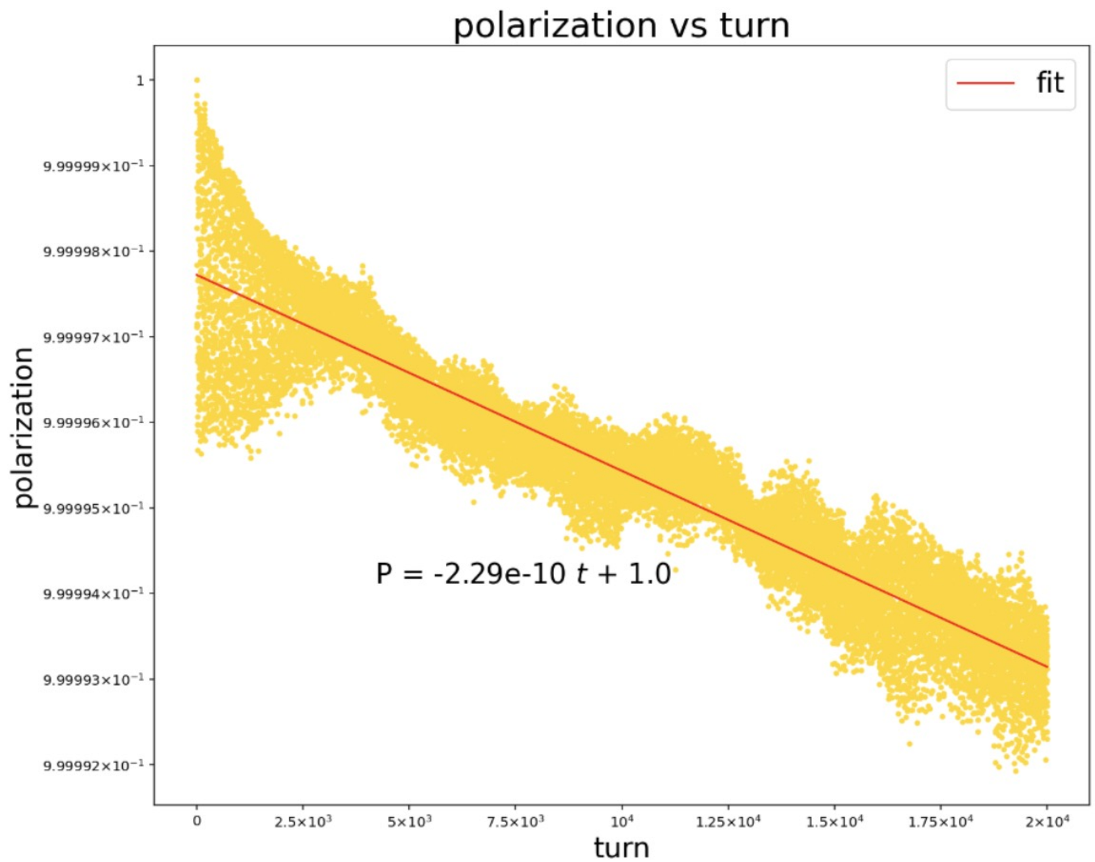
Y. Peng's (UVictoria)



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

Transverse polarization survival rate in HER

Y. Peng's (UVictoria)



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

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)

Polarization in SuperKEKB

Hardware needs

1. Low emittance Source
2. **Spin rotators**
3. Compton polarimeter

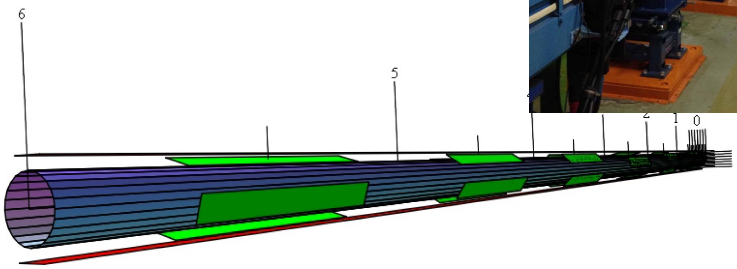
Use of solenoids and dipoles, plus the skew-quadrupoles (needed for decoupling) on either side of interaction point

BINP, ANL, BNL, TRIUMF-Victoria Groups

Polarization in SuperKEKB

Hardware needs

1. Low emittance Source
2. **Spin rotators**
3. Compton polarimeter



Preliminary studies of two concepts being considered:

1) BINP Concepts: Install Spin-rotator magnets in drift regions, requires repositioning of some magnets in ring
2) Compact Spin Rotator Concept: Combined-function magnets, which would replace two existing dipole magnets on either side of interaction point.

BINP, ANL, BNL, TRIUMF-Victoria Groups

Preliminary studies by BINP group

BINP Concepts: install spin-rotator magnets in drift regions

Introduce modest conversion of the geometry of electron beam bends in the experimental section of the HER storage ring to provide drift gaps with a length of about 10m for installing spin rotators. Requires repositioning of some magnets in ring.
Two concepts explored:

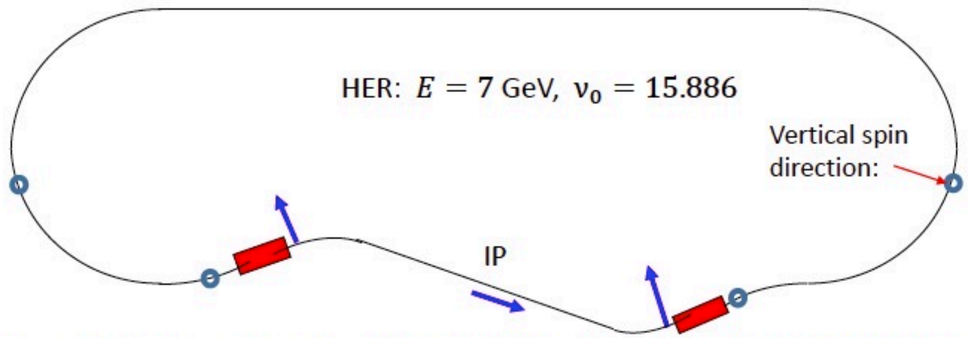
i) first approach uses a conventional spin rotator with separate solenoid and quadrupole magnets;

ii) second approach makes use of combined function solenoid-quadrupole magnets
This is favoured as it involves lower solenoid fields

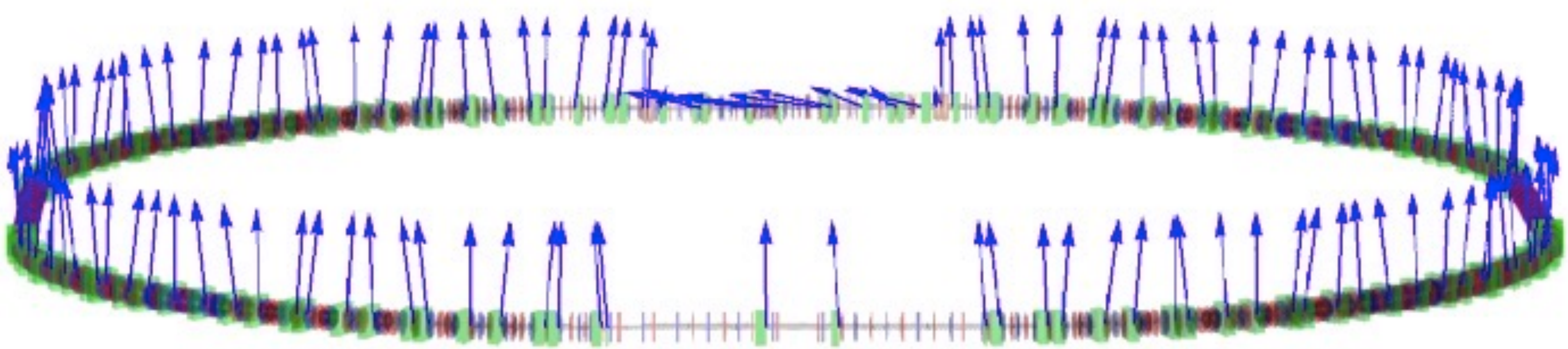
From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

BINP Spin Rotator Concept

A scheme with restoration of the vertical spin direction in main arcs



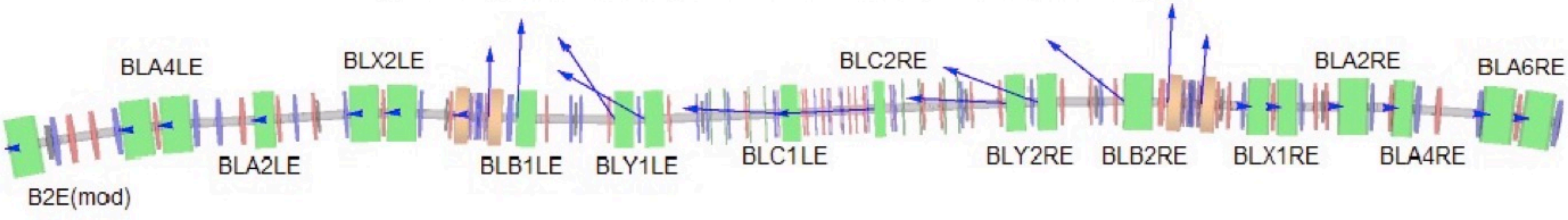
Spin direction is vertical in the main part of HER. Then it is rotated to the horizontal plane by the set of two solenoids, which are comprising the 90^0 spin rotator.



This antisymmetric layout (the S curve through the IP) preserves "strong spin-matching", i.e. minimizes the change of spin-phase advance with beam energy through the total rotator section (because the two rotators cancel each other)

From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

Preliminary studies by BINP group



"B2E(mod)"	"BLA2LE"	"BLA2RE"	"BLA4LE"	"BLA4RE"	"BLA6RE"	"BLB1LE"
0.0745895	−0.0181419	0.0591537	0.0520765	0.0280687	0.0501498	−0.0368136

"BLB2RE"	"BLC1LE"	"BLC2RE"	"BLX1RE"	"BLX2LE"	"BLY1LE"	"BLY2RE"
0.0548871	−0.00591049	0.0059199	−0.0310501	0.0570931	−0.0270415	0.018

In arcs spin is directed purely vertically, while at IP longitudinally.

From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

Preliminary studies by BINP group

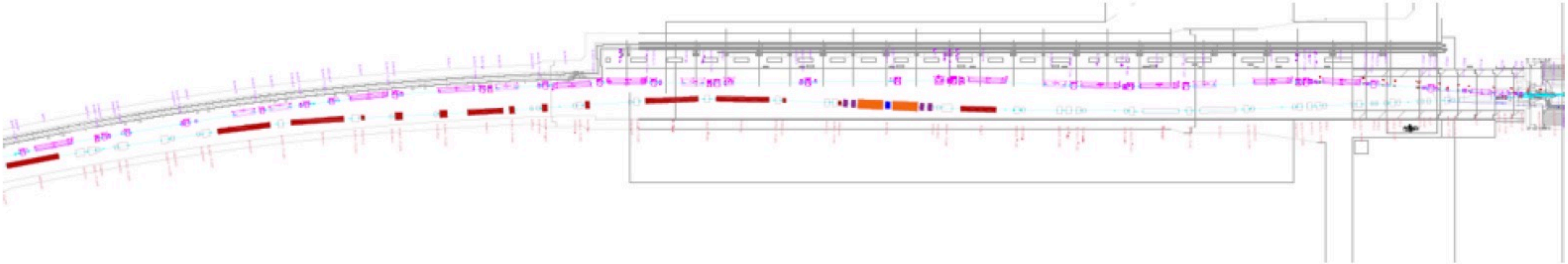


Figure 18: To the left from the IP half of experimental straight section. The modified magnetic elements of the HER ring are painted in dark brown, and the solenoids of the spin rotator are painted in dark yellow. The distance between the rings is great

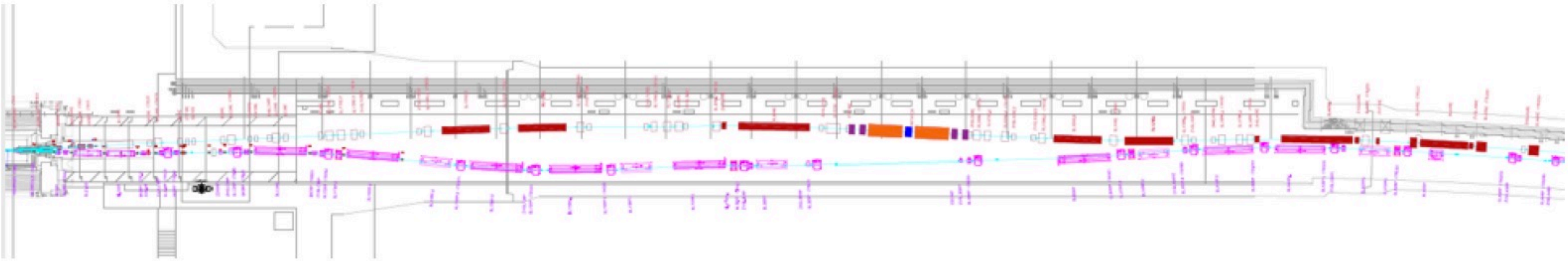


Figure 19: To the right from the IP half of straight section. At the entrance to the tunnel, the magnets of the rings are very close, but such technical problems can be solved.

Preliminary studies by BINP group

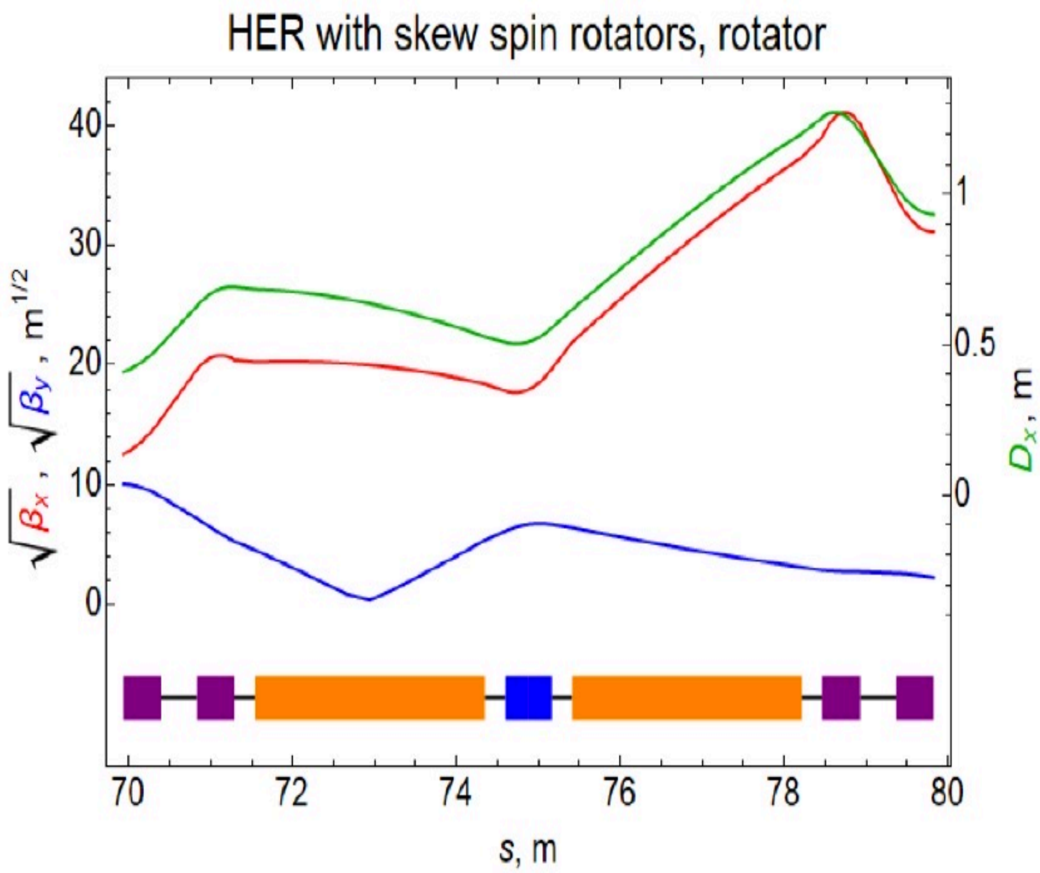


Figure 21: Optical functions of the spin rotator for the left half of the long interaction region.

e.g. Lattice functions for left-side spin rotator. Solenoids orange, central quad is normal, while doublets are rolled anti-symmetrically by $\varphi = \pm 22.474^0$.

From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

Preliminary studies by BINP group: option (i)

Element	Length, m	Field or Gradient: T, T/m
Quadrupole #1, #5	0.46227	-29.4792 ($\phi1 = -\phi5 = -22.474^o$)
Drift 1	0.436	
Quadrupole #2, #4	0.46227	28.5569 ($\phi2 = -\phi4 = -22.474^o$)
Drift 2	0.25	
Solenoid	2.8	6.54197
Drift 3	0.25	
Quadrupole #3	0.57004	-25.3736 ($\phi3 = 0$))

Table 12: Basic parameters of lenses and solenoids for BR = 23.3495 T·m (E = 7.15 GeV).

		Original parameters of dipoles		New parameters	
Name	Quantity	Length, m	Angle, rad	Length, m	Angle, rad
B2E.4	1	5.90220	0.0557427	5.90220	0.0745895
BLA4LE	2	5.90220	0.0663658	5.90220	0.0520765
BLA2LE	1	5.90220	0.0206421	**3.96143**	-0.0181419
BLX2LE	2	3.96143	0.0259281	**5.90220**	0.0570931
BLB1LE	1	3.96143	-0.0229996	3.96143	-0.0368136

Table 10: Lengths and rotation angles of the dipoles to the left of the intersection of the beams.

		Original parameters of dipoles		New parameters	
Name	Quantity	Length, m	Angle, rad	Length, m	Angle, rad
BLA6RE	2	5.90220	0.0501497	5.90220	0.0501498
BLA4RE	1	5.90220	0.0480687	**3.96143**	0.0280687
BLA2RE	1	3.96143	0.0348280	**5.90220**	0.0591537
BLX1RE	2	3.96143	-0.0221788	3.96143	-0.0310501
BLB2RE	1	3.96143	0.0234696	**5.90220**	0.0548871
BLY2RE	2	3.96143	0.0270000	3.96143	0.0180000

Table 11: Lengths and rotation angles of the dipoles to the right of the intersection of the beams.

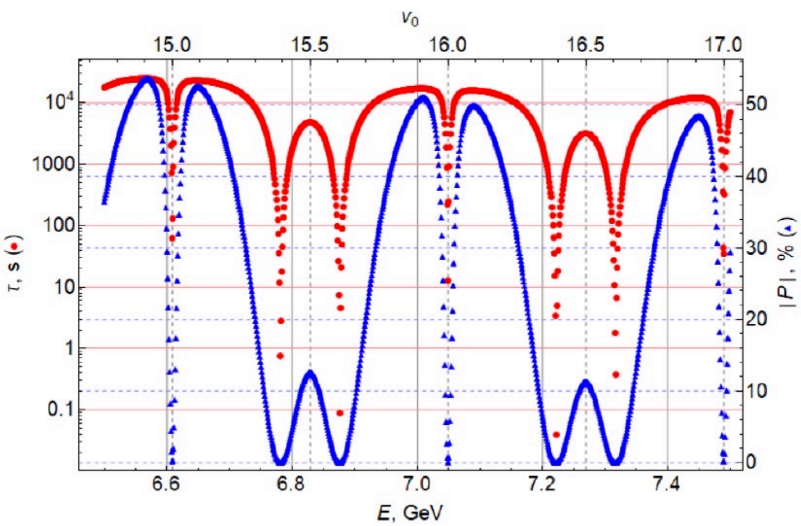


Figure 23: Dependence of the radiation spin relaxation time on energy with the rotator version from Table 12 with rotated extreme doublets of the lenses, see Fig. 21.

Depolarization lifetime at E=7.15GeV is ~10000s (~3 hrs)

Note: beam is topped-up @ 50Hz continuously (current beam lifetime without top-up <1hr)

From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

Preliminary studies by BINP group: option (ii)

Element	Length, m	Field or Gradient: T, T/m
Drift #1, #17	0.34556	$B_s = G = 0$
Pure Solenoid #2, #16	0.15	$B_s = 4.067373$
Quadrupole plus Solenoid: #3, #15	0.7	-20.067768 ($\phi3 = -\phi15 = -19.822^o$)
Solenoid #4, #14	0.4	$B_s = 4.067373$
Quadrupole plus Solenoid: #5, #13	0.7	23.232294 ($\phi5 = -\phi13 = -14.5297^o$)
Solenoid #6, #12	0.8	$B_s = 4.067373$
Quadrupole plus Solenoid: #7, #11	0.7	-5.385630 ($\phi7 = -\phi11 = -7.3598^o$)
Solenoid #8, #10	0.8	
Quadrupole plus Solenoid: #9	0.7	-22.806964 ($\phi9 = 0^o$)

Table 13: Basic parameters of lenses and solenoids of a spin rotator with a superposition of solenoidal and quadrupole fields for BR = 23.3495 T·m (E = 7.15 GeV). The sequence of numbering of structure elements: 1, 2,..., 17.

Element	Length, m	Field or Gradient: T, T/m
Drift #1, #17	0.34556	$B_s = G = 0$
Solenoid: #2, #16	0.35	$B_s = 5.15983$
Quadrupole: #3, #15	0.3	-41.5055 ($\phi3 = -\phi15 = -20.25818^o$)
Solenoid #4, #14	0.8	$B_s = 5.15983$
Quadrupole: #5, #13	0.3	45.5005 ($\phi5 = -\phi13 = -15.19364^o$)
Solenoid #6, #12	1.2	$B_s = 5.15983$
Quadrupole: #7, #11	0.3	-7.56501 ($\phi7 = -\phi11 = 7.59682^o$)
Solenoid #8, #10	1.2	5.15983
Quadrupole: #9	0.3	-53.2734 ($\phi9 = 0^o$)

Table 14: Parameters of lenses and solenoids of a spin rotator with alternating solenoidal and quadrupole fields for BR = 23.3495 T·m (E = 7.15 GeV).

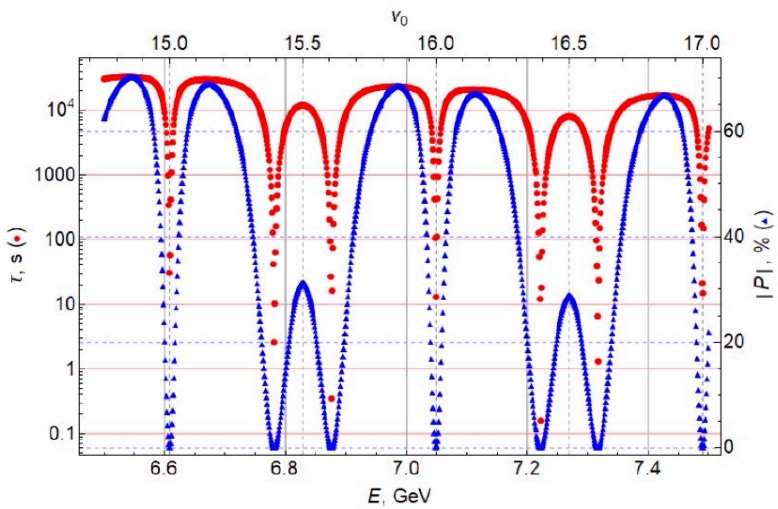


Figure 26: Radiation spin relaxation time and equilibrium degree of polarization versus energy for the rotator optics option from Table 14.

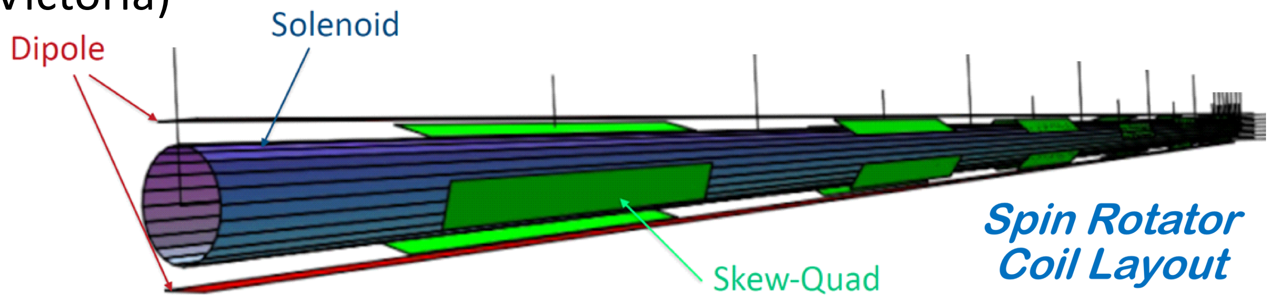
Depolarization lifetime at E=7.15GeV is ~19000s

Note: beam is topped-up @ 50Hz continuously (current beam lifetime without top-up <1hr)

From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

Novel concept: Compact spin rotator

Y. Peng's (UVictoria)



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

- Replace some existing ring dipoles on both sides of the IP with the dipole-solenoid combined function magnets and keep the original dipole strength to preserve the machine geometry
- Avoids repositioning of other magnets in the ring
- Install 6 skew-quadruple on top of each rotator section to compensate for the x-y plane coupling caused by solenoids
- **Original machine can be recovered by turning off solenoid and skew-quadrupole fields + retune with only the dipoles**

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

Compact spin rotator

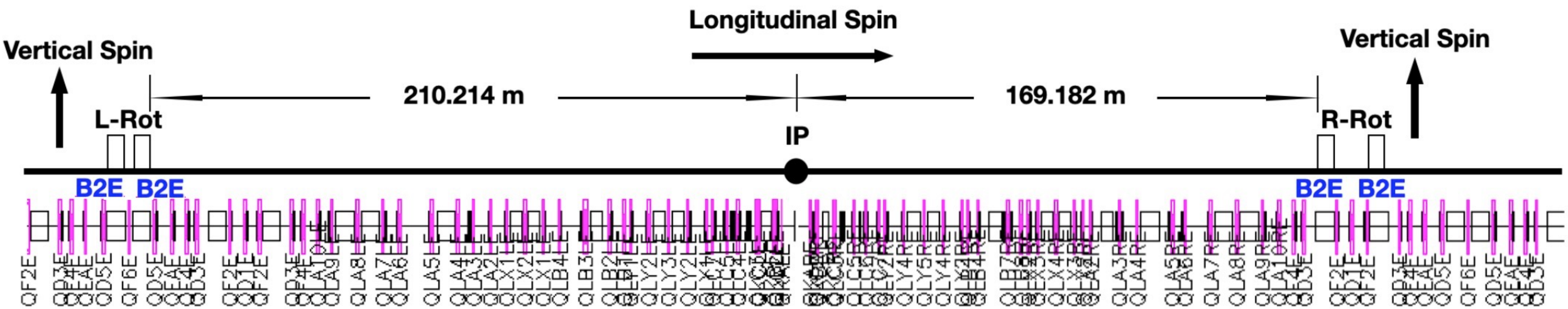
Y. Peng's (UVictoria)

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
  - Demin provided SAD lattice files for HER translated for BMAD

Compact spin rotator

Y. Peng's (UVictoria)



- 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

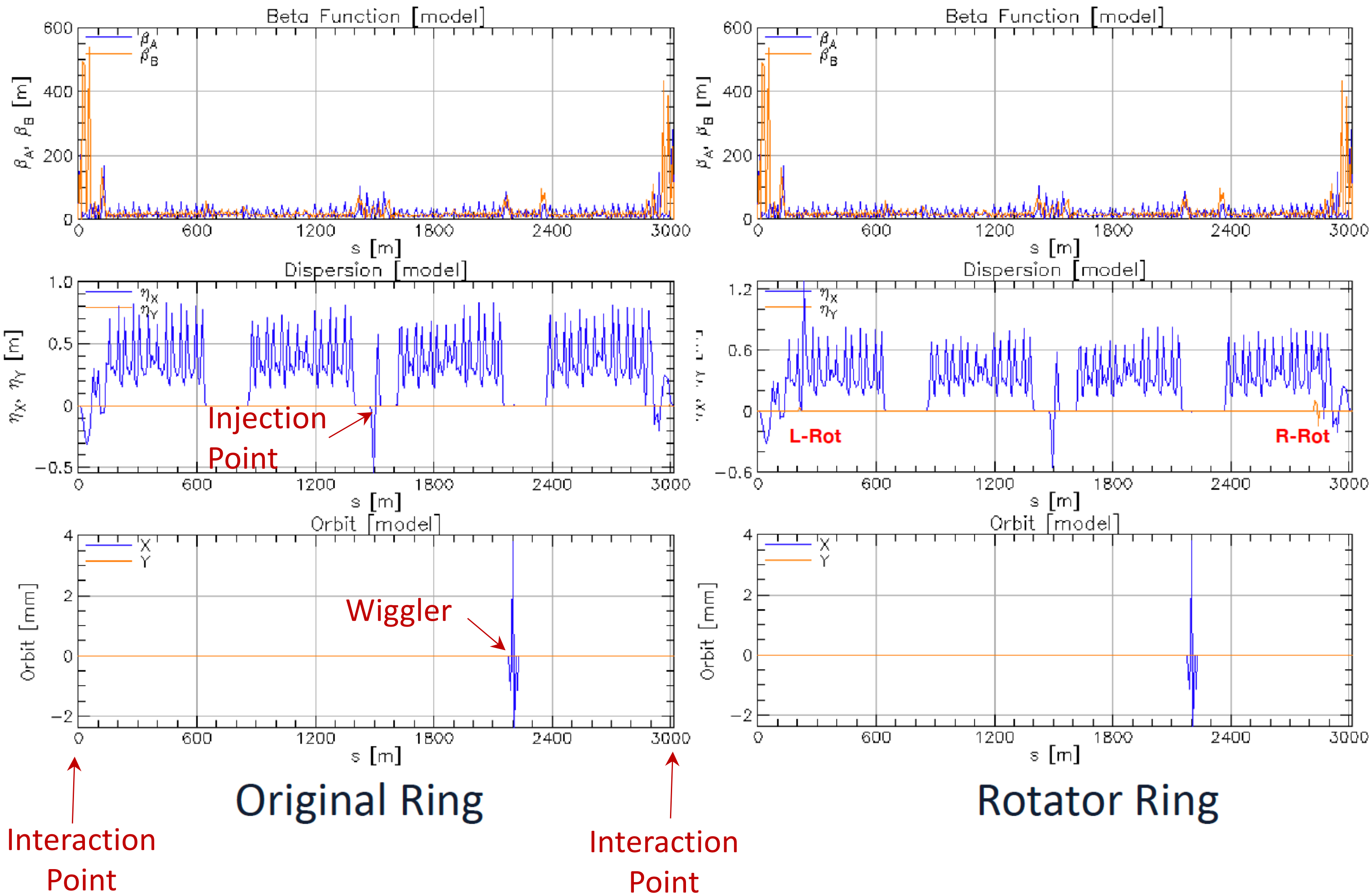
Compact spin rotator

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

Beta x & y

Diffusion x & y

Orbit



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

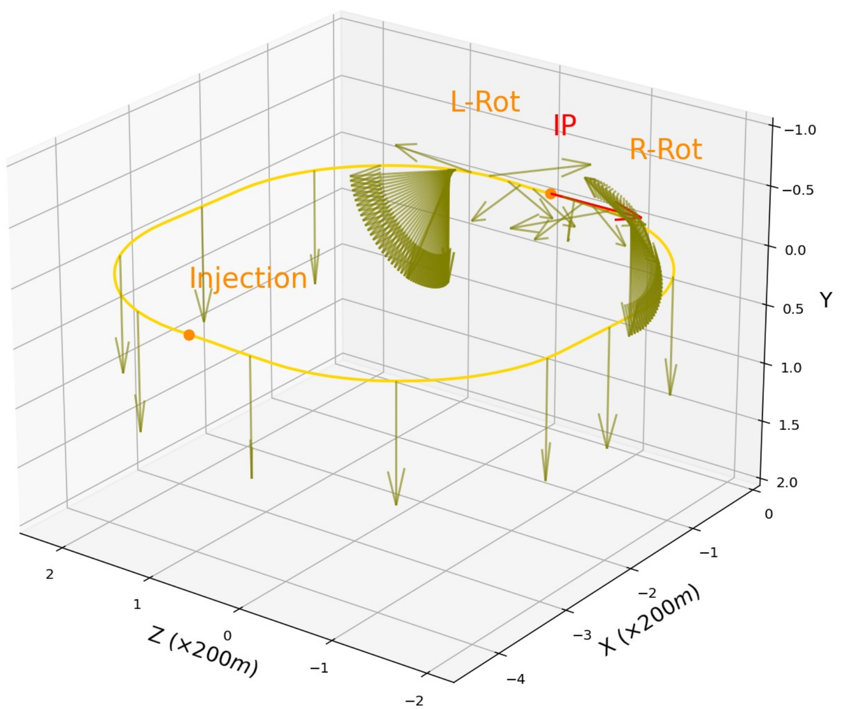
Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}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

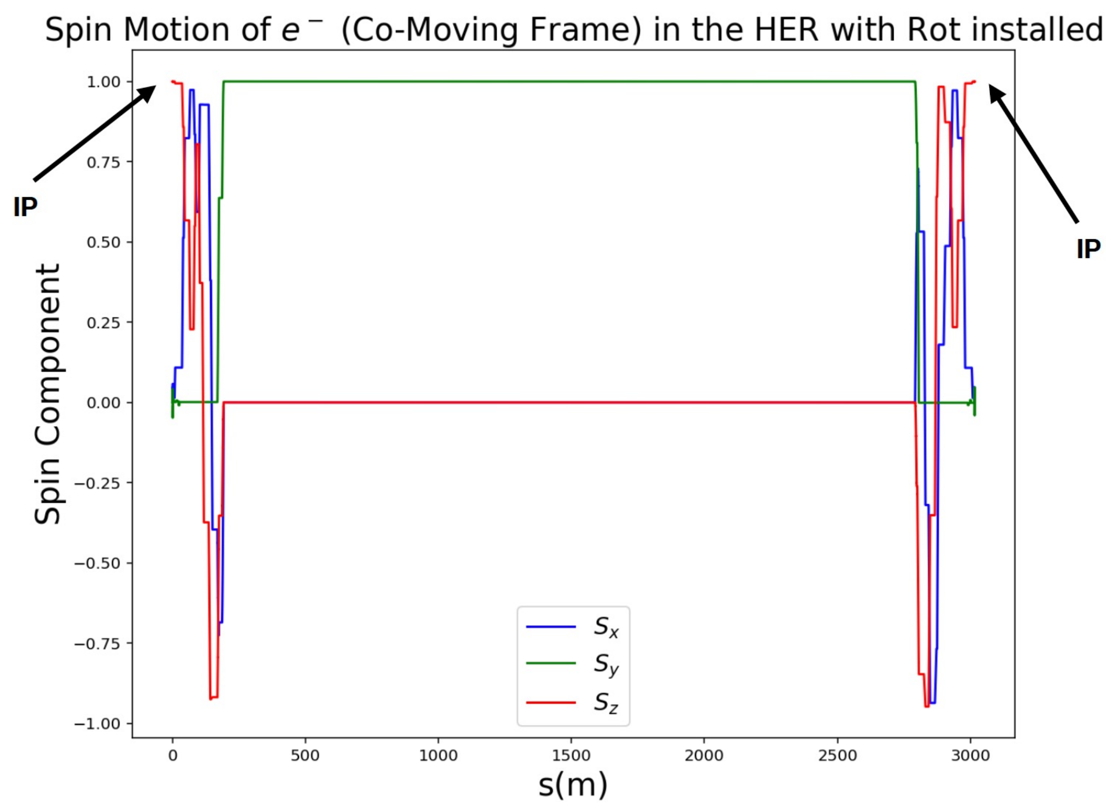
Compact spin rotator

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

Y. Peng's (UVictoria)

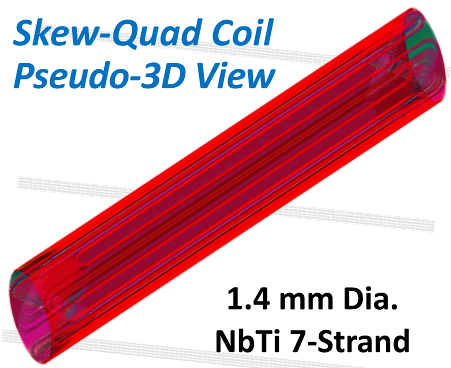
	Solenoid	Field (T)
L-Rot	B2EALSQ	-4.8431
	B2EBLSQ	-2.5774
R-Rot	B2EARSQ	-3.6084
	B2EBRSQ	-3.9420

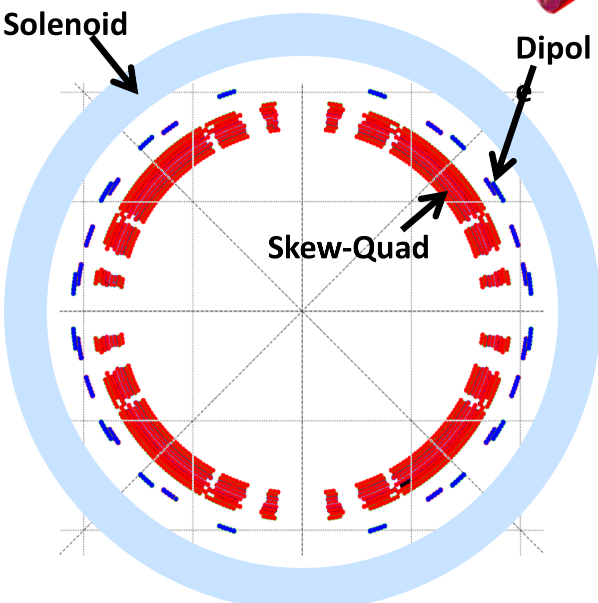
- Solenoid fields below 5 T limit
- Maximum skew-quad strength is ~20 T/m, below 30T/m limit
- Maximum Ring quad is ~ 14 T/m, which is achievable

Compact Spin Rotator – Coil Feasibility

Brett Parker (BNL) – see yesterday's talk for more details

Skew-Quad Coil
Pseudo-3D View





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.

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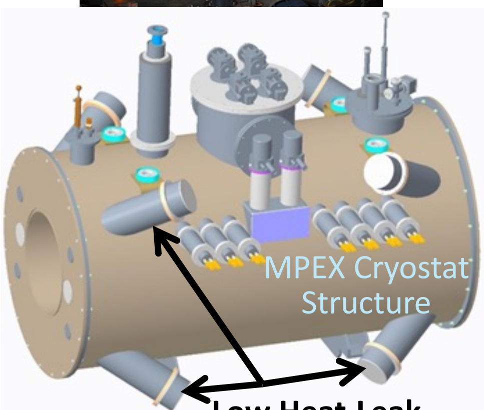
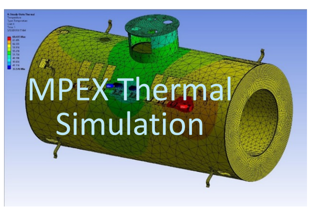
Compact Spin Rotator - Cryostat System Feasibility

Brett Parker (BNL) – see yesterday's talk for more details





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.**

From Brett Parker’s presentation yesterday

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:

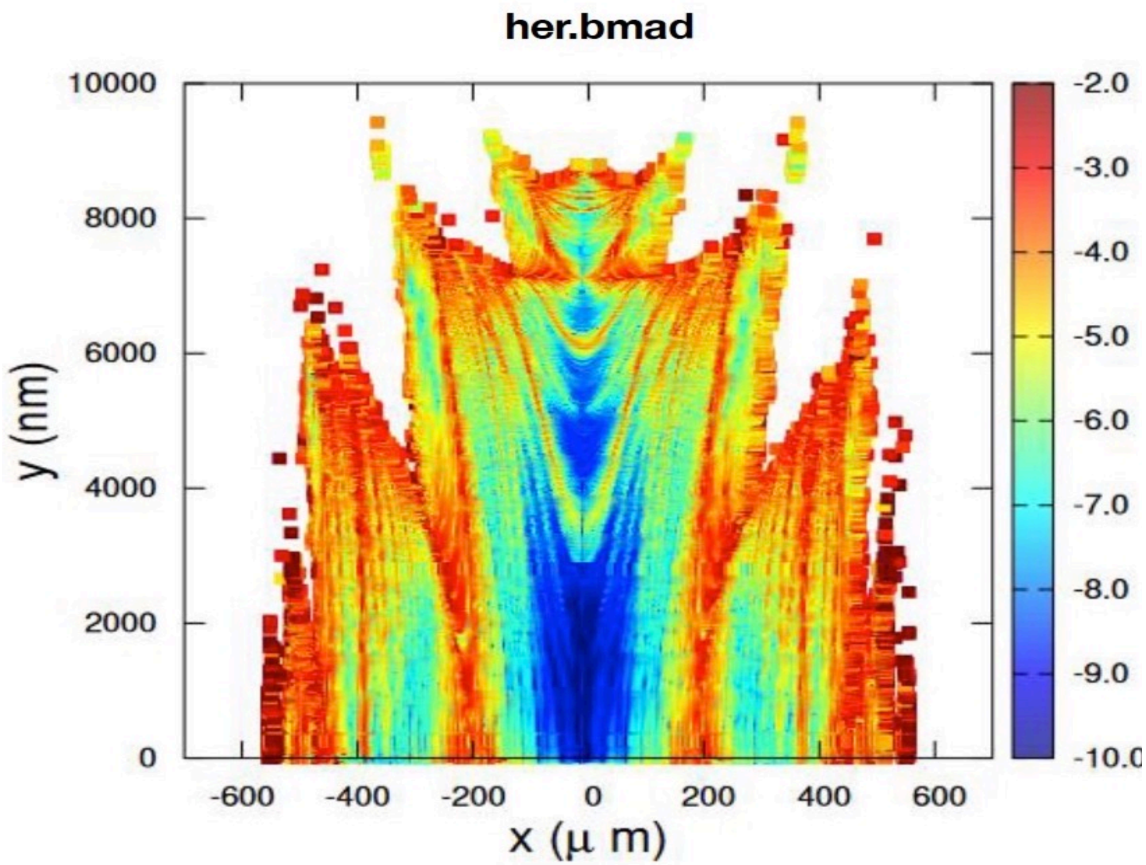
- Solenoid coil (use SuperKEKB experience)
- Interface accelerator requirements
  - ❖ Minimum warm bore size
  - ❖ Space for positron beam
  - ❖ Installation space in tunnel
  - ❖ Check all 4 locations
  - ❖ Check cryo-safety requirements
- Magnet parameter interface

Compact spin rotator

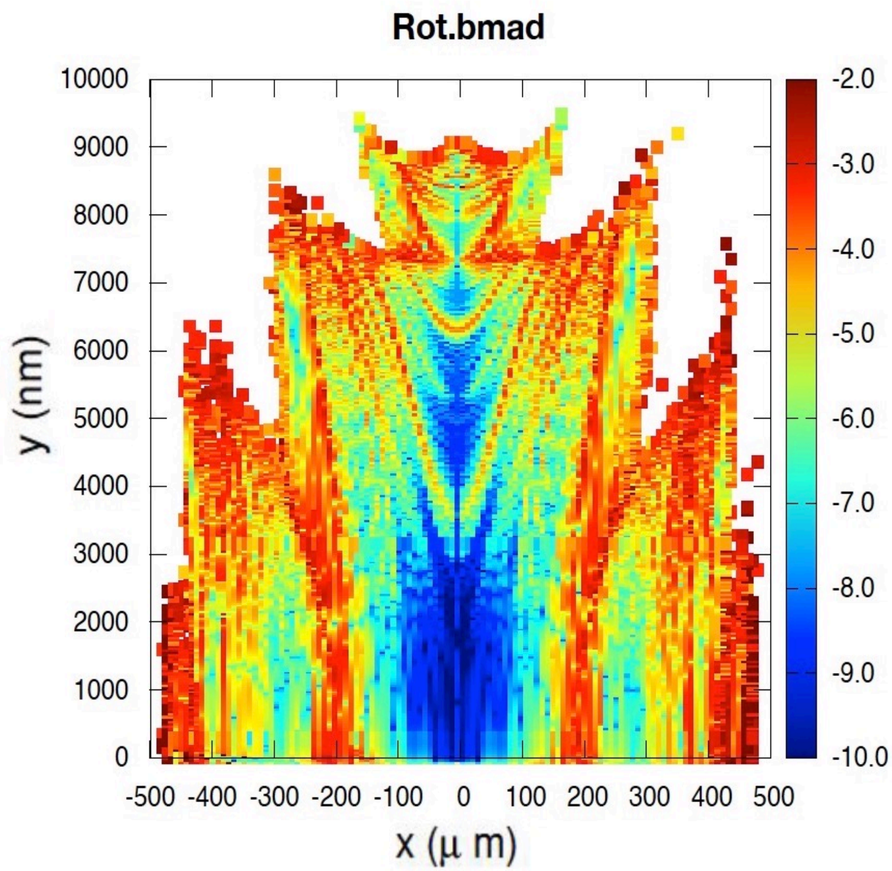
Initial preliminary Frequency Map Analysis (FMA) dynamic aperture studies using BMAD – show no large changes

work by Noah Tessema (UVictoria)

Original HER Lattice

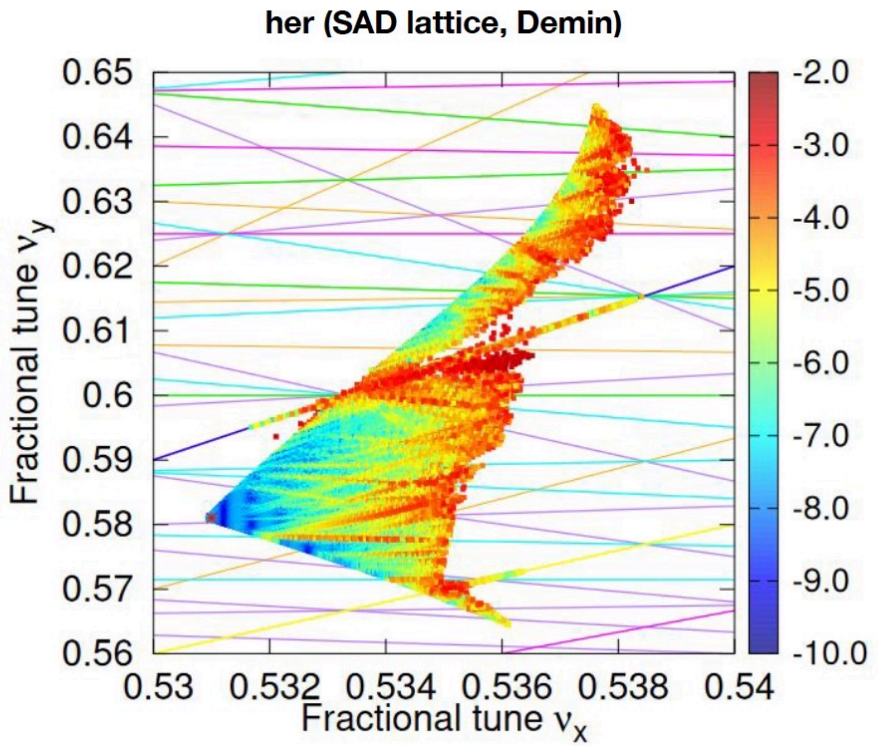


HER Lattice with spin rotator

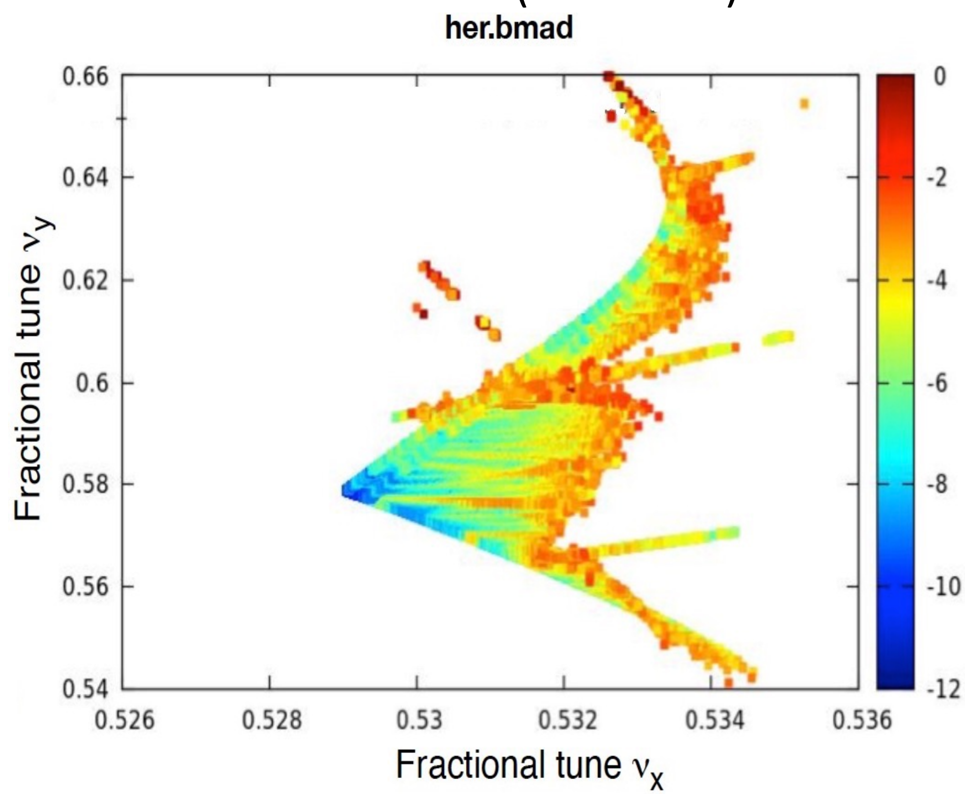


Comparing SAD FMA to BMAD FMA in original HER Lattice

Original HER Lattice with SAD



Original HER Lattice with BMAD
Noah Tessema (UVictoria)



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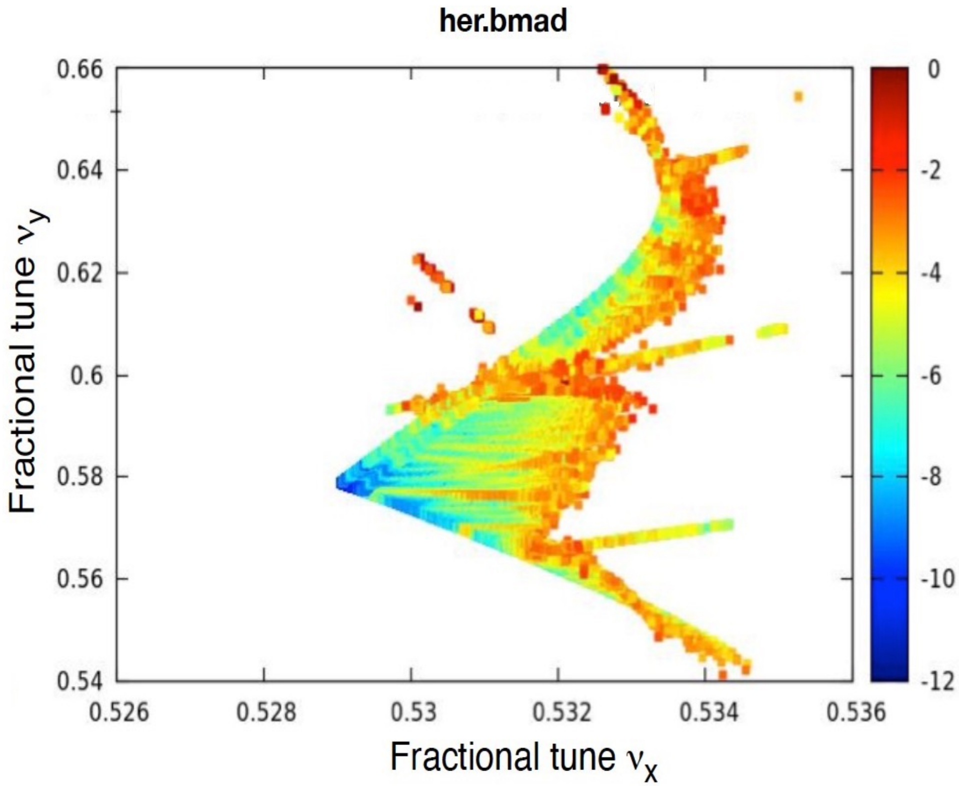
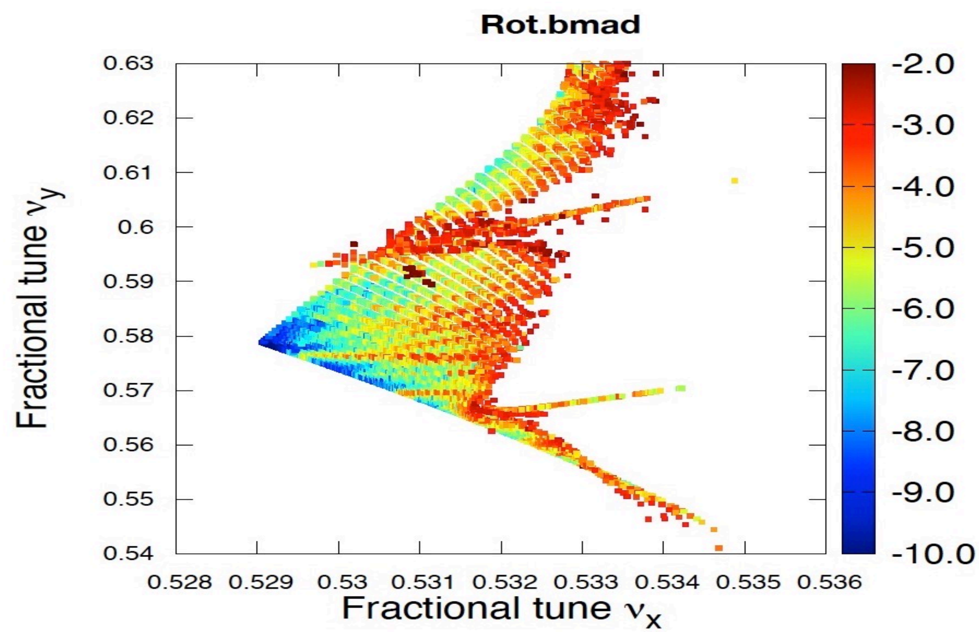


HER Lattice with spin rotator



Currently conducting Long Term Tracking studies with radiation damping and radiation fluctuations/quantum excitation

Polarization in SuperKEKB

Hardware needs

1. Low emittance Source
2. Spin rotators
3. **Compton polarimeter**

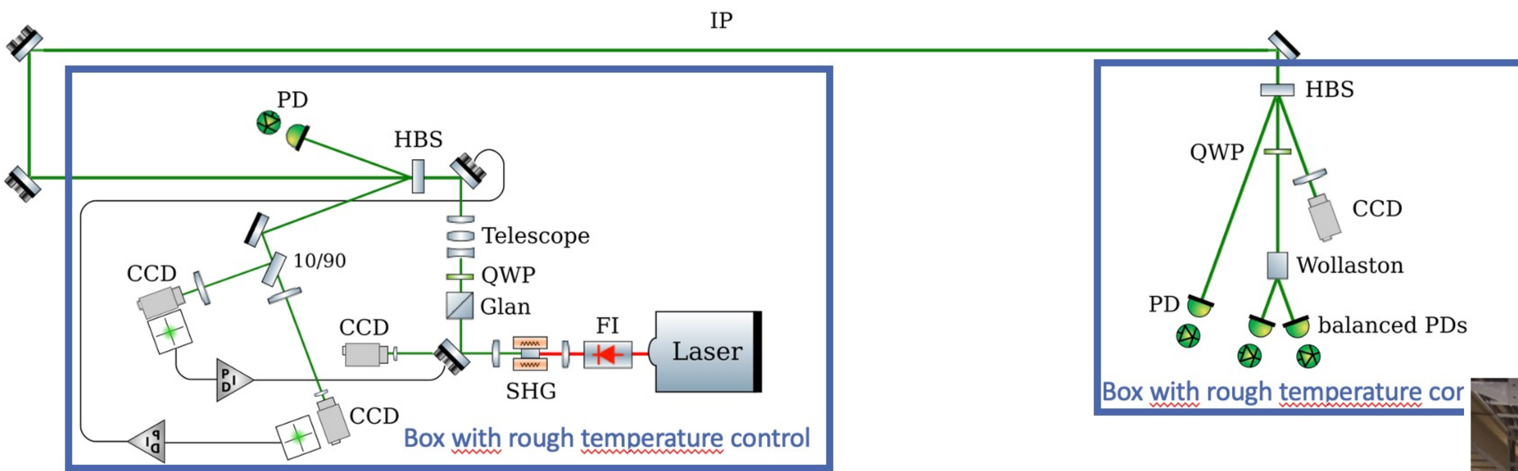
Figure 1: SuperKEKB left side cryostat at KEK.

Space is available outside
Cryostats for the final focusing quads

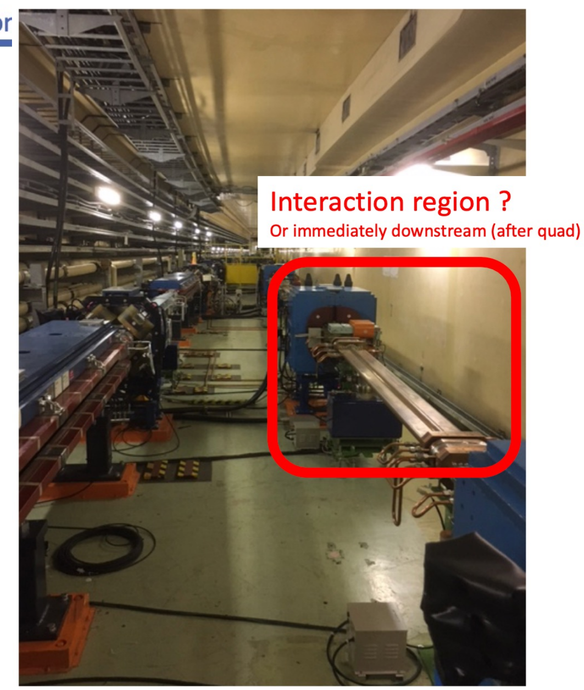
LAL Orsay and U. Manitoba groups

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**



Main challenges -> laser integration in pre-defined environment
High rep-rate (250MHz) laser considered --> detection capabilities
Polarization control and accurate monitoring being worked on at IJCLab



See two related talks later today:

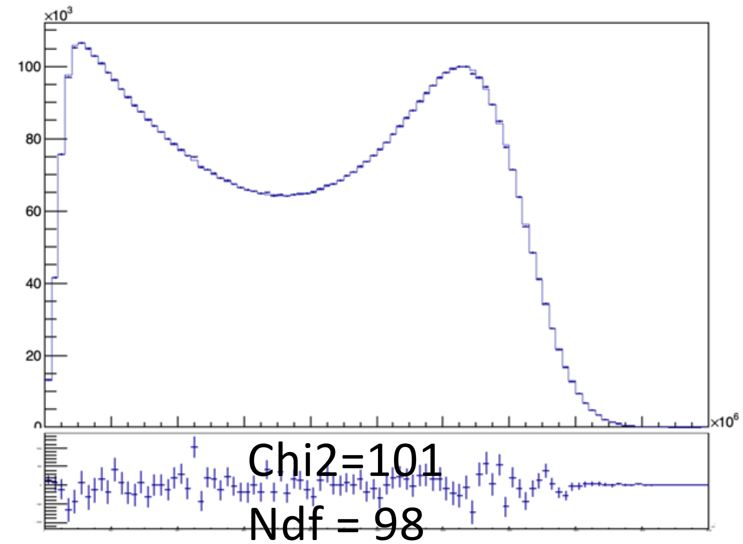
Aurelien Martens, "Real time laser polarimetry for Compton polarimetry"

Farah Mawas, "Update of the sensitivities studies of the SuperKEKB Compton polarimeter"

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**

Possiblity to extract beam polarization from scattered photons
bunch/bunch being investigated
Cope with high rep-rate (250MHz)
Need precise understanding of background contribution
Detailed simulations ongoing



Perfectly aligned, calibrated, known average beam energy, known e-beam phase-space parameters

See two related talks later today:
Aurelien Martens, "Real time laser polarimetry for Compton polarimetry"
Farah Mawas, "Update of the sensitivities studies of the SuperKEKB Compton polarimeter"

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 cm²) and 9th generation chip at DESY.

Version 10 will be submitted for production by the end of this year (full 2x2 cm²).

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

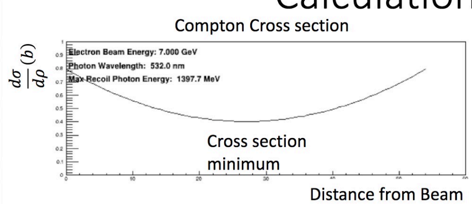
Version 8 at UofM

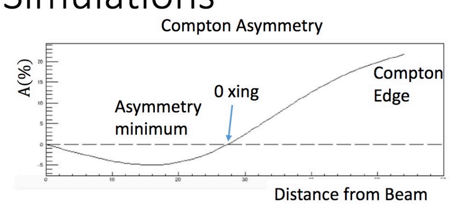
The chip is primarily developed by groups at the U. of Heidelberg and the Karlsruhe Institute of Technology, and intended for various experiments:

- 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 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
- Caleb Miller deploying this with *BABAR* data at UVic – very promising! Preliminary results with *BABAR* Υ(4S) dataset ($432fb^{-1}$) yield 0.5% combined statistical $\oplus$ systematic uncertainty from only $\tau \to \rho\, \nu$ with $\tau \to e\, \nu\nu$ tag

See Caleb Miller's talk later today: "Tau Polarimetry"

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 Υ(1S) where CM is precisely known to also calibrate LER e+ energy; would provide precision CM energies above the Υ(4S)
  - Unmeasurably small azimuthal dependence ($O(10^{-7})$) in SM, when e+ is not polarized (studies by A. Aleksejevs), but may have beyond SM possibilities – to be investigated

Stage 2: implement spin rotators and longitudinal Compton polarimeters

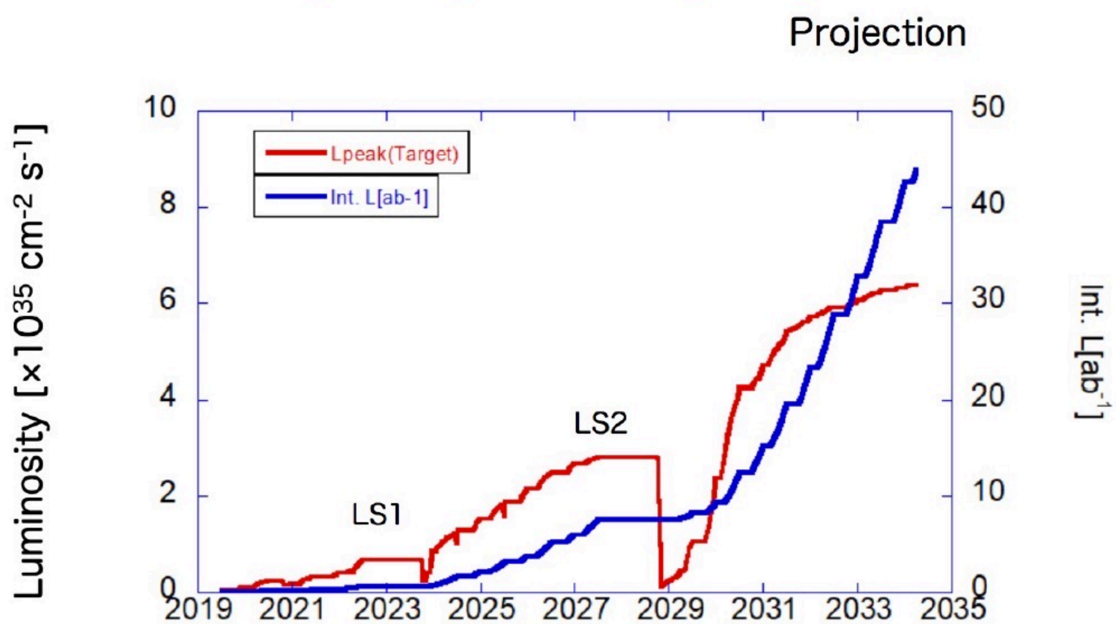
- Initially with dedicated polarization runs and start Chiral Belle electroweak physics program

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}.

SuperKEKB polarization upgrade

- Would aim to install longitudinal polarization in Long Shutdown 2 (LS2) for new final focus ~2027, or later
- Polarization upgrade R&D in MEXT KEK Roadmap 2021-26



LS2
- No sooner than 2026, more likely to start sometime in 2027
- IR modification
  QCS, lattice
  Belle modification might be needed

Other (unknown) factors
- Long-term budget outlook
- Electricity rate

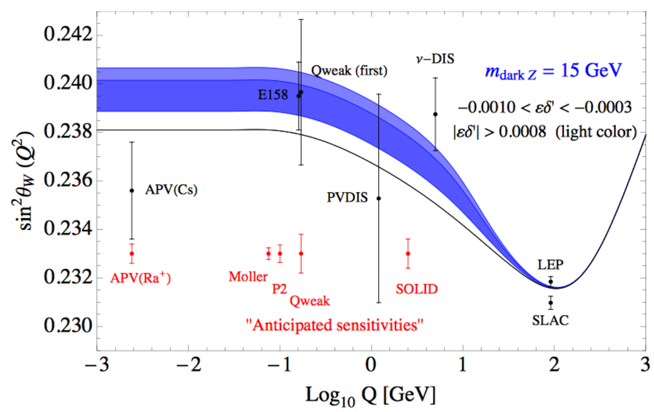
June 2022 projections

Summary

- e^- polarization upgrade at SuperKEKB would open a unique discovery window with precision electroweak physics
  - Measure the b, charm, tau, muon vector couplings with the highest precision and competitive electron coupling measurement
  - Unique probe of universality at unprecedented precision
- Also get significant improvements to tau LFV, Michel parameters, LFV, EDM, and F_2(10GeV)

Summary

- competitive with measurements at Z-pole (until FCC) but at 10.58 GeV and complementary to Moller and low energy PV
  - test running of couplings
  - probe new physics at TeV scale complementary to LHC
  - probe 'Dark Sector'



- Build on international partnerships with KEK to create a unique discovery machine

Thankyou for your attention…

…and consider taking the plunge and join 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

Summary

By opening this ***unique*** window on New Physics …
we could find something REALLY exciting

Additional Information

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)	

Growing international collaboration of Accelerator and Particle Physicists ~ half from outside Belle II

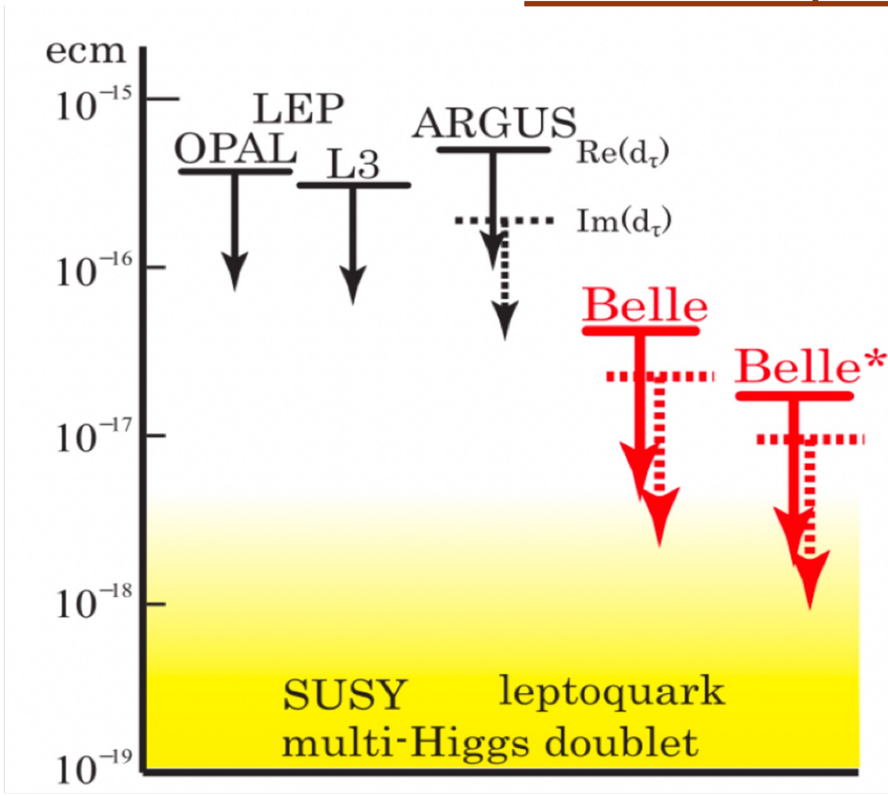
- Canada: TRIUMF, UVic, Manitoba, UBC/IPP
- France: LAL/Orsay
- KEK & Hiroshima Univ. + Oide-san (CERN)
- Russia: BINP
- USA: ANL, BLN, Louisville, Duke

Theorists in Canada, Italy, Russia & U.S. published recently on physics enabled by this project

Snowmass White Paper (2022) – being used as starting point for CDR. LOI and TDR to follow, then construction.

Additional Attraction: **Opportunity not just for physics, but serves as real-world project to develop technologies for learning and training for future e+e- polarization projects**

Electric dipole moments of τ lepton



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

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

– 95% confidence intervals

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

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

➢ Preliminary studies at Belle II show much better control in agreement between Data-MC

➢ After improved control of systematics, extrapolation based on statistical errors only

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

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