2024 US Belle II Summer Workshop

Chiral Belle: e^- Beam Polarization Upgrade for SuperKEKB

Michael Roney

University of Victoria

20 June 2024

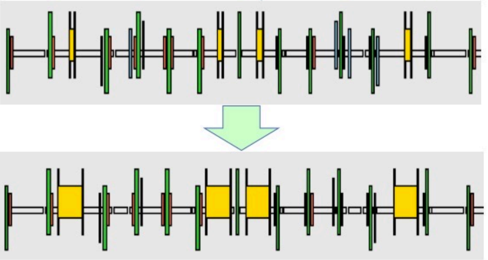
University of Victoria

Upgrading SuperKEKB with polarized electrons

Opens New Windows for Discovery with Belle II

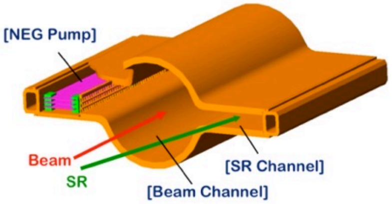
- Extremely rich and unique high precision electroweak program
- Probe of Dark Sector
- Tau Lepton Magnetic Form factor F_2(10GeV) → τ g-2
- Polarized Beam also provides:
  - Improved precision measurements of τ Michel Parameters, electric dipole moment (EDM)
  - Reduces backgrounds in $\tau \rightarrow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

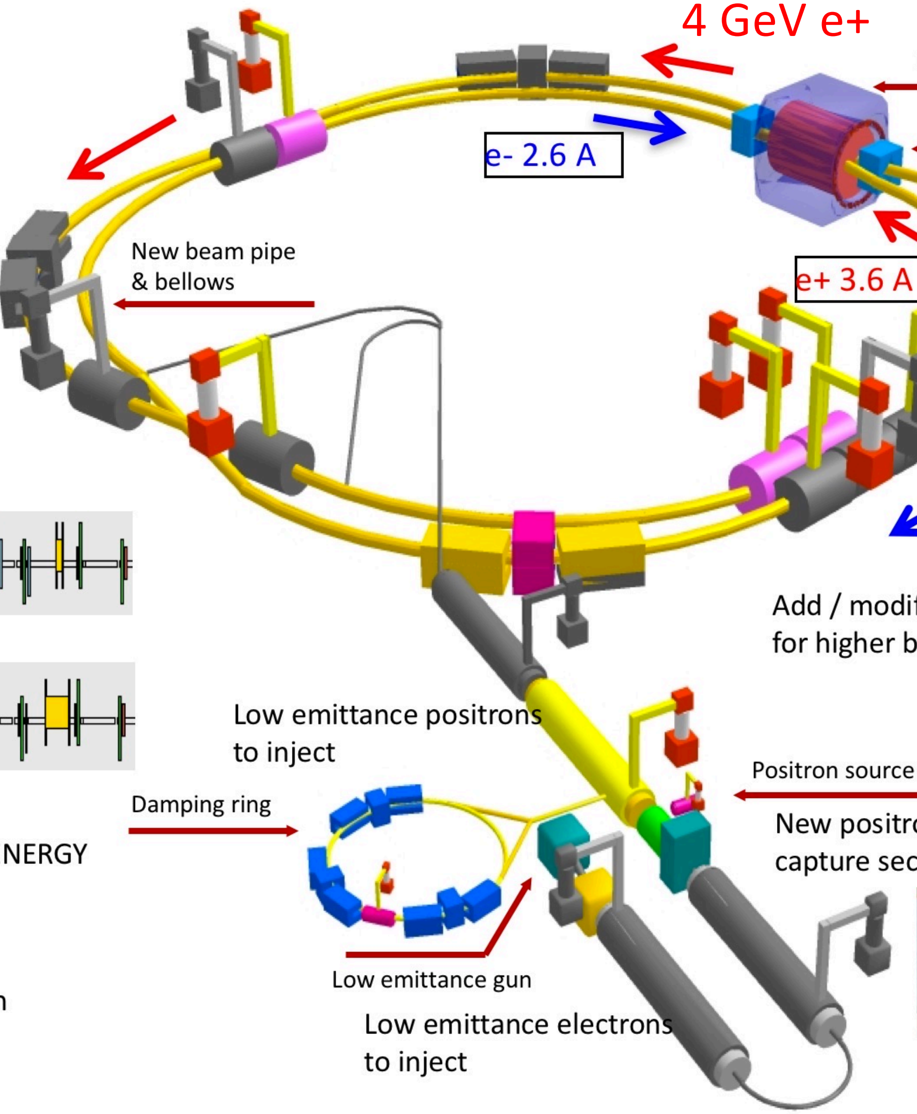
Replace short dipoles with longer ones (LER)



Redesign the lattices of HIGH ENERGY RING (HER) & LOW ENERGY RING (LER) to squeeze the emittance

TiN-coated beam pipe with antechambers





4 GeV e+

Belle II

New IR

e- 2.6 A

e+ 3.6 A

New beam pipe & bellows

7GeV e-

Add / modify RF systems for higher beam current

Low emittance positrons to inject

Damping ring

Positron source

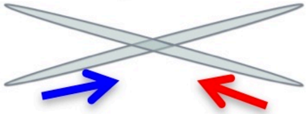
New positron target / capture section

Low emittance gun

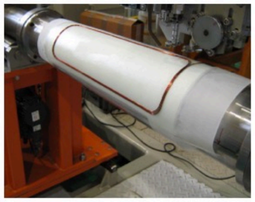
Low emittance electrons to inject

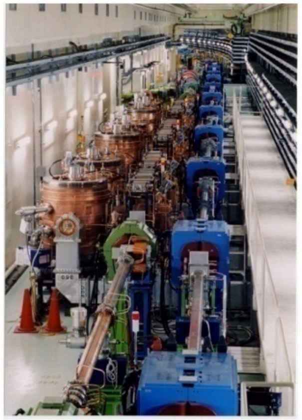
Super KEKB

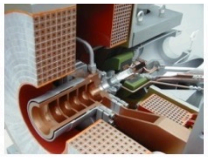
Colliding bunches



New superconducting /permanent final focusing quads near the IP



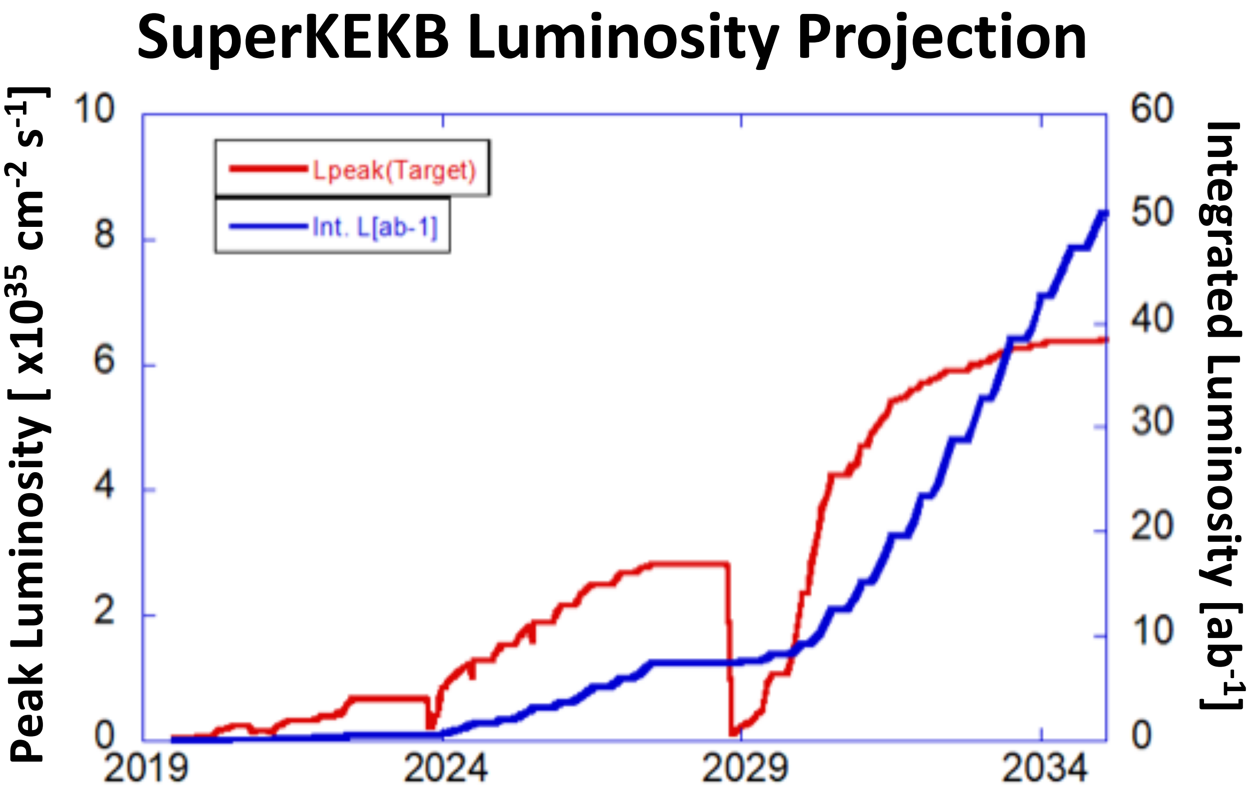




To obtain x40 higher luminosity

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 ELECTRONS 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 ELECTRONS BEAM

Data with polarized e^- beam to be collected by Belle II and used simultaneously for conventional non-polarized beam physics program: no negative impact on existing program

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

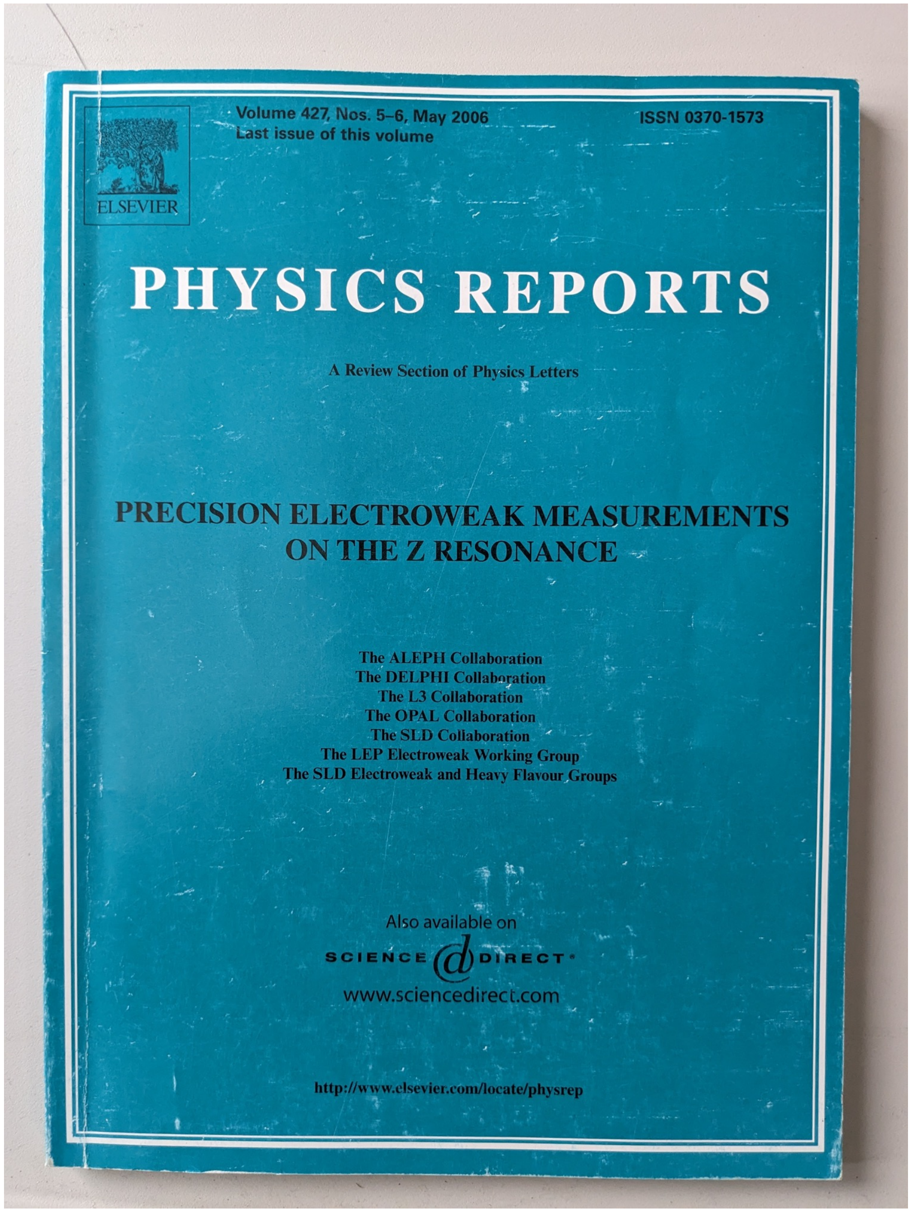
- **Left-Right Asymmetries** (A_{LR}) yield high precision measurements of the neutral current vector couplings (g_V) to each of five fermion flavours, *f* :
  - **beauty (D-type)**
  - **charm (U-type)**
  - **tau**
  - **muon**
  - **electron**

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

as well as light quarks

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

Precision Electroweak Measurements Dominated by LEP and SLD at the Z^0



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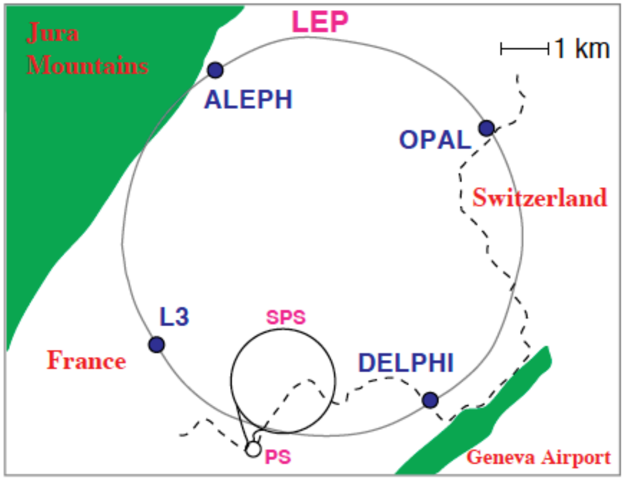

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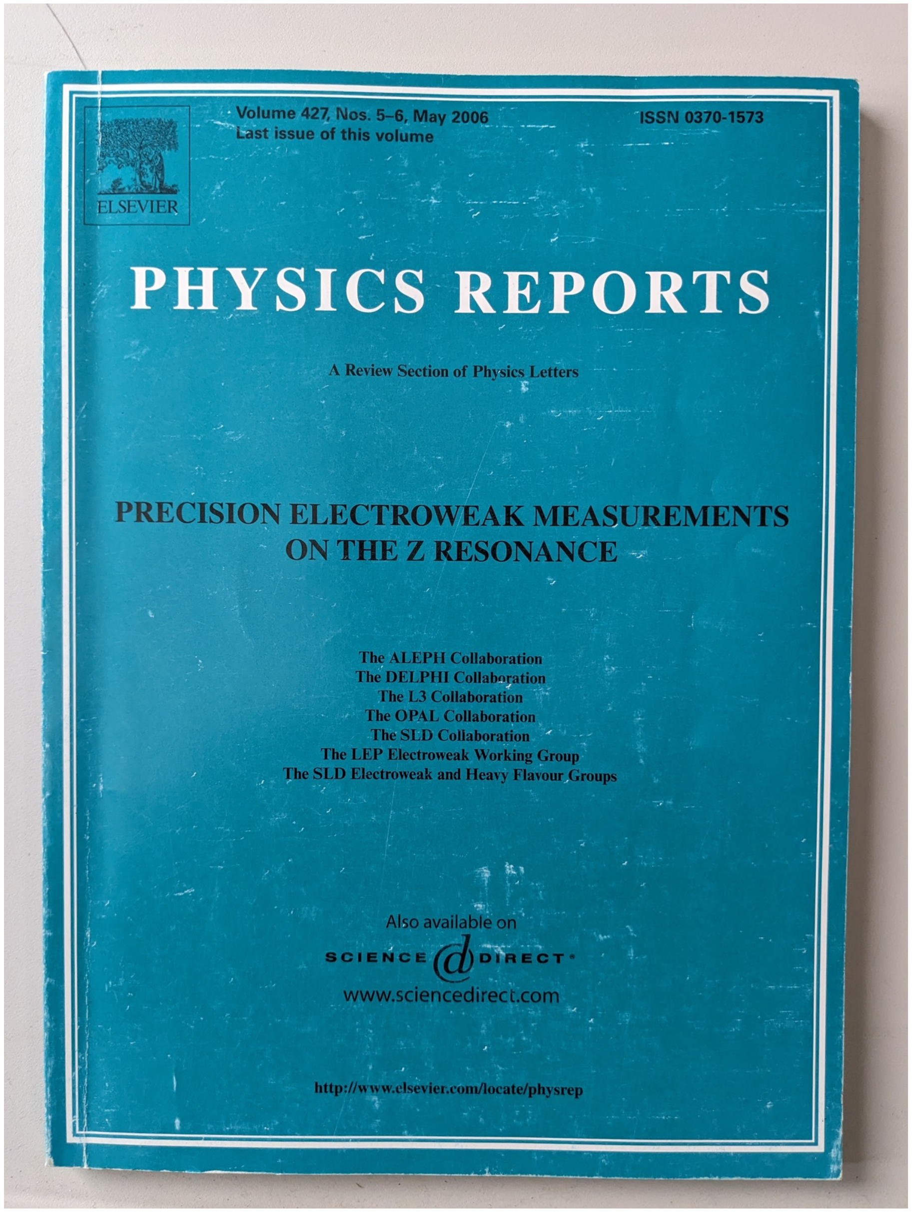

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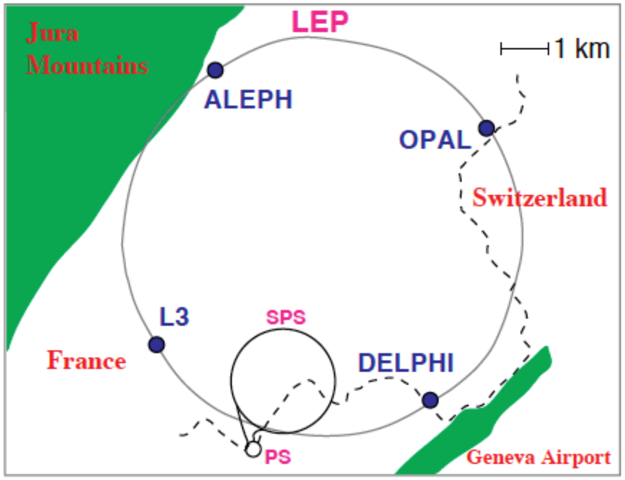

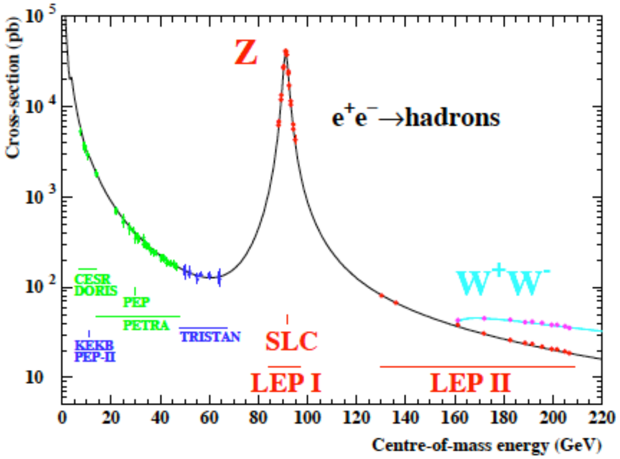

$$m_Z = 91.1875 \pm 0.0021\ \text{GeV}$$

$$\Gamma_Z = 2.4952 \pm 0.0023\ \text{GeV}$$

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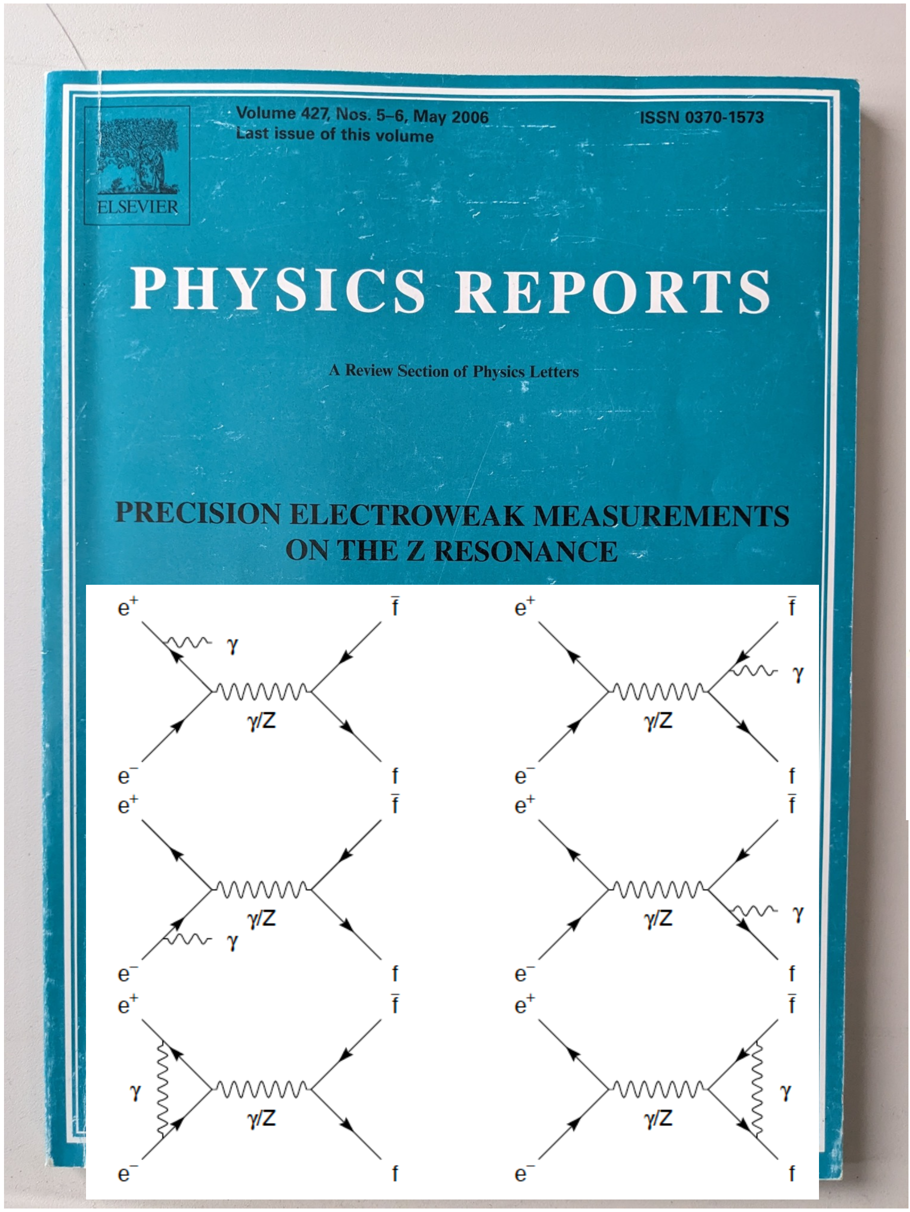

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$$\frac{2s}{\pi}\frac{1}{N_c^{\mathrm{f}}}\frac{d\sigma_{\mathrm{ew}}}{d\cos\theta}(\mathrm{e^+e^-}\to \mathrm{f\bar{f}}) = \underbrace{|\alpha(s)Q_{\mathrm{f}}|^2(1+\cos^2\theta)}_{\sigma^\gamma} \underbrace{-8\Re\left\{\alpha^*(s)Q_{\mathrm{f}}\chi(s)\left[\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Vf}}(1+\cos^2\theta)+2\mathcal{G}_{\mathrm{Ae}}\mathcal{G}_{\mathrm{Af}}\cos\theta\right]\right\}}_{\gamma\text{–Z interference}} \underbrace{\begin{array}{c}+16|\chi(s)|^2\left[(|\mathcal{G}_{\mathrm{Ve}}|^2+|\mathcal{G}_{\mathrm{Ae}}|^2)(|\mathcal{G}_{\mathrm{Vf}}|^2+|\mathcal{G}_{\mathrm{Af}}|^2)(1+\cos^2\theta)\right.\\ \left.+8\Re\{\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Ae}}{}^*\}\Re\{\mathcal{G}_{\mathrm{Vf}}\mathcal{G}_{\mathrm{Af}}{}^*\}\cos\theta\right]\end{array}}_{\sigma^{\mathrm{Z}}}$$

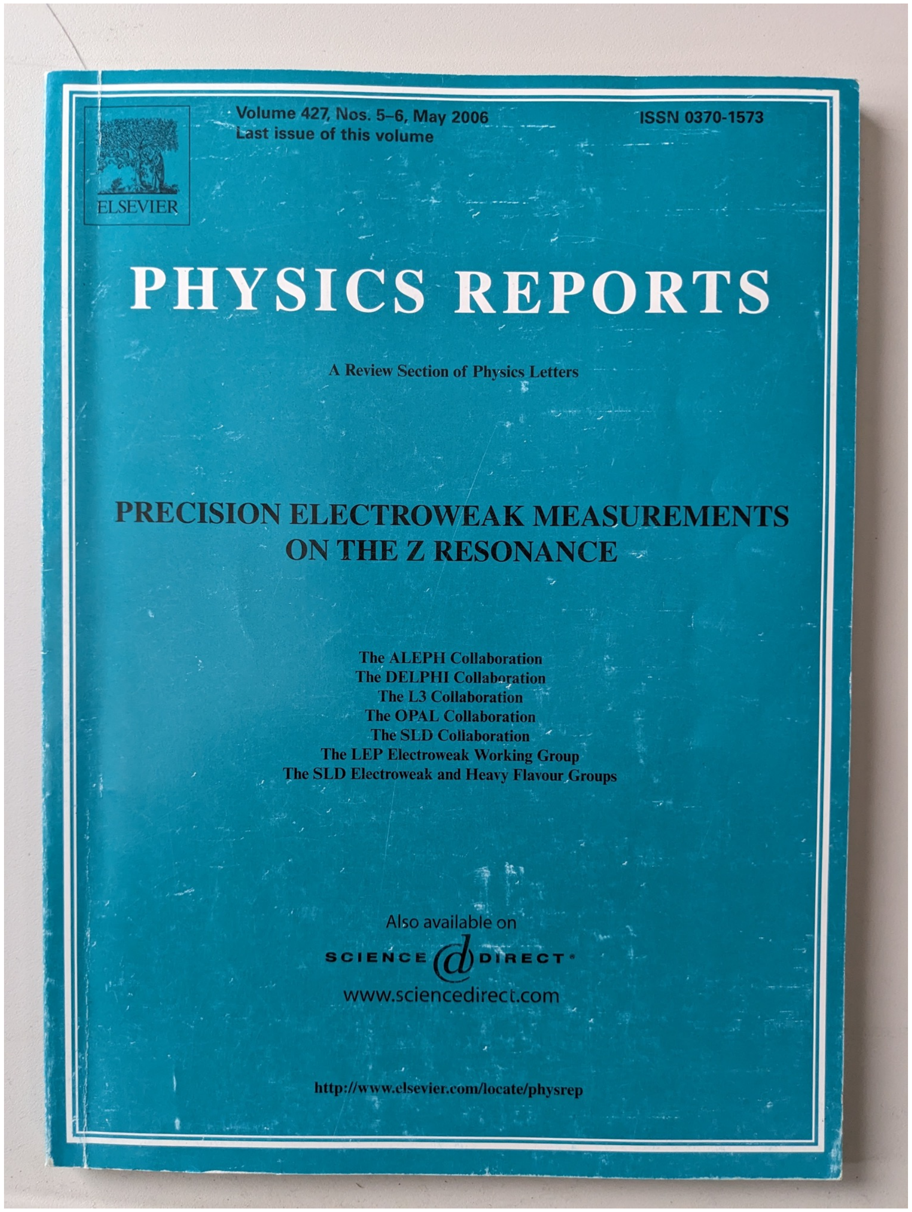
with:

$$\chi(s) = \frac{G_{\mathrm{F}}m_{\mathrm{Z}}^2}{8\pi\sqrt{2}}\frac{s}{s-m_{\mathrm{Z}}^2+is\Gamma_{\mathrm{Z}}/m_{\mathrm{Z}}},$$

$$\frac{g_{\mathrm{Vf}}}{g_{\mathrm{Af}}} = \Re\left(\frac{\mathcal{G}_{\mathrm{Vf}}}{\mathcal{G}_{\mathrm{Af}}}\right) = 1-4|Q_{\mathrm{f}}|\sin^2\theta_{\mathrm{eff}}^{\mathrm{f}}$$

Real effective Vector and Axial Vector Couplings of Z^0 to each fermion *f*

Precision Electroweak Measurements Dominated by LEP and SLD at the Z^0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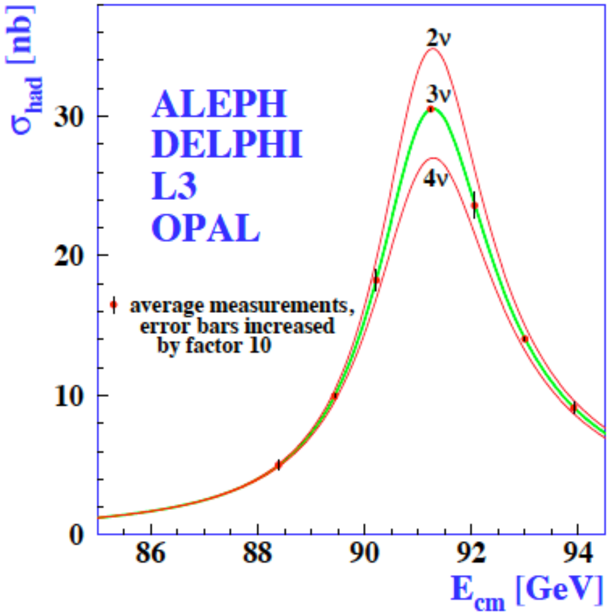


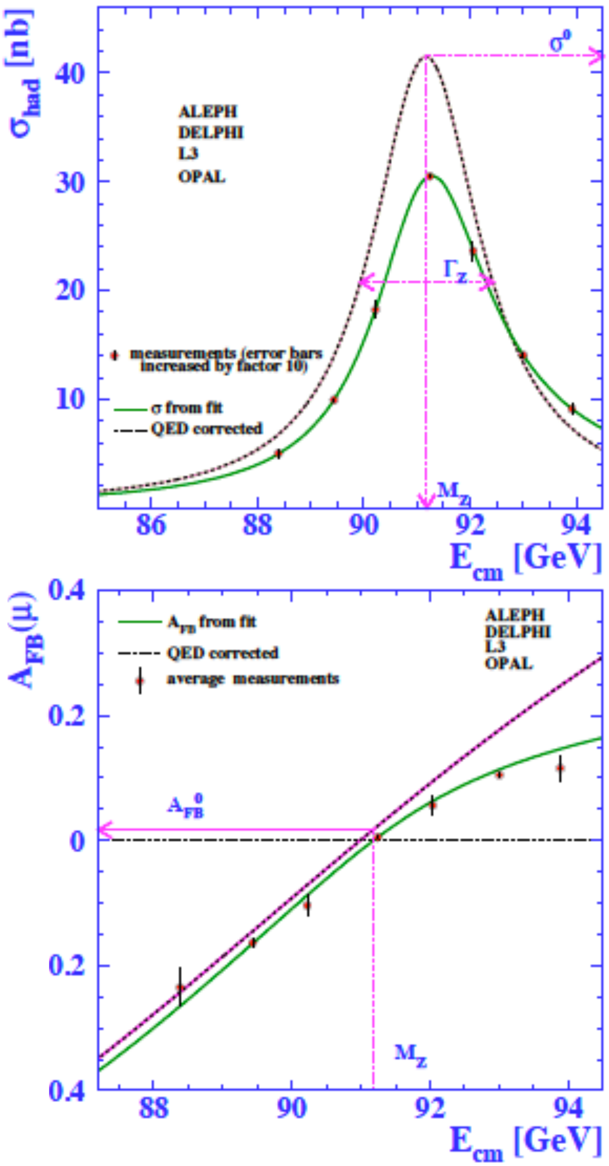
The number of light neutrino species determined to be 2.9840 ± 0.0082

Precision Electroweak Measurements Dominated by LEP and SLD at the Z^0

$$\mathcal{A}_{\mathrm{f}} = \frac{g_{\mathrm{Lf}}^2 - g_{\mathrm{Rf}}^2}{g_{\mathrm{Lf}}^2 + g_{\mathrm{Rf}}^2} = \frac{2 g_{\mathrm{Vf}} g_{\mathrm{Af}}}{g_{\mathrm{Vf}}^2 + g_{\mathrm{Af}}^2} = 2\frac{g_{\mathrm{Vf}}/g_{\mathrm{Af}}}{1 + (g_{\mathrm{Vf}}/g_{\mathrm{Af}})^2}$$

$$A_{\mathrm{FB}} = (N_{\mathrm{F}} - N_{\mathrm{B}})/(N_{\mathrm{F}} + N_{\mathrm{B}})$$

$$A_{\mathrm{FB}}^{0,\mathrm{f}} = \frac{3}{4}\mathcal{A}_{\mathrm{e}}\mathcal{A}_{\mathrm{f}}$$



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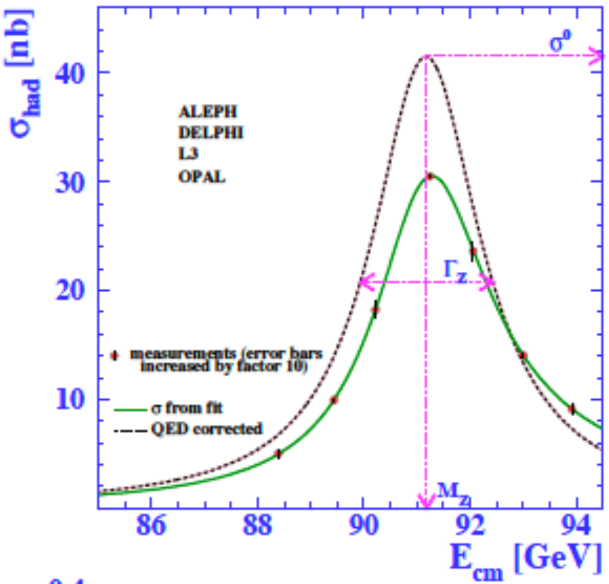
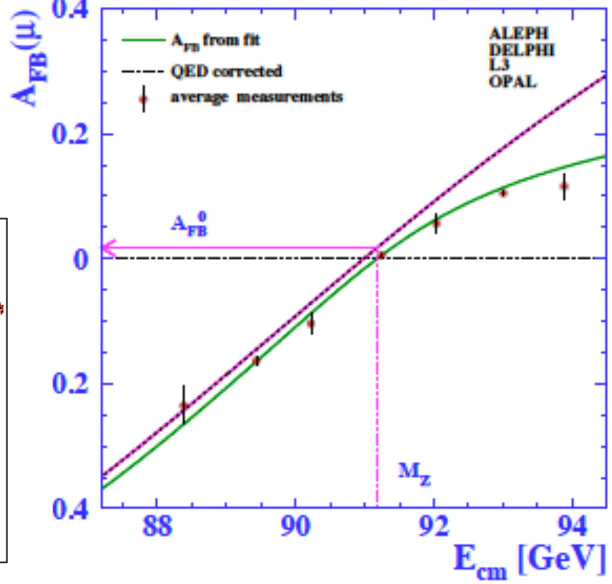
$$A_{\mathrm{FB}} = (N_{\mathrm{F}} - N_{\mathrm{B}})/(N_{\mathrm{F}} + N_{\mathrm{B}})$$

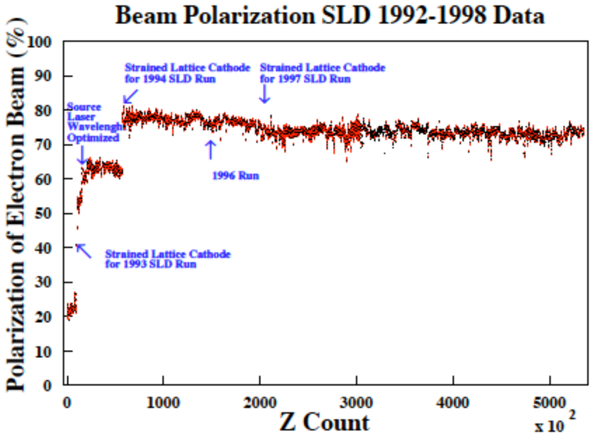
$$A_{\mathrm{FB}}^{0,\mathrm{f}} = \frac{3}{4}\mathcal{A}_{\mathrm{e}}\mathcal{A}_{\mathrm{f}}$$

$$A_{\mathrm{LR}}^{0} = \mathcal{A}_{\mathrm{e}}$$

$$A_{\mathrm{LR}} = \frac{N_{\mathrm{L}} - N_{\mathrm{R}}}{N_{\mathrm{L}} + N_{\mathrm{R}}} \frac{1}{\langle \mathcal{P}_{\mathrm{e}} \rangle}$$







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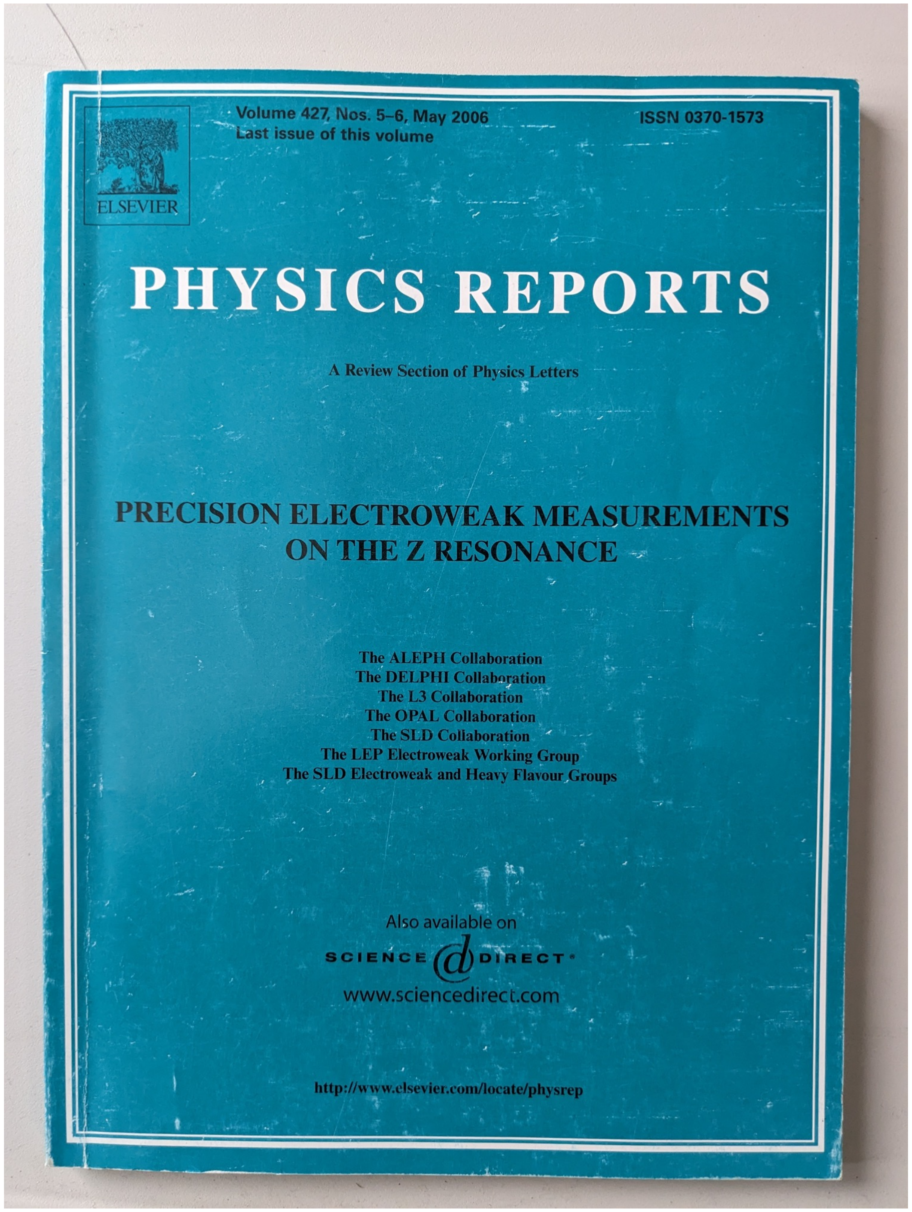

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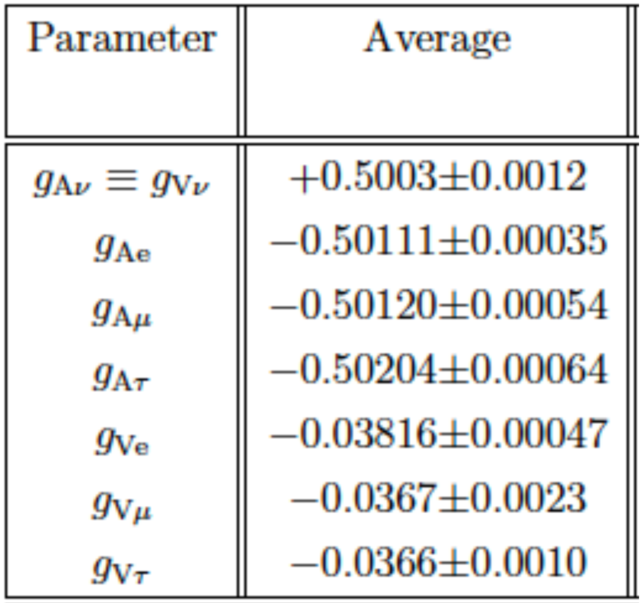
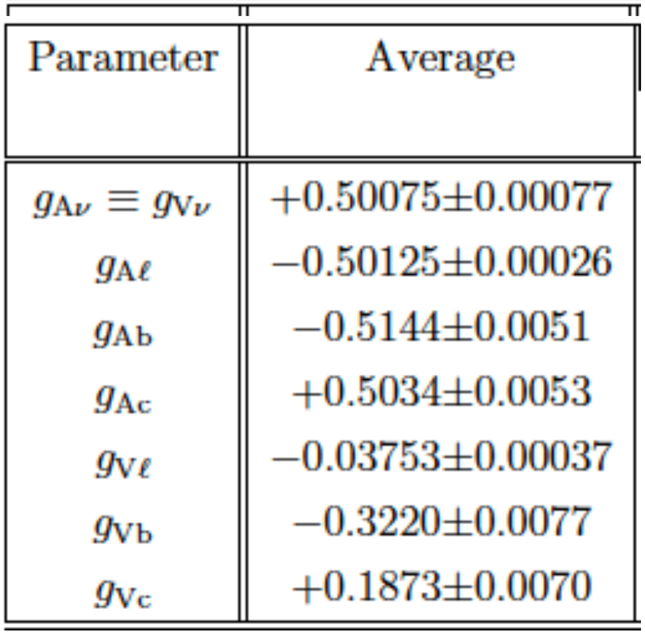


Parameter	Average
$g_{A\nu} \equiv g_{V\nu}$	$+0.5003 \pm 0.0012$
g_{Ae}	-0.50111 ± 0.00035
$g_{A\mu}$	-0.50120 ± 0.00054
$g_{A\tau}$	-0.50204 ± 0.00064
g_{Ve}	-0.03816 ± 0.00047
$g_{V\mu}$	-0.0367 ± 0.0023
$g_{V\tau}$	-0.0366 ± 0.0010



Parameter	Average
$g_{A\nu} \equiv g_{V\nu}$	$+0.50075 \pm 0.00077$
$g_{A\ell}$	-0.50125 ± 0.00026
g_{Ab}	-0.5144 ± 0.0051
g_{Ac}	$+0.5034 \pm 0.0053$
$g_{V\ell}$	-0.03753 ± 0.00037
g_{Vb}	-0.3220 ± 0.0077
g_{Vc}	$+0.1873 \pm 0.0070$

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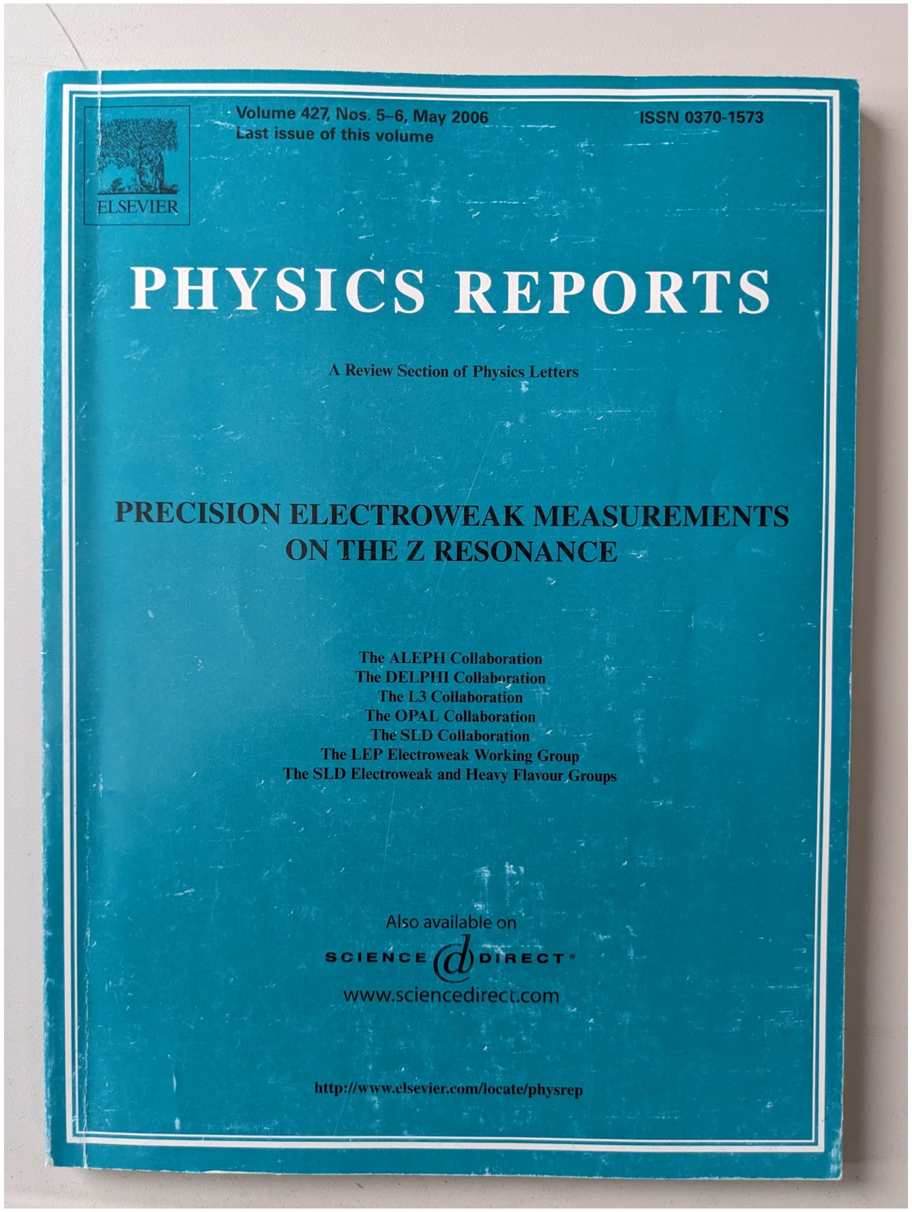

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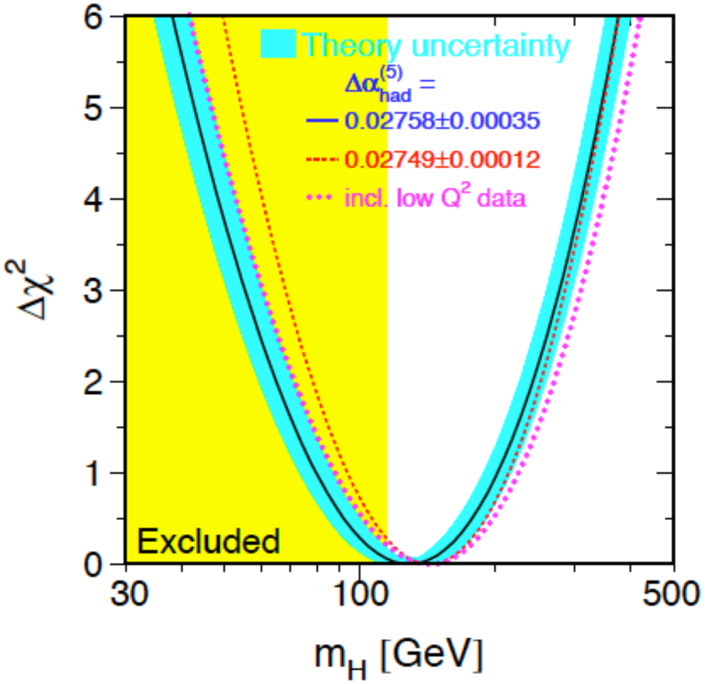

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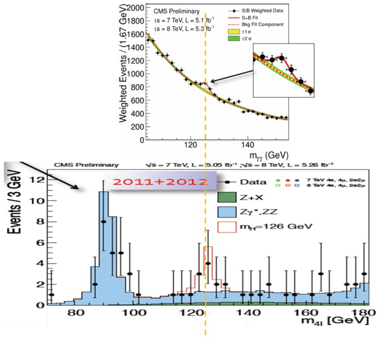
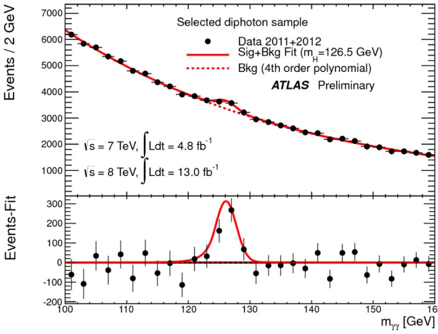
Higgs discovered at 125 GeV in 2012





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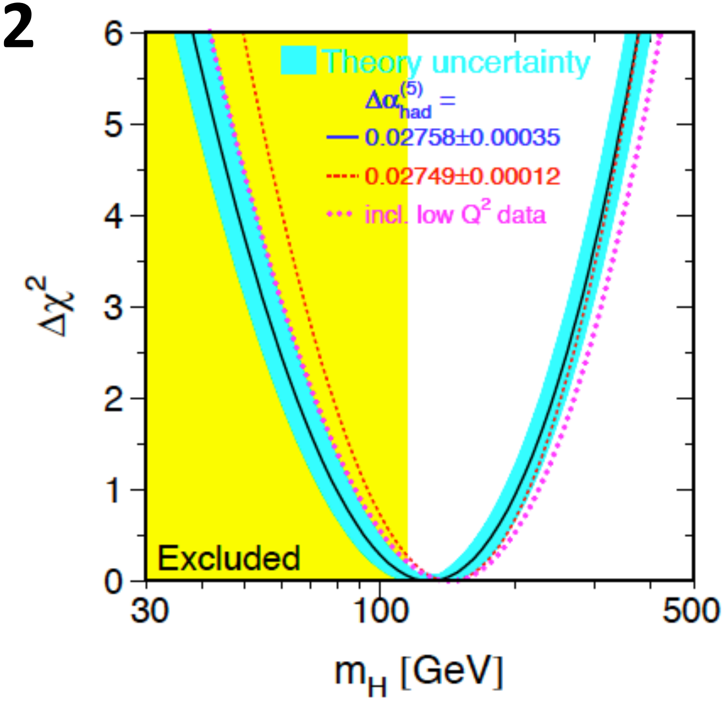
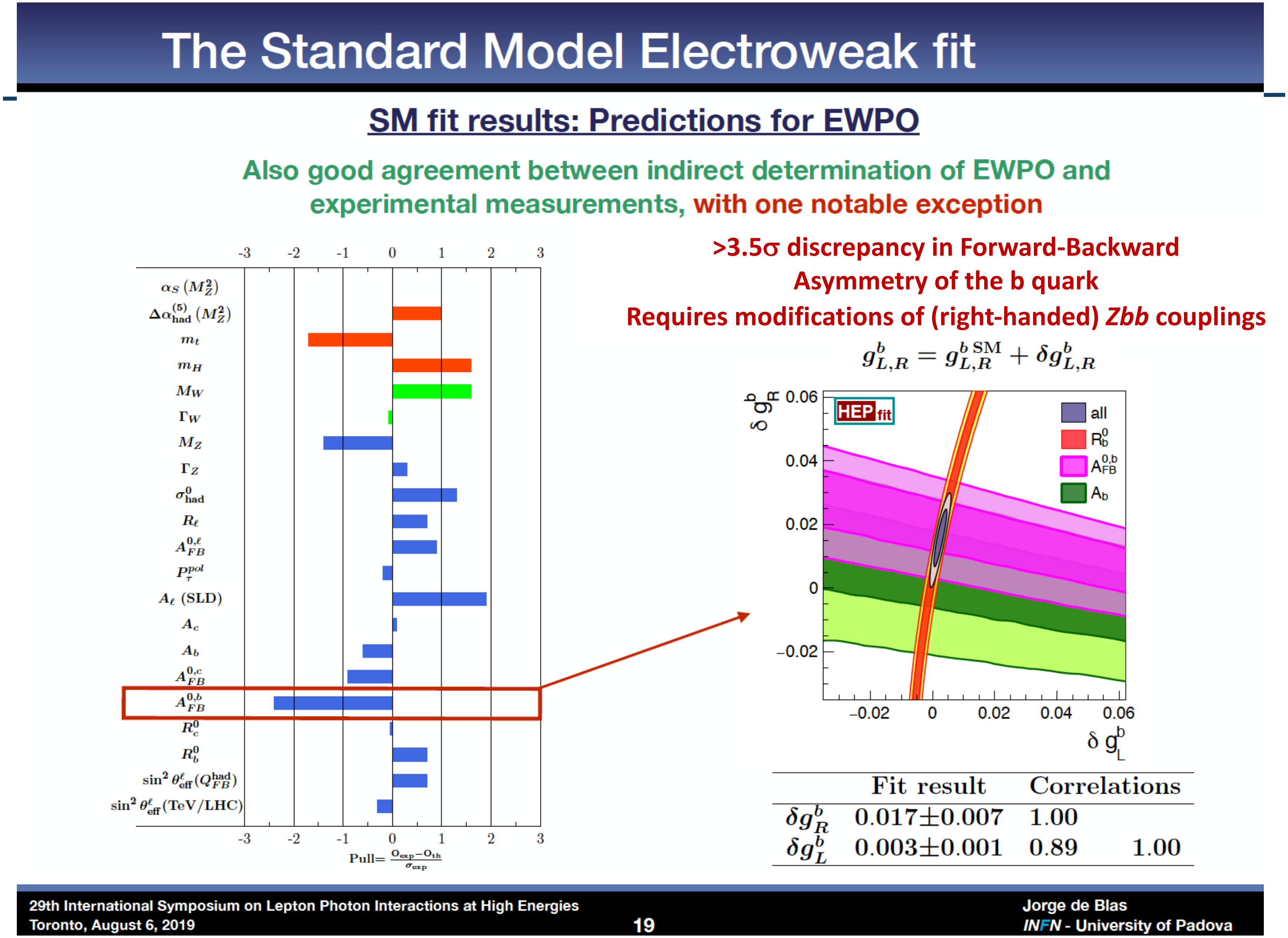


From Jorge de Blas's talk this morning on EW Parameter Fits:



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

>3.5σ discrepancy in Forward-Backward Asymmetry of the b quark

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

$$g_{L,R}^b = g_{L,R}^{b\,{\rm SM}} + \delta g_{L,R}^b$$

	Fit result	Correlations	
δg_R^b	0.017 ± 0.007	1.00	
δg_L^b	0.003 ± 0.001	0.89	1.00

29th International Symposium on Lepton Photon Interactions at High Energies
Toronto, August 6, 2019

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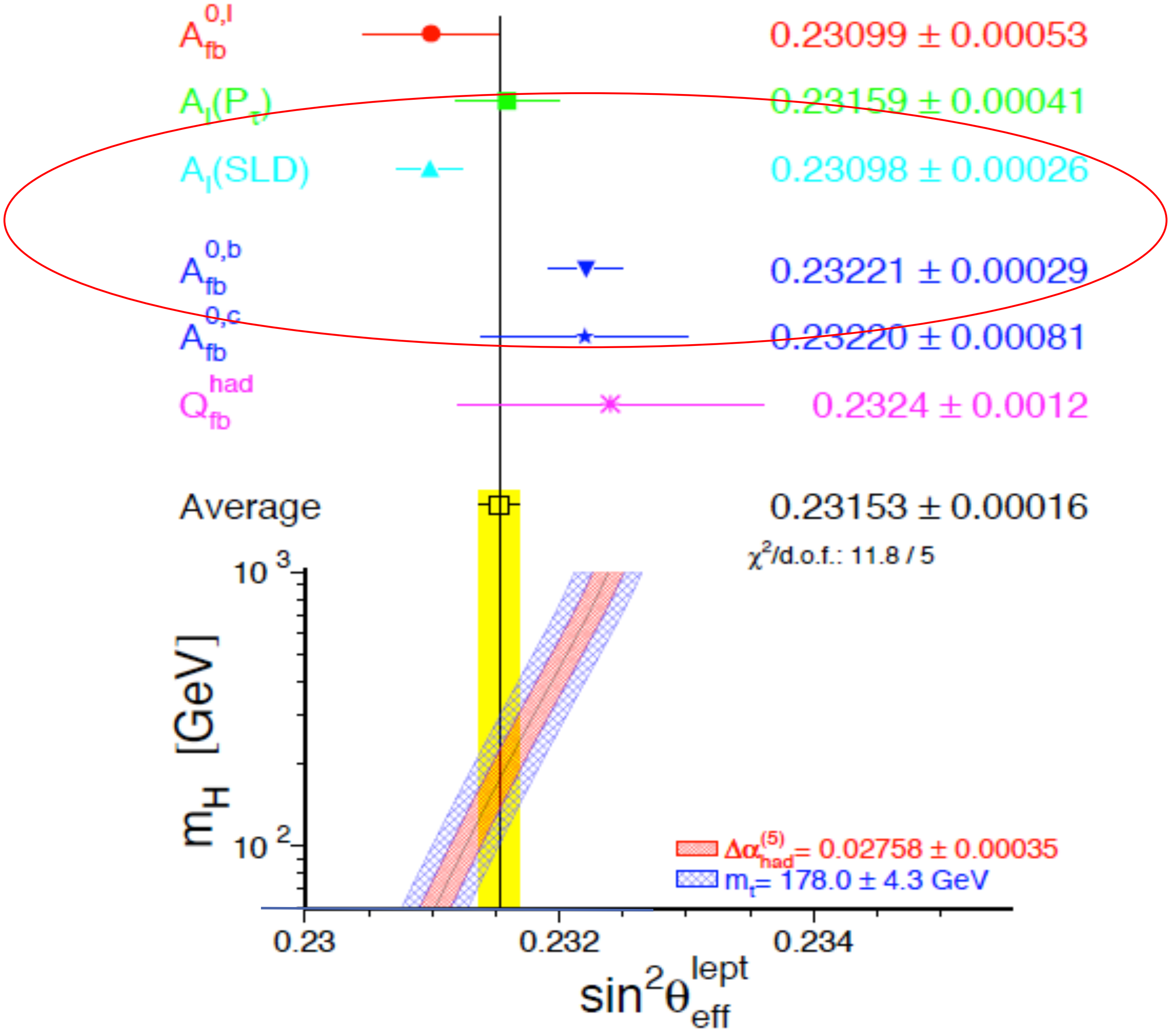
Jorge de Blas
INFN - University of Padova

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)

‘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 :

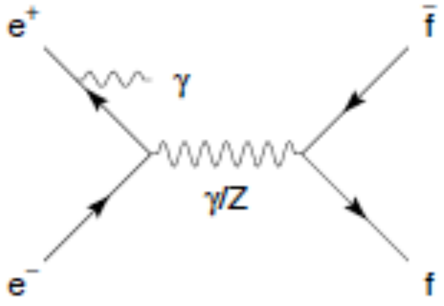
$$\sin^2\theta_{\text{eff}}^{\text{lepton}} = 0.23098 \pm 0.00026$$

- 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:

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

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

(for s-channel Born)



‘Chiral Belle’ Left-Right Asymmetries

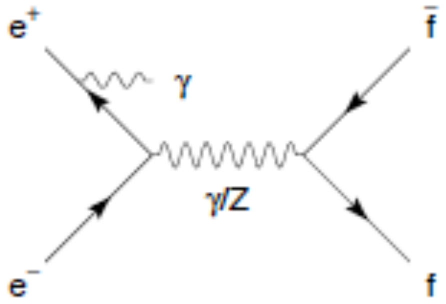
Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode.

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

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

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

(for s-channel Born)



Source generates mainly right-handed electrons

Source generates mainly left-handed electrons

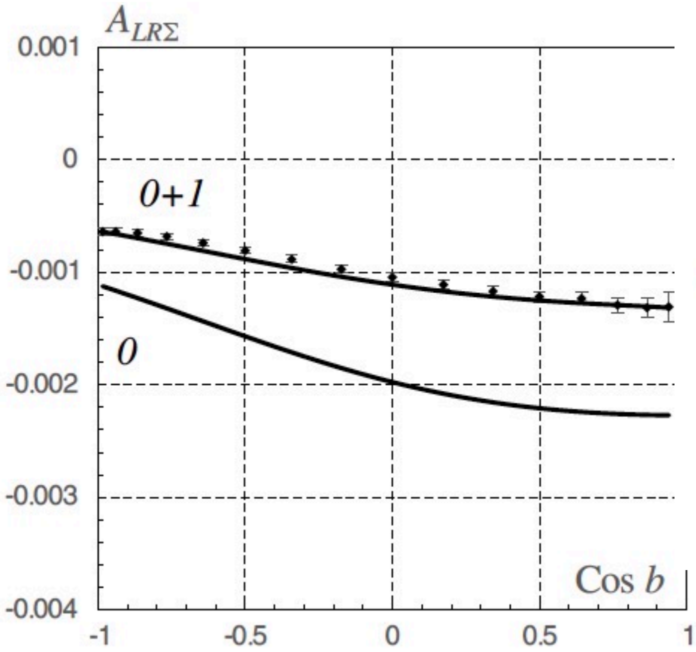
For A_{LR} calculation with NLO corrections for mu-pair final state, see:
Aleksejevs, Barkanova, Roney, Zykunov “NLO radiative corrections for Forward-Backward and Left-Right Asymmetries at a B Factory”, arXiv:1801.08510

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)

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

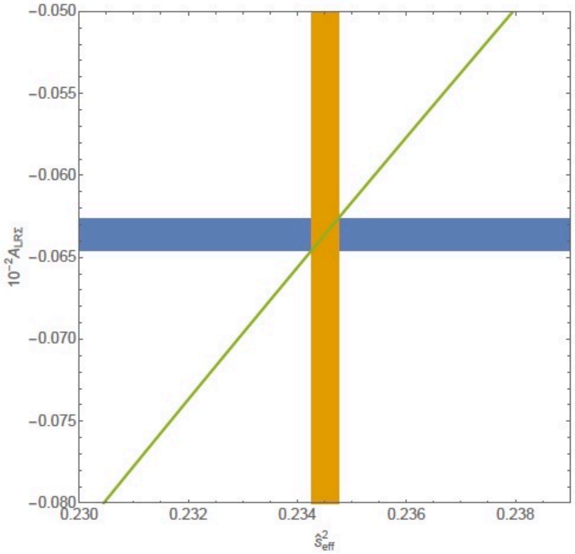


$$\Sigma_L^C = \int_{\cos b}^{\cos a} \sigma_L^C \cdot d(\cos\theta), \quad \Sigma_R^C = \int_{\cos b}^{\cos a} \sigma_R^C \cdot d(\cos\theta)$$

a=10° & energy of photons < 2GeV

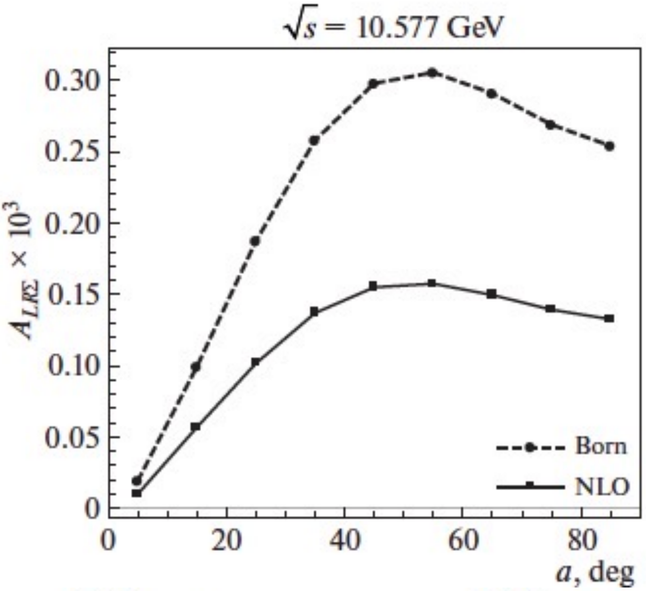
Phys.Rev. D101 (2020) no.5, 053003

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



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

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



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

PHYSICS OF ATOMIC NUCLEI Vol. 83 No. 3 2020

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]

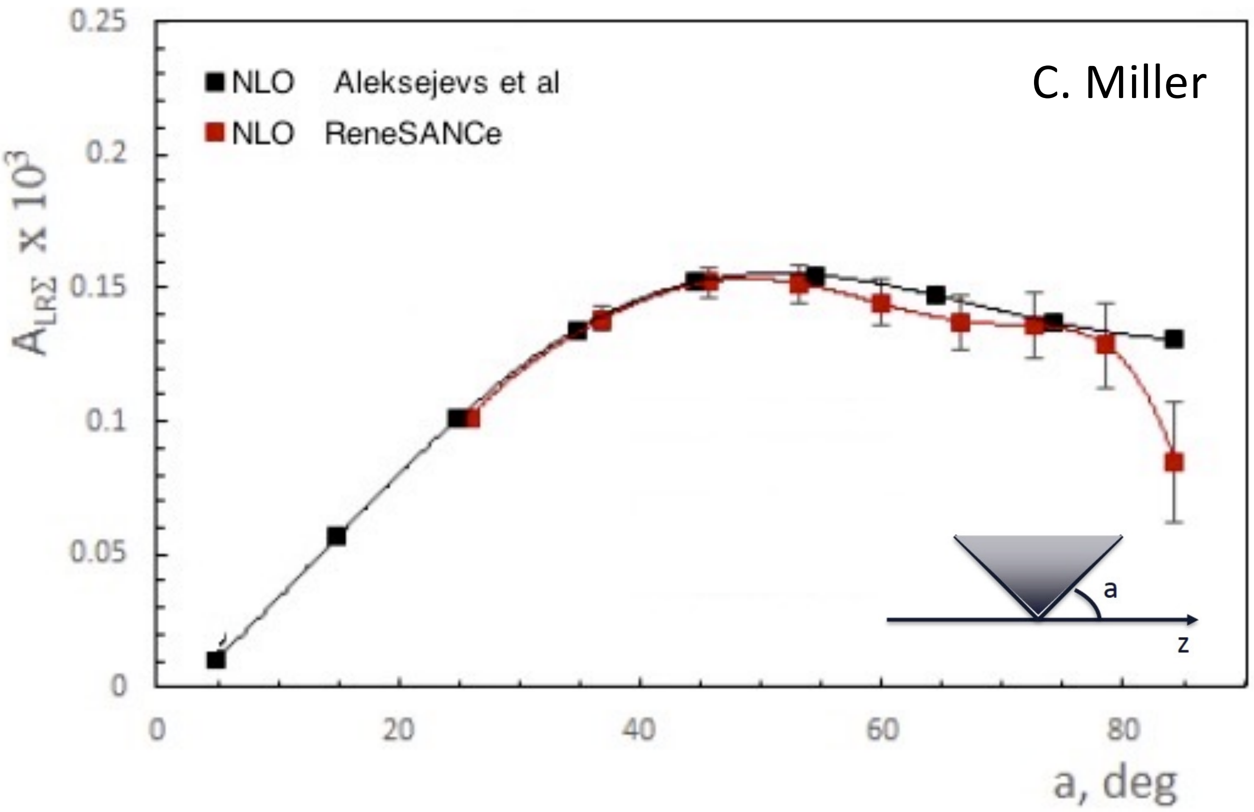
Recently developed generator with beam polarization capable of producing Bhabhas

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

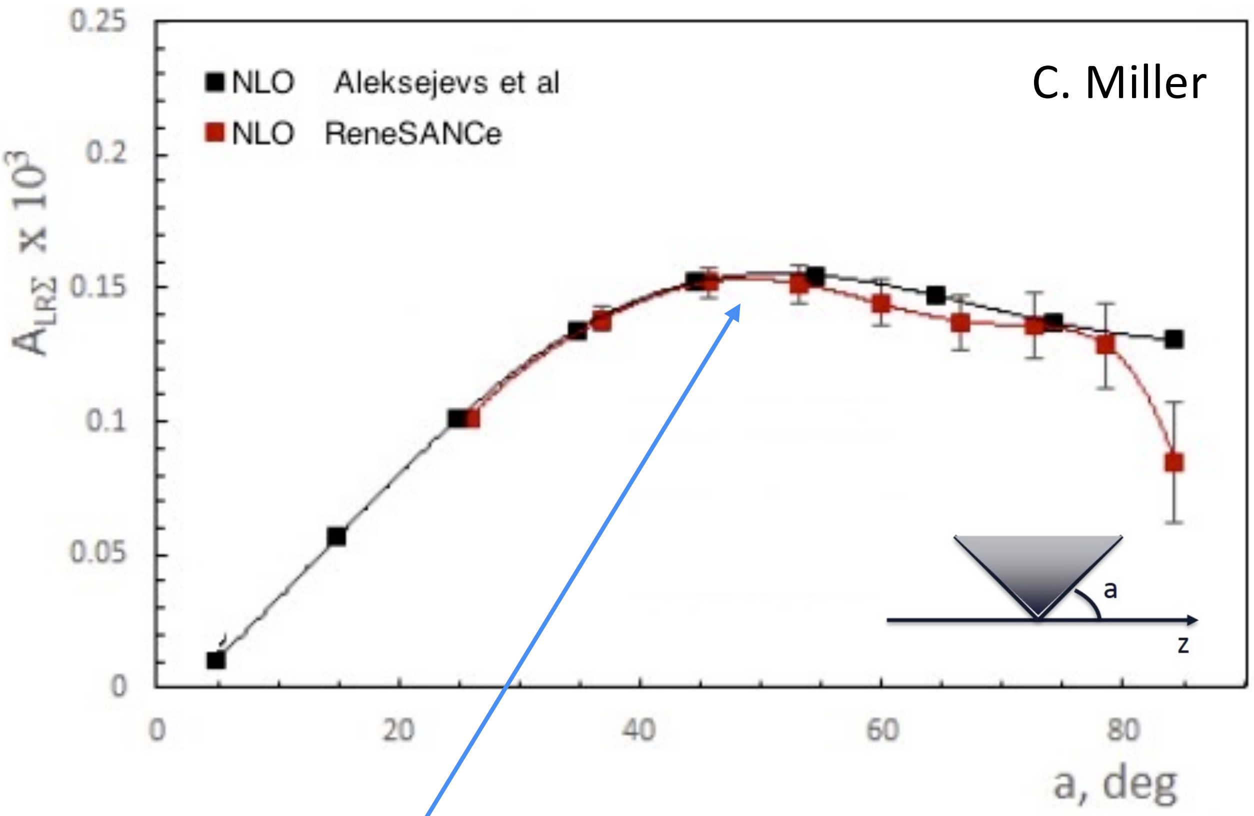
ReneSANCe *cf* Aleksejevs *et al*



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*



C. Miller

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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^{-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

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

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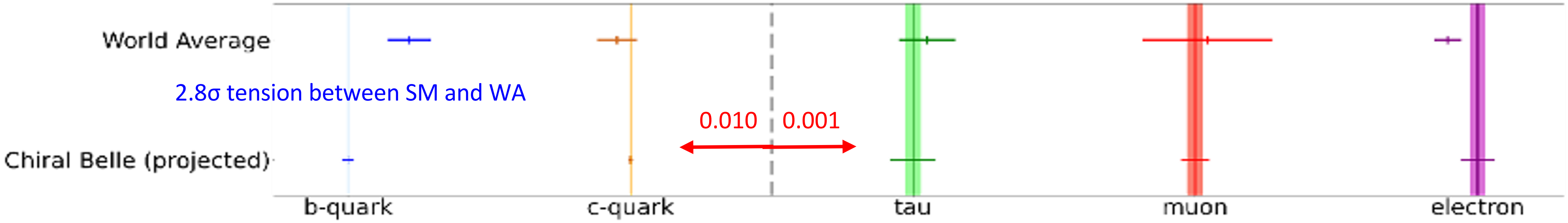
$\sin^2\Theta_W$ - Chiral Belle combined leptons with 40 ab^{-1} have error ~current WA

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	0.0017 (>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) : σ(g_V^f) = $0.00033_{\text{stat}} \pm 0.00018_{\text{sys}}$ [*cf.* SM error of ±0.0003]



2.8σ tension between SM and WA

0.010

0.001

Staging of Chiral Belle Precision electroweak measurements

Chiral Belle Measures Weak Mixing Angle, θ_W, for each fermion, f by measuring A^f_{LR}, Left-Right Asymmetry of e+e- $\rightarrow f\,\bar{f}$ cross sections where:

$$A^f_{LR} \propto g^f_V$$

Standard Model: Neutral Current vector Coupling of fermion f:

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

$T^f_3 = -\frac{1}{2}$ f = e, mu, tau,b

$T^f_3 = +\frac{1}{2}$ f= c-quark

Q_f = charge of f

Fermion *f*	g^f_V **(Standard Model)**	g^f_V **(World Average)**	$\sigma(g^f_V)$ **Chiral Belle 0.5ab^{-1}**	$\sigma(g^f_V)$ **Chiral Belle 1ab^{-1}**	$\sigma(g^f_V)$ **Chiral Belle 5ab^{-1}**	$\sigma(g^f_V)$ **Chiral Belle 20ab^{-1}**
b-quark	-0.3437 ± 0.0001	-0.3220 ±0.0077 (2.8σ off SM)	0.0026 **3x better than World Ave σ**	0.0022 **>3x better than World Ave σ**	0.0018 **>4x better than World Ave σ**	0.0017 **>4x better than World Ave σ**
c-quark	0.1920 ± 0.0002	0.1873 ± 0.0070	0.005	0.0036 **2x better than World Ave σ**	0.0018 **4x better than World Ave σ**	0.0011 **>6x better than World Ave σ**
Tau	-0.0371 ± 0.0003	-0.0366 ± 0.0010	0.0069	0.0049	0.0022	0.0011 (~ W.A. σ)
Muon	-0.0371 ± 0.0003	-0.03667 ± 0.0023	0.0043	0.0031	0.0014 **1.6x better than World Ave σ**	0.0007 **>3x better than World Ave σ**
Electron	-0.0371 ± 0.0003	-0.03816 ± 0.00047	0.0055	0.0039	0.0017	0.0006 (~ W.A. σ)

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Chiral Belle probes both high and low energy scales

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

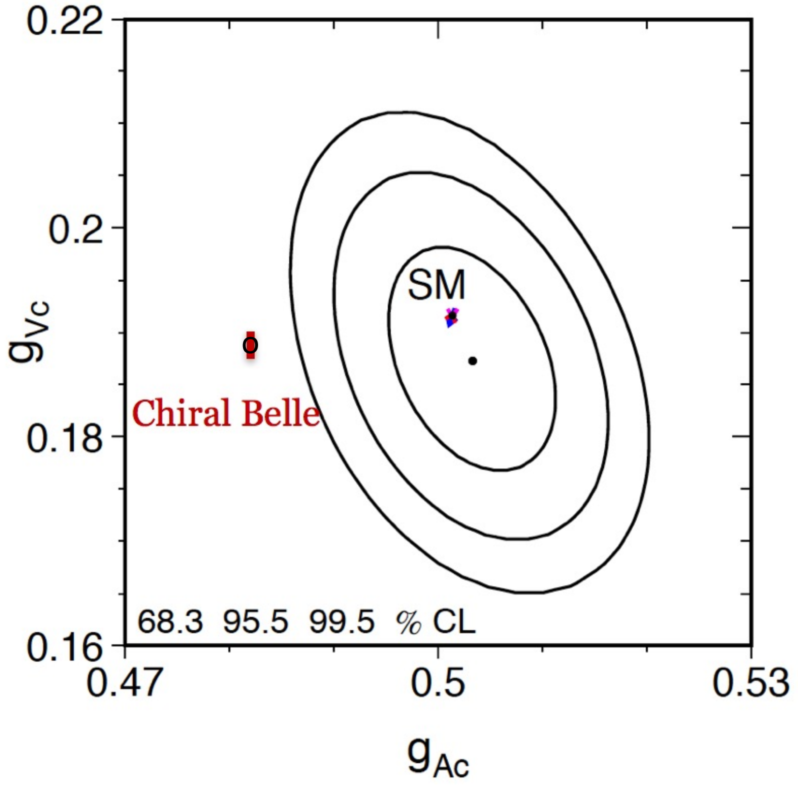
c-quark:

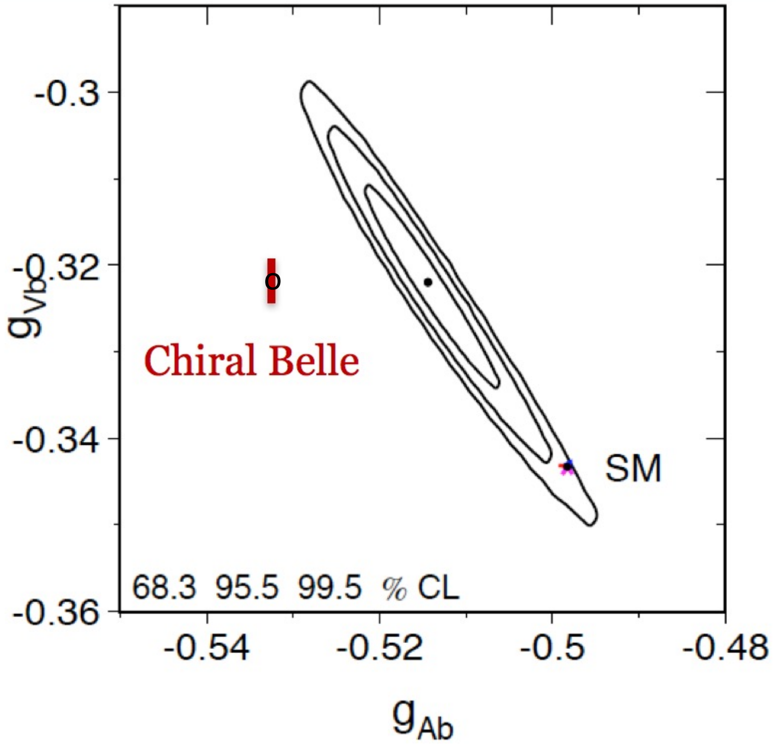
Chiral Belle ~7 times more precise

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

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

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

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.

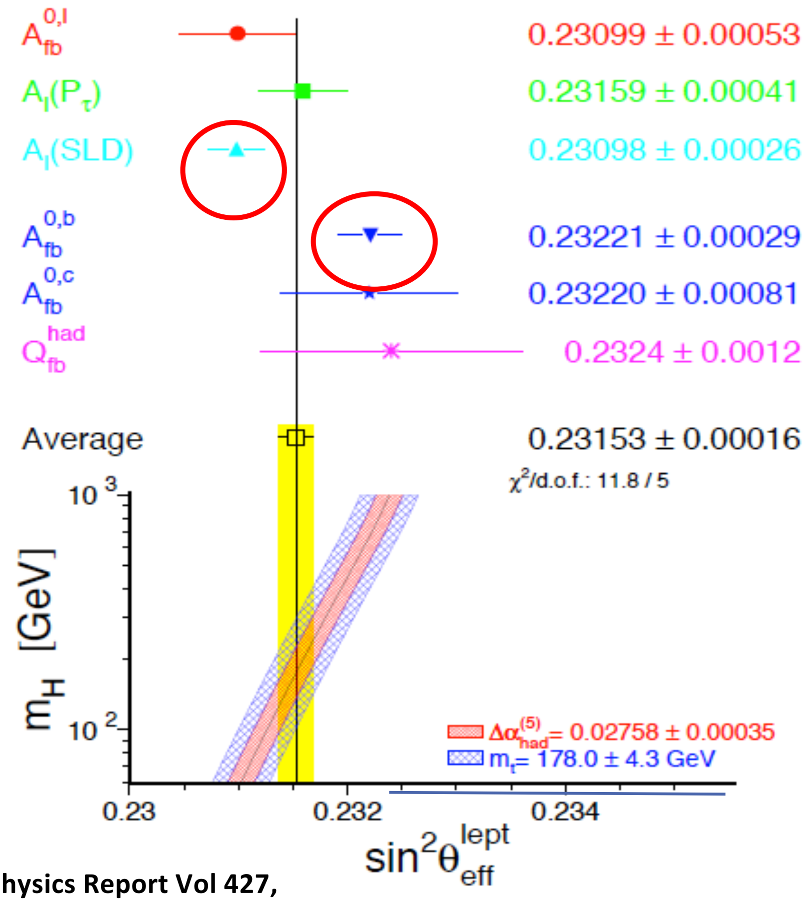
Produces VERY high precision evaluation of Standard Model predictions of the ratios

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)

Existing tension in data on the Z-Pole



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

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

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

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

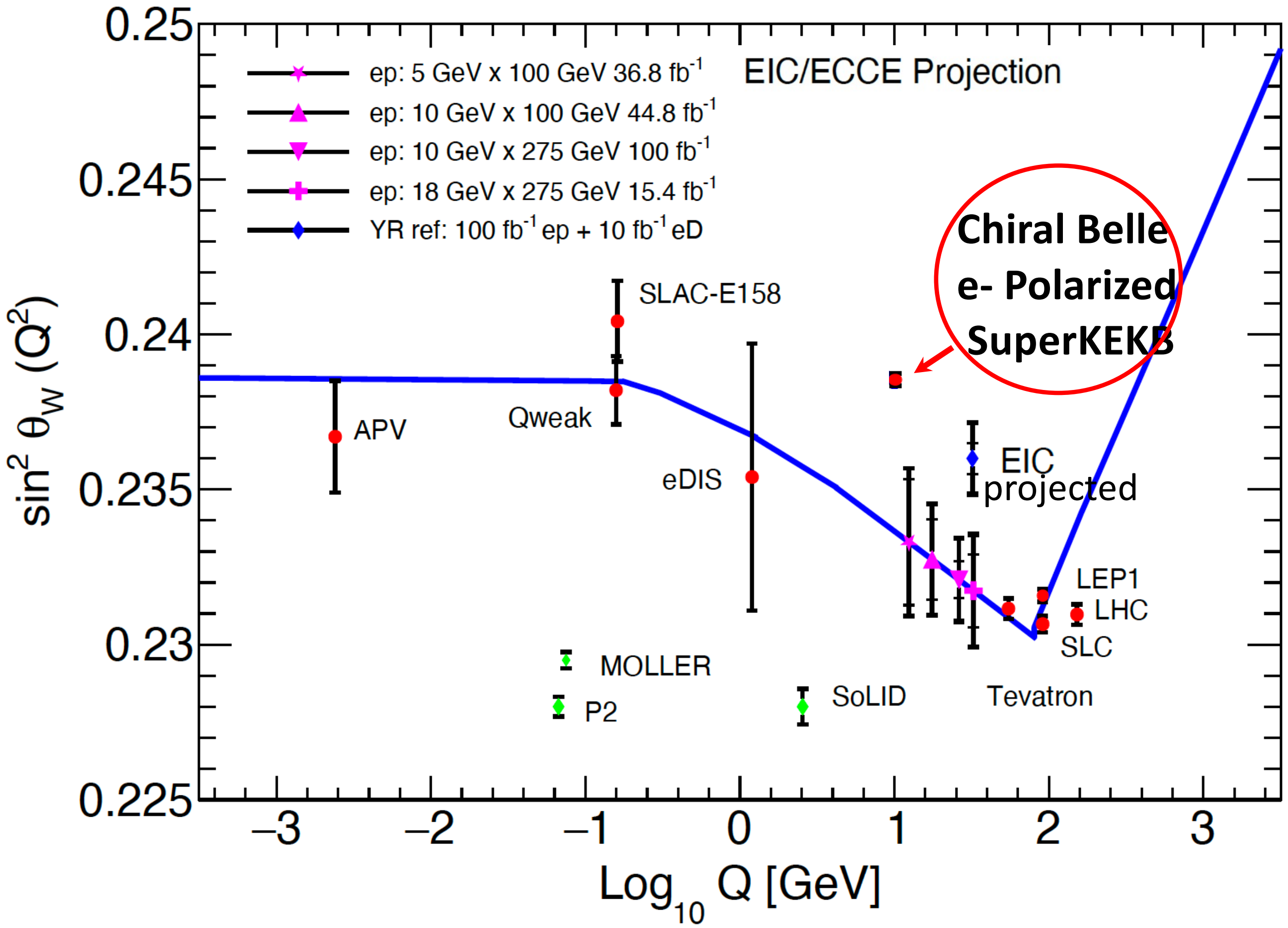
40ab^{-1} @ Chiral Belle gives Highest precision neutral-current universality measurements by many factors (e.g. Chiral Belle b-quark to c-quark universality measurement is >14x more precise than combined World Average)

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



Chiral Belle
e- Polarized
SuperKEKB

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

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

Figure Adapted from *Phys Rev D 106, 016006 (2022)*
(used in EIC Snowmass Whitepaper *arXiv:2203.13199v2)*
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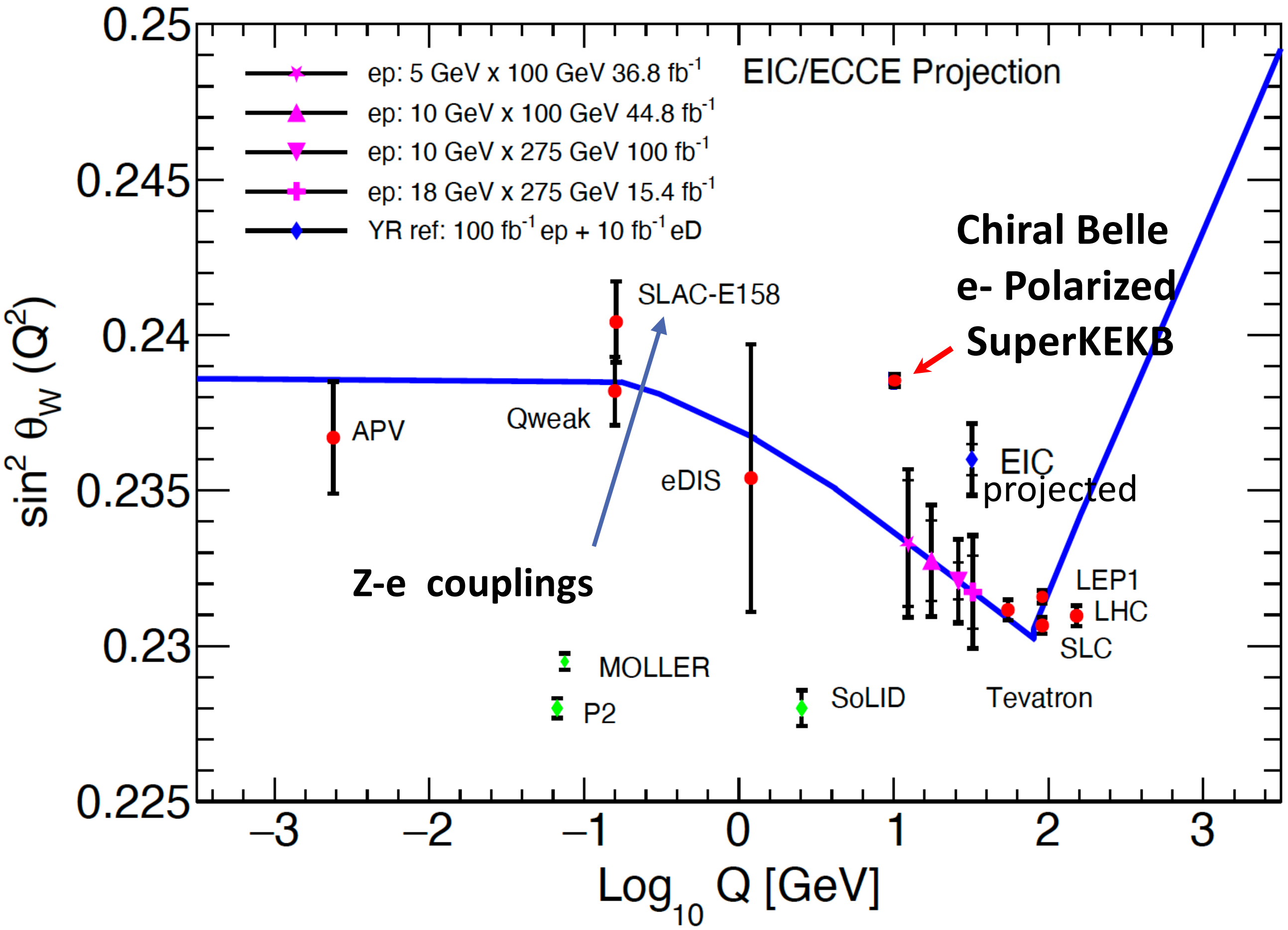

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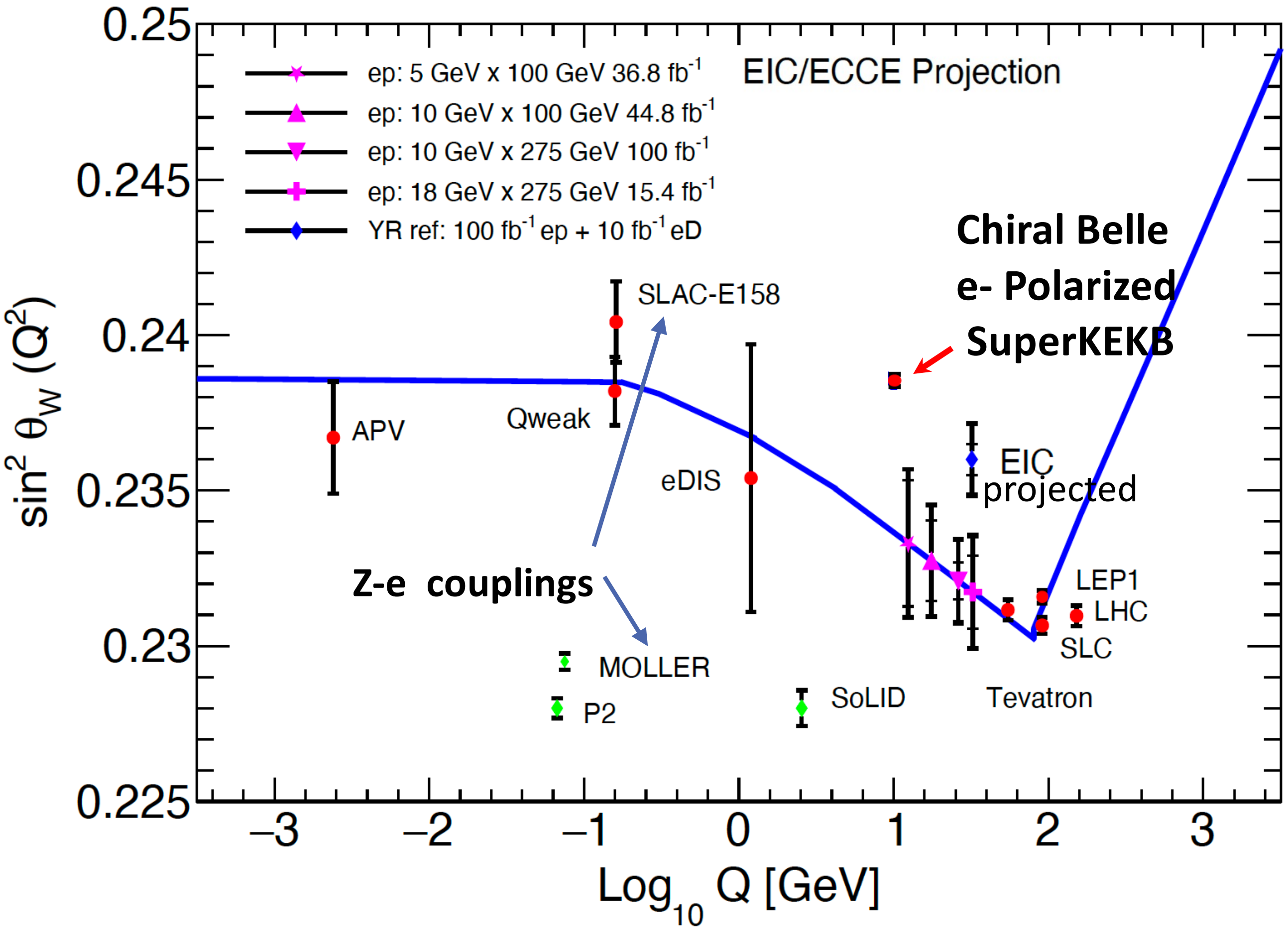

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cf **Chiral Belle: e, μ, τ, c- & b-quarks**

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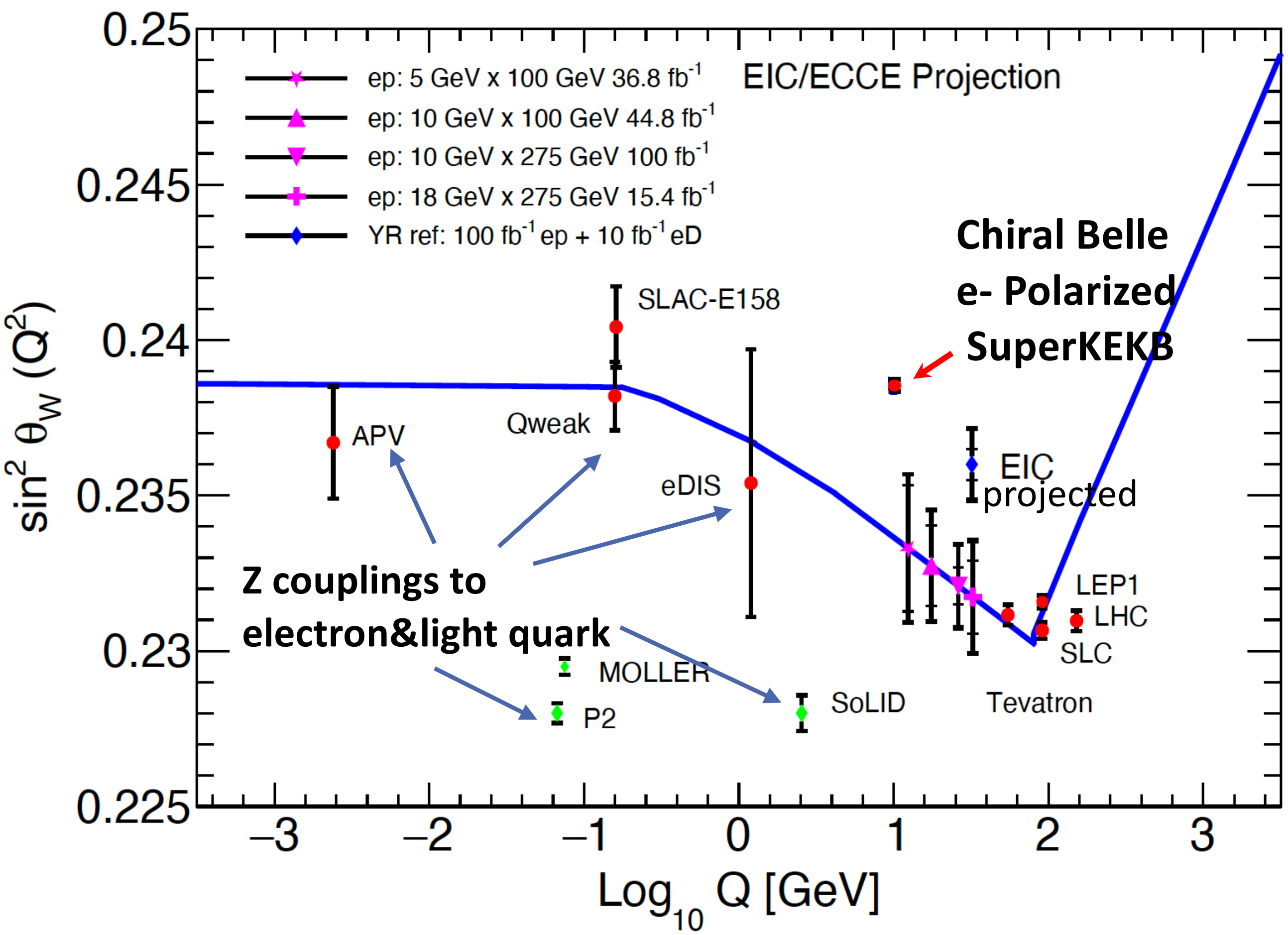

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e- Polarized
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Z couplings to
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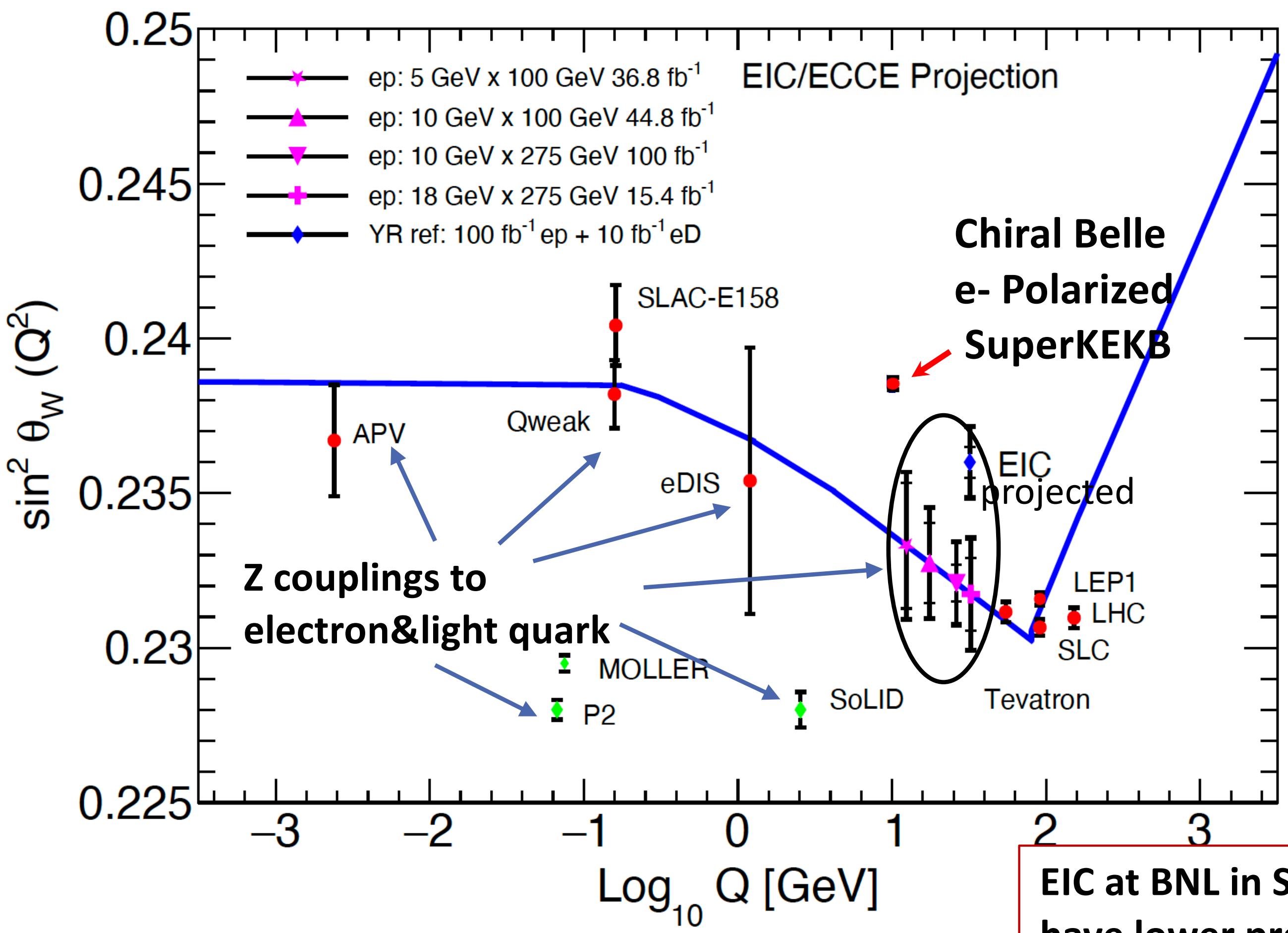

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EIC at BNL in SuperKEKB energy range, but EIC will have lower precision and only for couplings involving 1st generation fermions $\sigma_{\sin 2\theta W}$ (EIC) = 0.0012
***cf*   0.0002 @ Chiral Belle**

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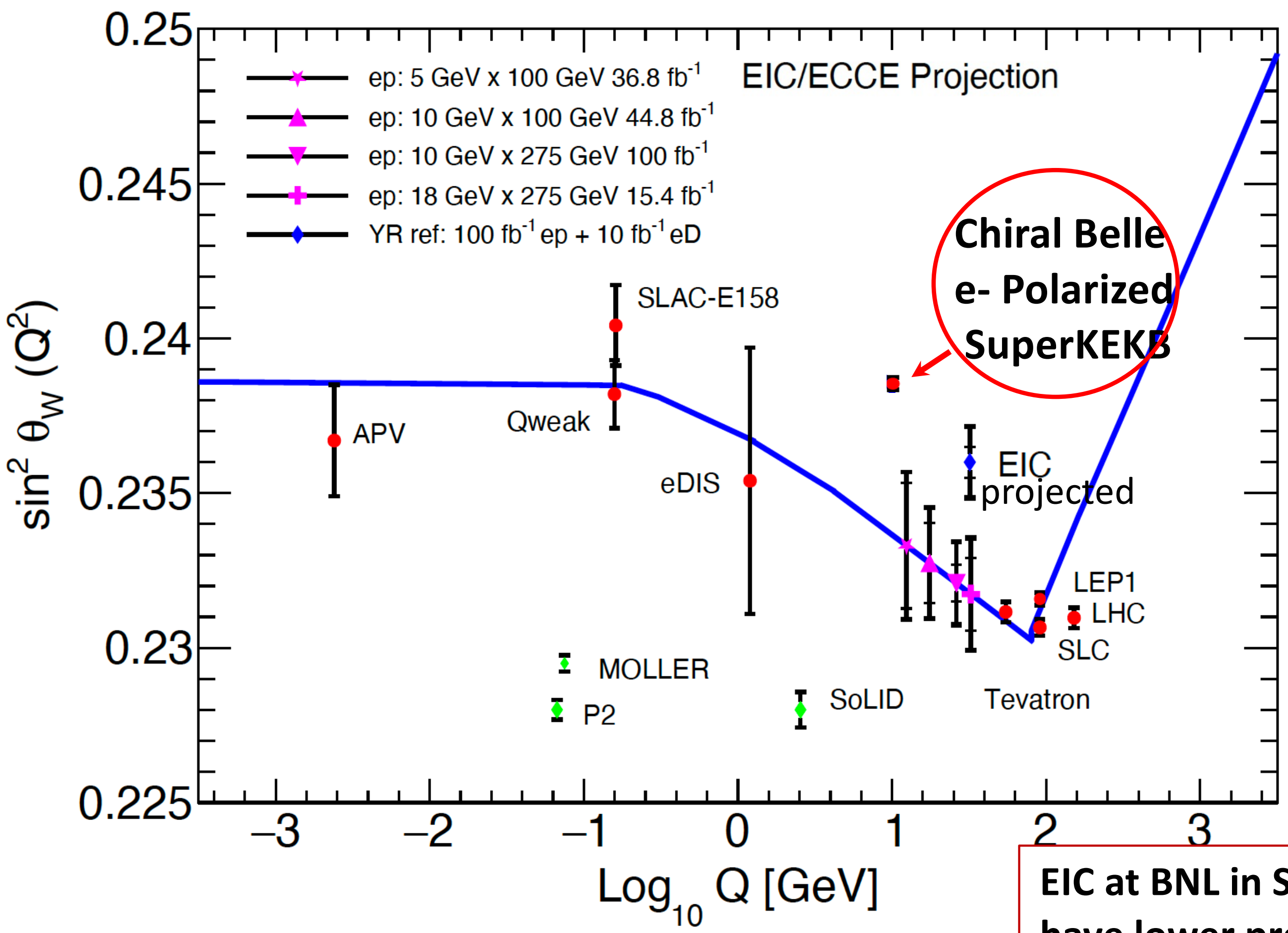

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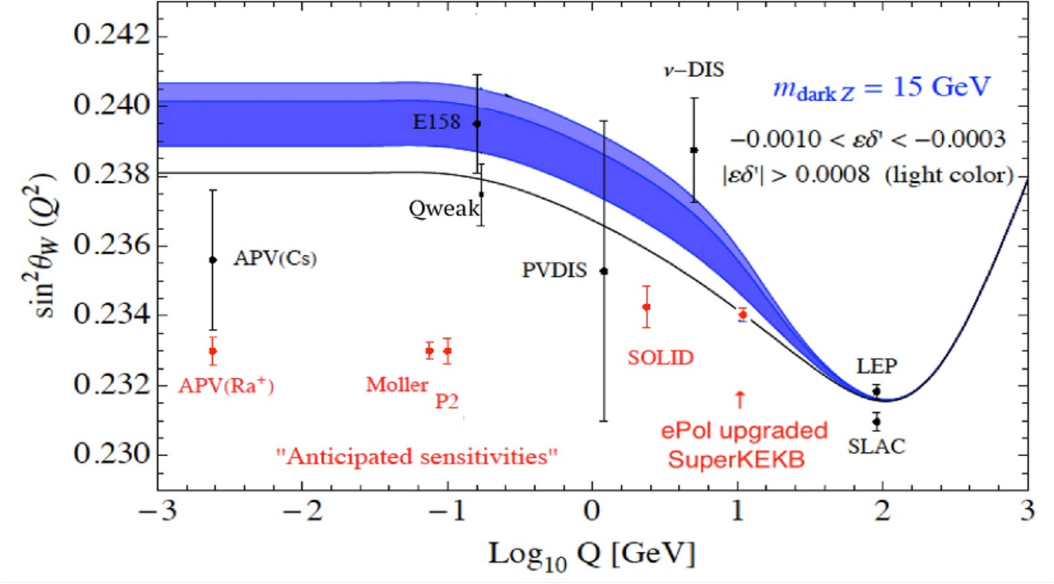
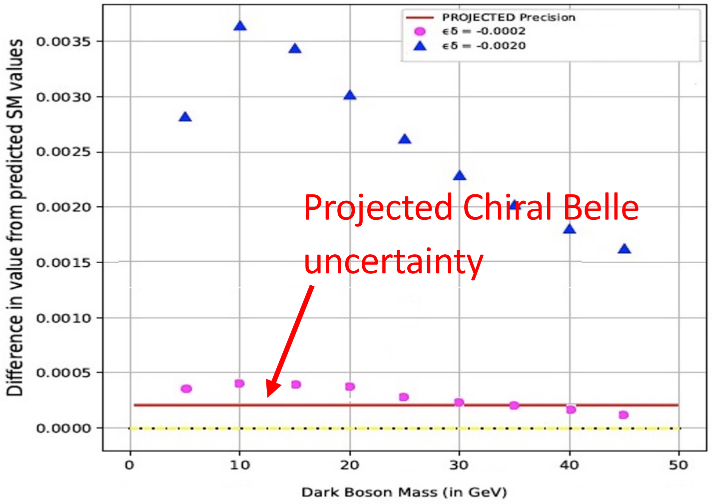
Upgrading SuperKEKB with e- Polarized Beams: Chiral Belle ⟶ unique probe of Dark Sector

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



Projected Chiral Belle uncertainty

- **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**

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 physics broader program includes:

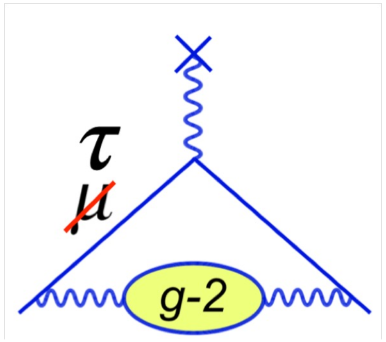
- Tau Lepton Magnetic Form factor F_2(10GeV) → τ g-2
- τ electric dipole moment (EDM)
- Improved precision measurements of τ Michel Parameters
- e^- beam polarization can be used to reduce backgrounds in $\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$ – leading to improved sensitivities; 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

$$\boxed{a_\ell = (g_\ell - 2)/2}$$

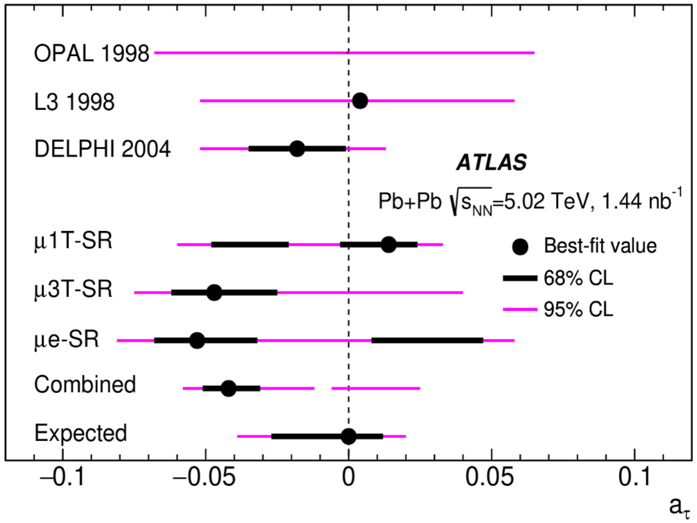
Tensions in anomalous magnetic moment of muon…

Expectation from Minimal flavor violation:



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

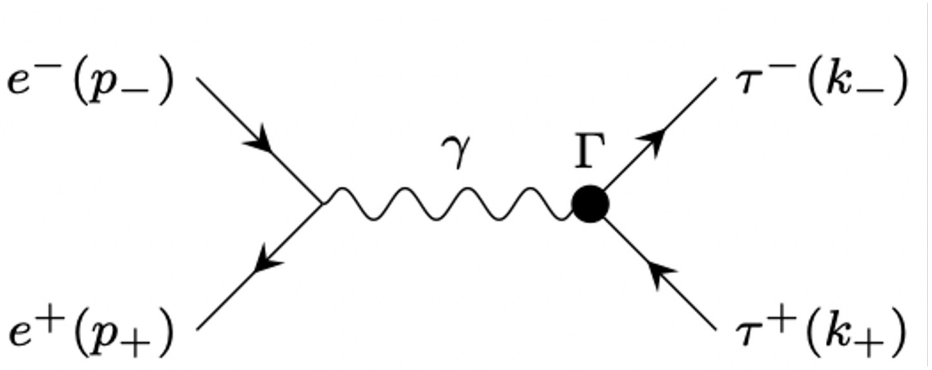
Current bound in tau ~ $\mathcal{O}(10^{-2})$
Chiral Belle reach ~10^{-5} with 40ab^{-1}
(~$2\text{x}10^{-5}$ with 10ab^{-1})



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

See also
Quentin Buat – ATLAS tau g-2 talk at Tau 2023
Paul Bühler – ALICE tau g-2 talk at Tau 2023
Gabriel González-Springberg – tau g-2 talk at Tau 2023

Effective field theory approach to τ-pair production



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

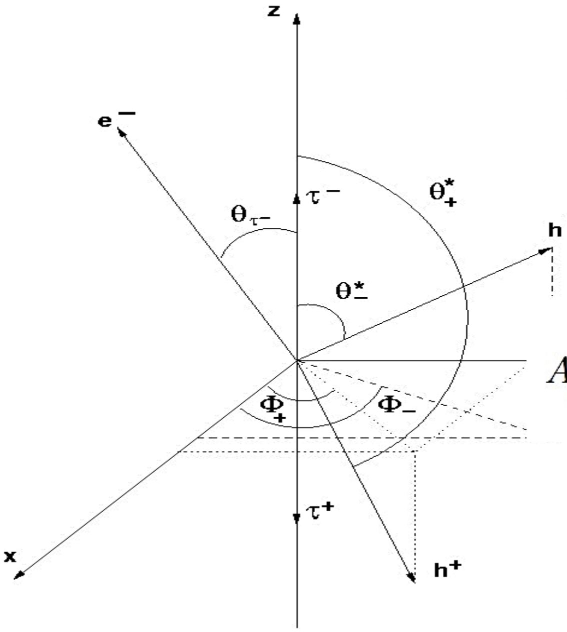
- $F_1\left(q^2\right)$, $F_2\left(q^2\right)$ are called the Dirac and Pauli; $F_1(0) = 1;$ $F_2(0) = a_\tau$
- $g = 2 \cdot [F_1(0) + F_2(0)] = 2 + 2F_2(0)$ $d_\tau^\gamma = \frac{e}{2m_\tau} \cdot F_3(0)$

Leading term:

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

"Schwinger term"

Magnetic dipole moment of τ lepton



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

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

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

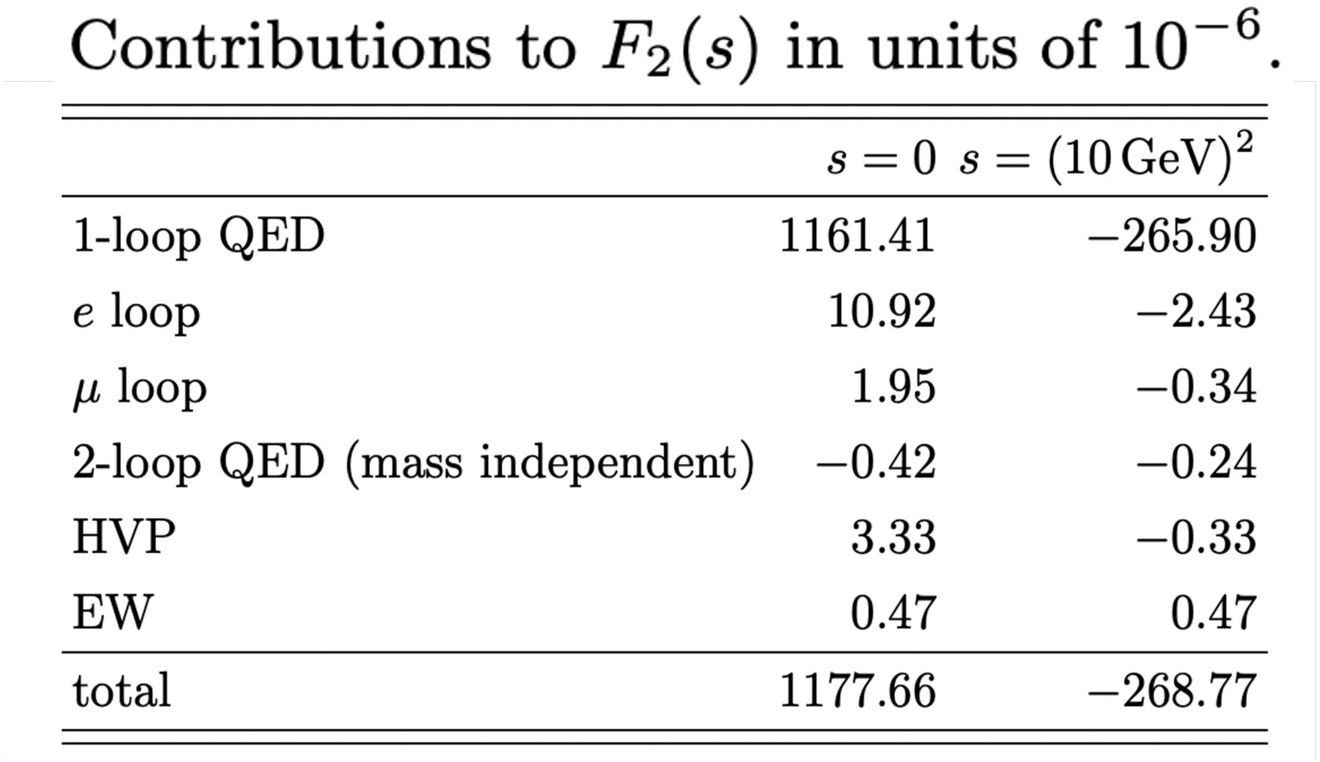
$$\mathrm{Re}(F_2^{\mathrm{eff}}) = \mp\frac{8(3-\beta^2)}{3\pi\gamma\beta^2\alpha_\pm}\left(A_T^{\pm} - \frac{\pi}{2\gamma}A_L^{\pm}\right)$$

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

Magnetic dipole moment of τ lepton

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



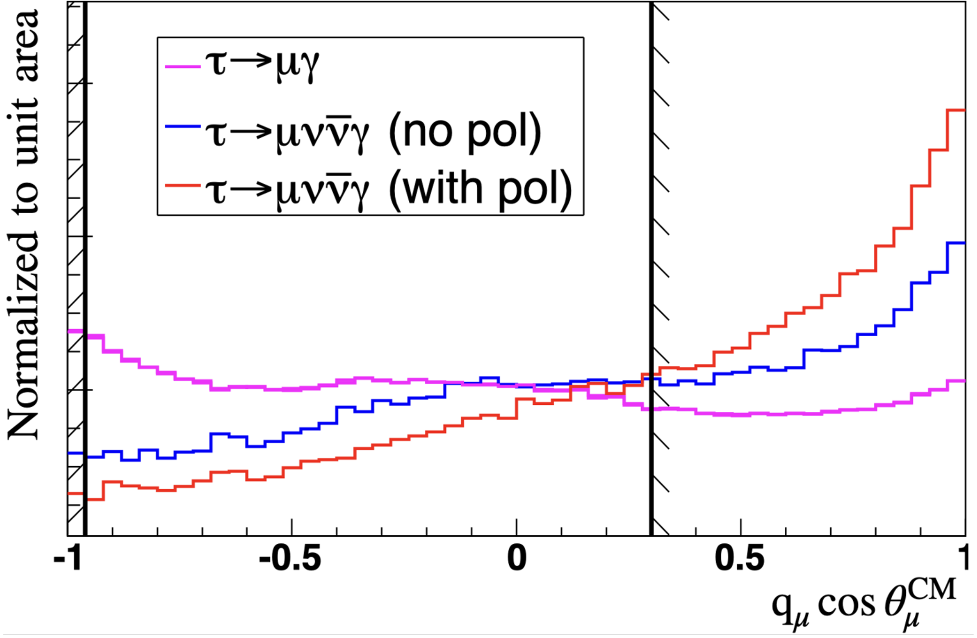
Contributions to $F_2(s)$ in units of 10^{-6}.

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

Search for lepton flavor violation in τ decays

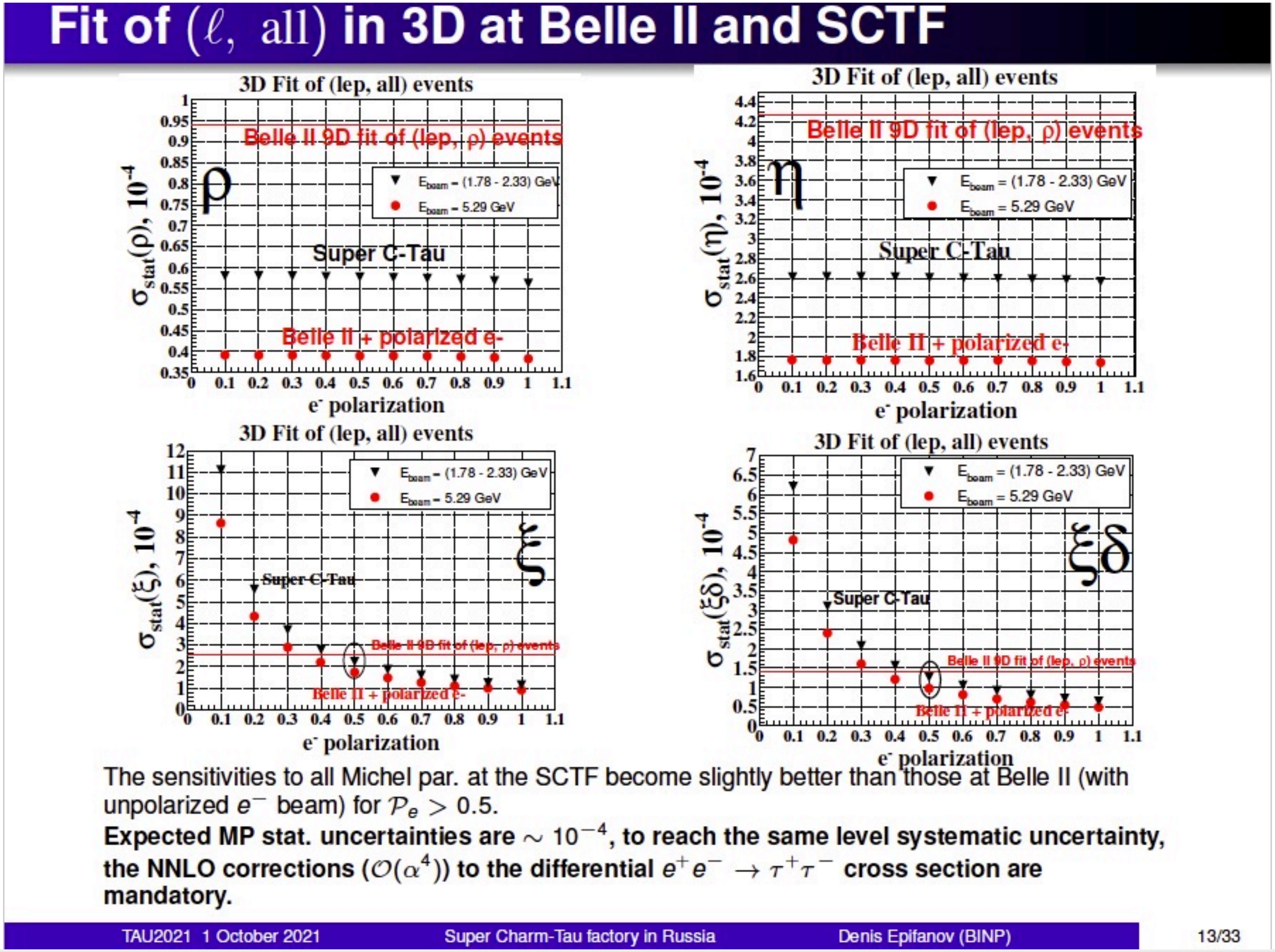
- Belle II to probe LFV in several channels $\simeq \mathcal{O}(10^{-10})$ to $\mathcal{O}(10^{-9})$ with 50 ab^{-1}
- With beam polarization, helicity distributions can suppress backgrounds
- Optimization study shows at least 10% improvement in τ→ℓγ sensitivity



- Possible to disentangle helicity structure of LFV in τ→ℓℓℓ 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 $(\ell,\ \mathrm{all})$ 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

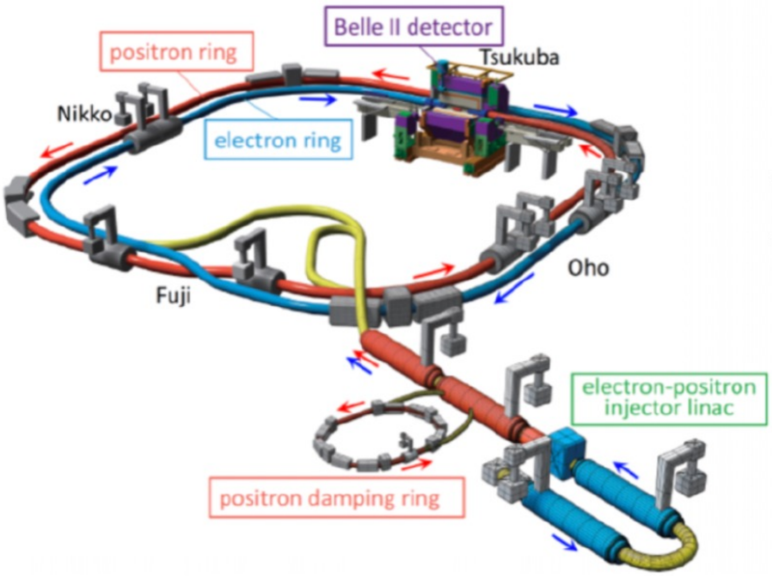
It would be very exciting to have both projects probing tau sector with polarized e- beams

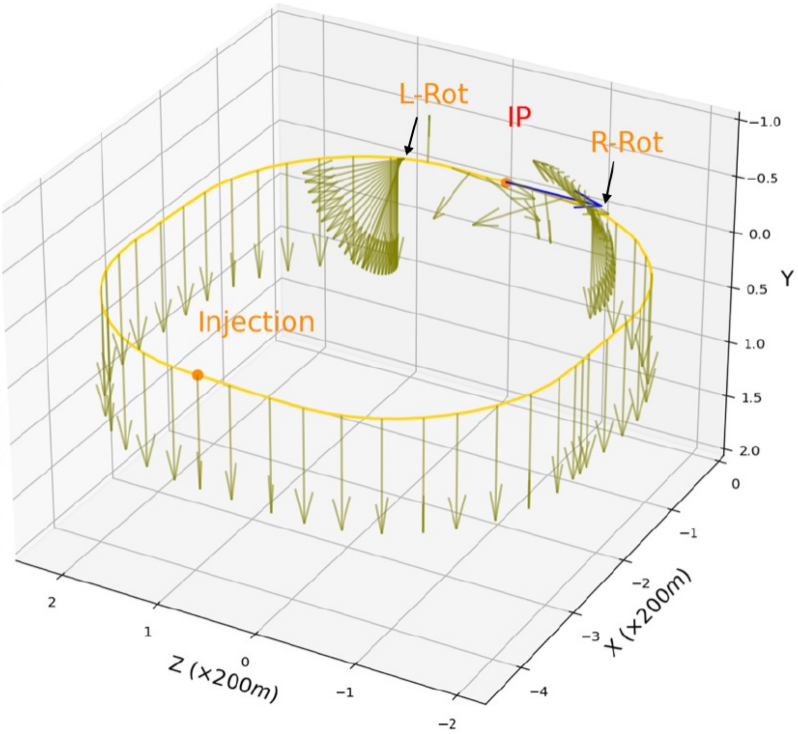
50/ab of polarized Belle II data assumed in these studies

e- beam polarization in SuperKEKB

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

e- beam polarization in SuperKEKB





Polarization in SuperKEKB

- These precision 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

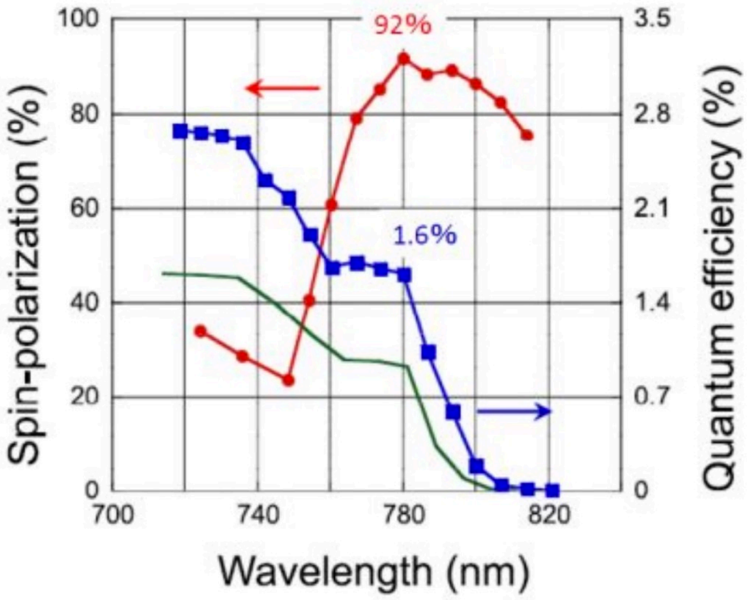
e- beam polarization in SuperKEKB

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

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

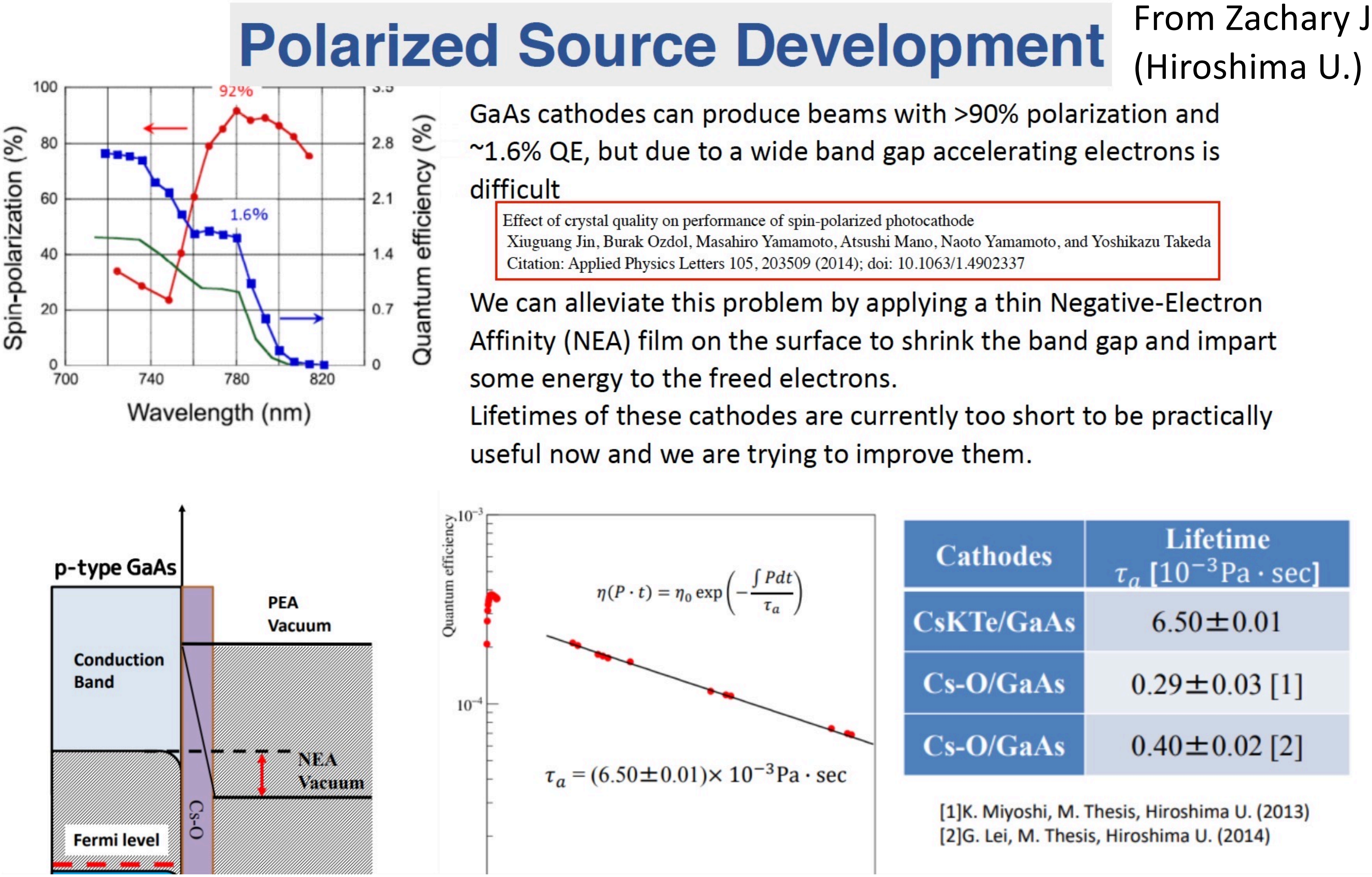
50 mm-mrad horizontal emittance

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

From Zachary J. Liptak
(Hiroshima U.)



Polarized Source Development

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

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

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

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

$$\tau_a = (6.50\pm0.01)\times 10^{-3}\,\mathrm{Pa\cdot sec}$$

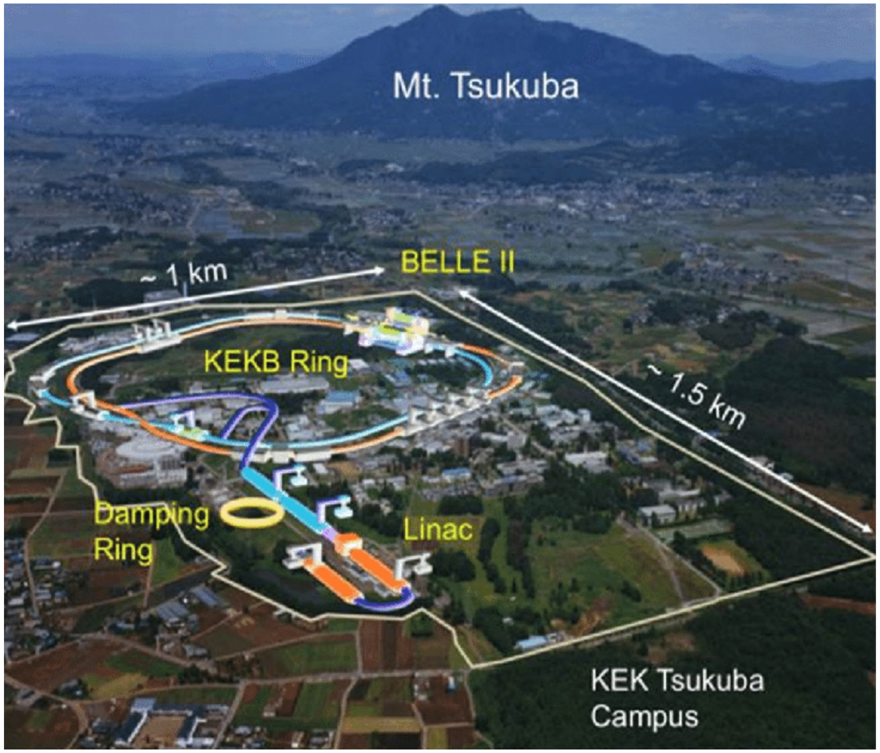
Cathodes	Lifetime τ_a [10^{-3} Pa · sec]
CsKTe/GaAs	6.50±0.01
Cs-O/GaAs	0.29±0.03 [1]
Cs-O/GaAs	0.40±0.02 [2]

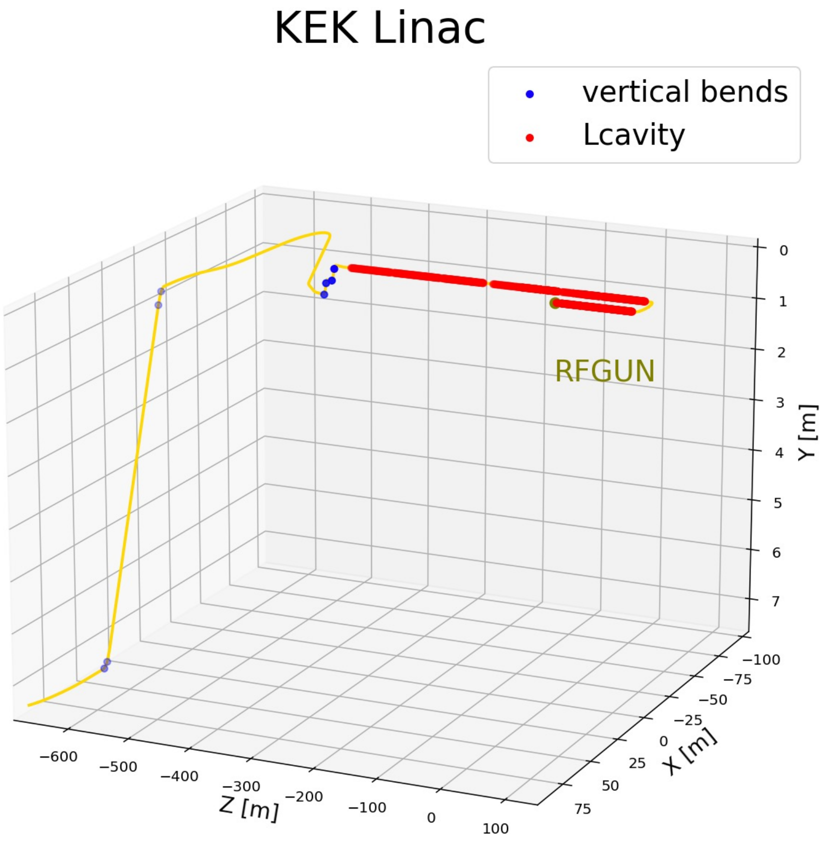
[1]K. Miyoshi, M. Thesis, Hiroshima U. (2013)
[2]G. Lei, M. Thesis, Hiroshima U. (2014)

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

KEK Injection Linac polarization BMAD studies

Y. Peng’s (UVictoria)

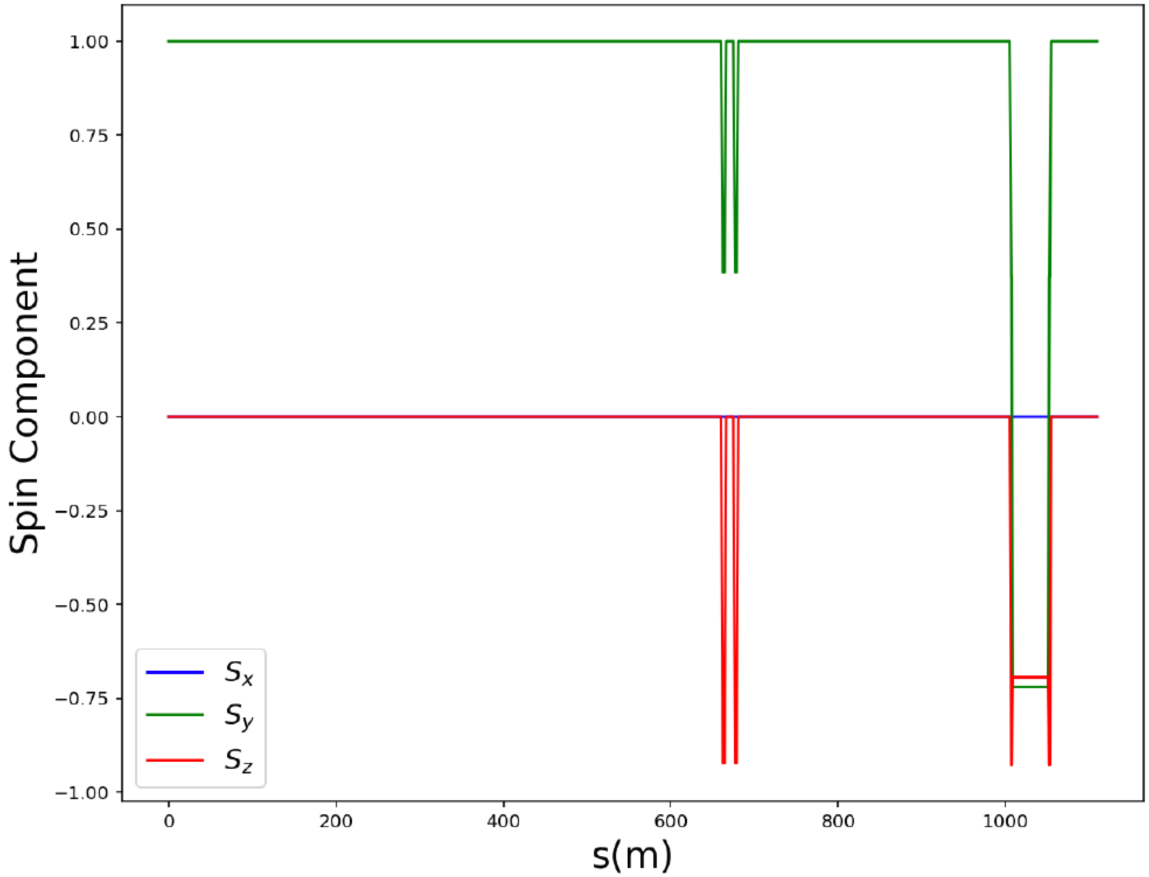



KEK Linac

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

Spin motion in the KEK Injection Linac

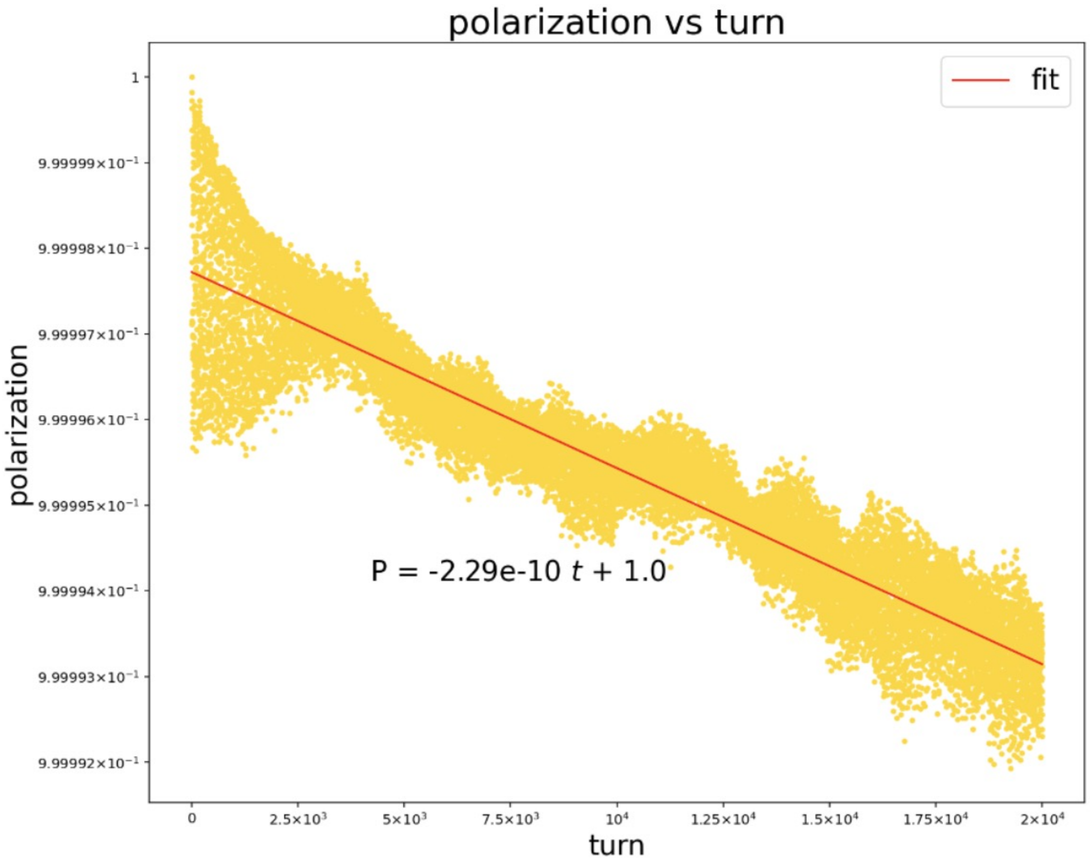
Y. Peng's (UVictoria)



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

Polarization in SuperKEKB

Hardware needs

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

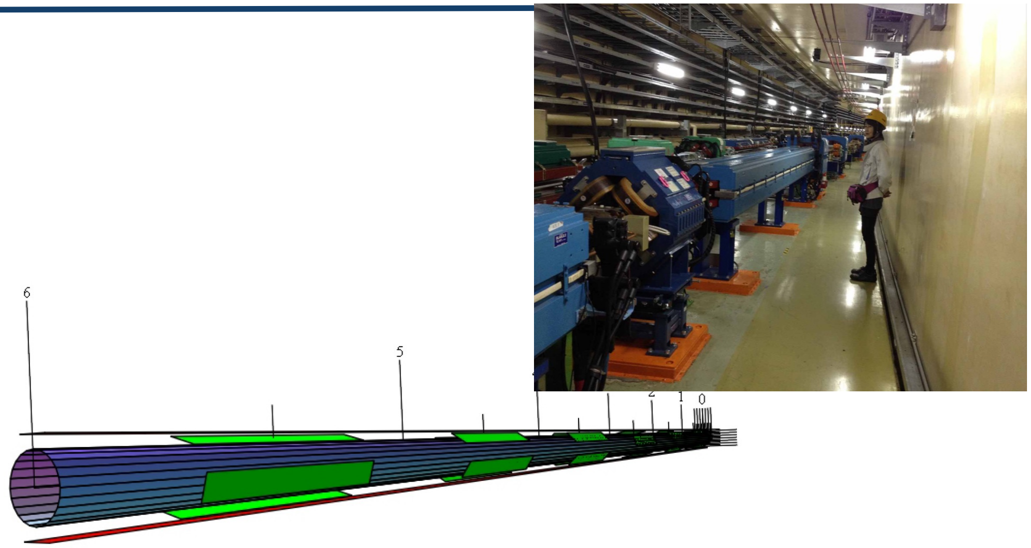
Use of solenoids and dipoles, plus the skew-quadrupoles (needed for decoupling) on either side of interaction point

BINP, ANL, BNL, TRIUMF-Victoria Groups

Polarization in SuperKEKB

Hardware needs

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

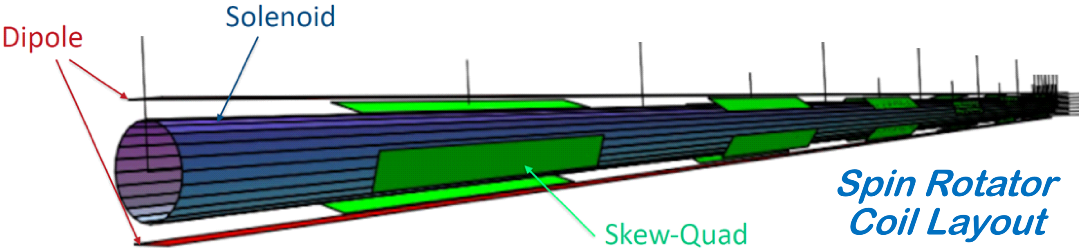


Preliminary studies of two concepts being considered:

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

Novel Concept: Compact spin rotator



Spin Rotator Coil Layout

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

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

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

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

Compact spin rotator

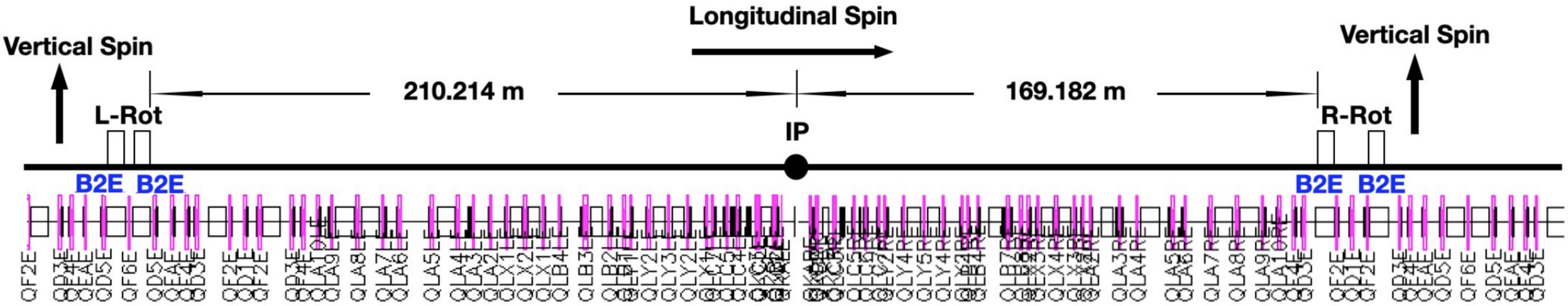
Y. Peng's (Uvictoria) + Uli Wienands (ANL)

Working Constraints for the Design

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

Compact spin rotator

Y. Peng's (UVictoria)



- 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

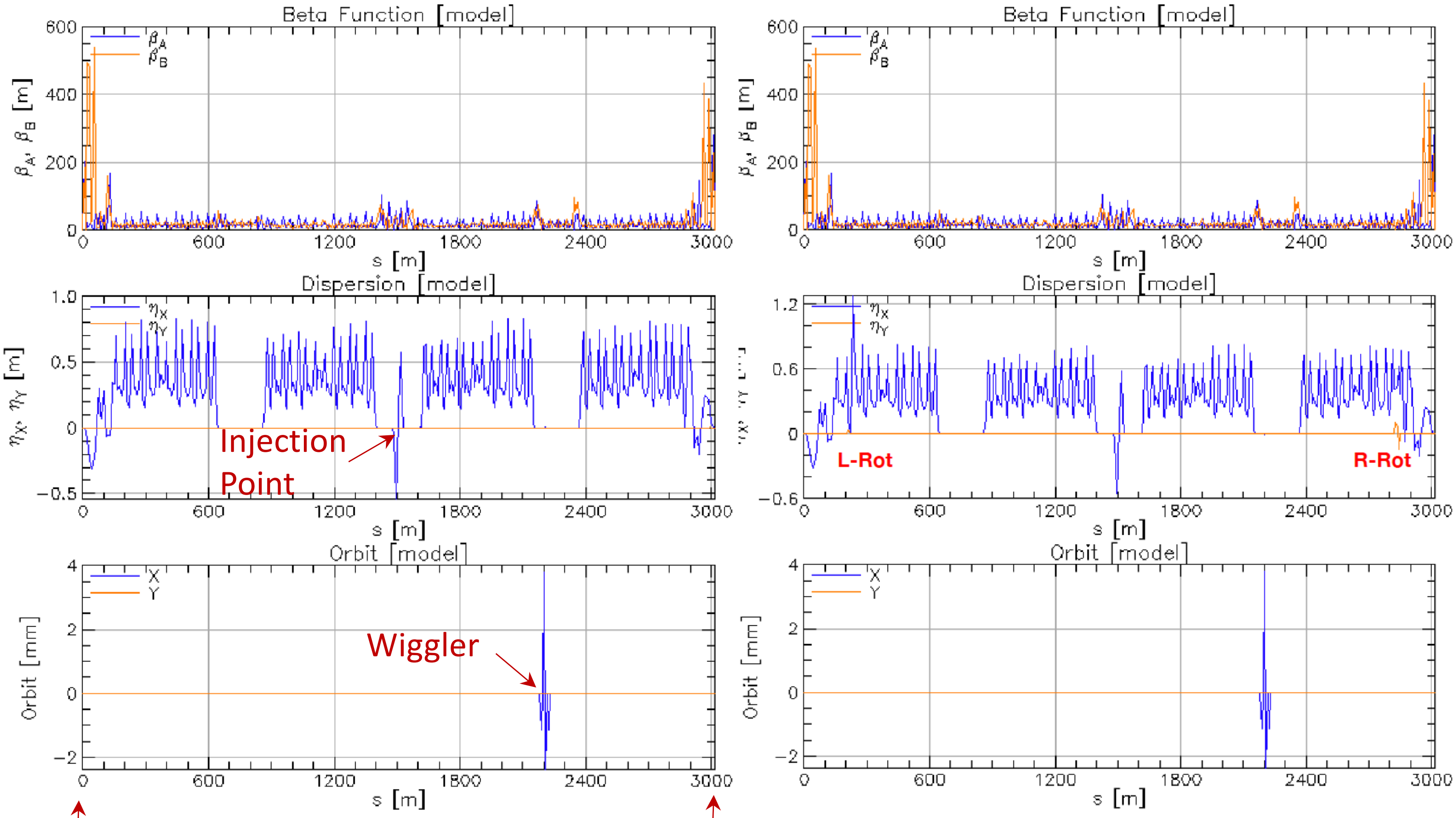
Compact spin rotator

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

Beta
x & y

Diffusion
x & y

Orbit



Interaction Point

Original Ring

Interaction Point

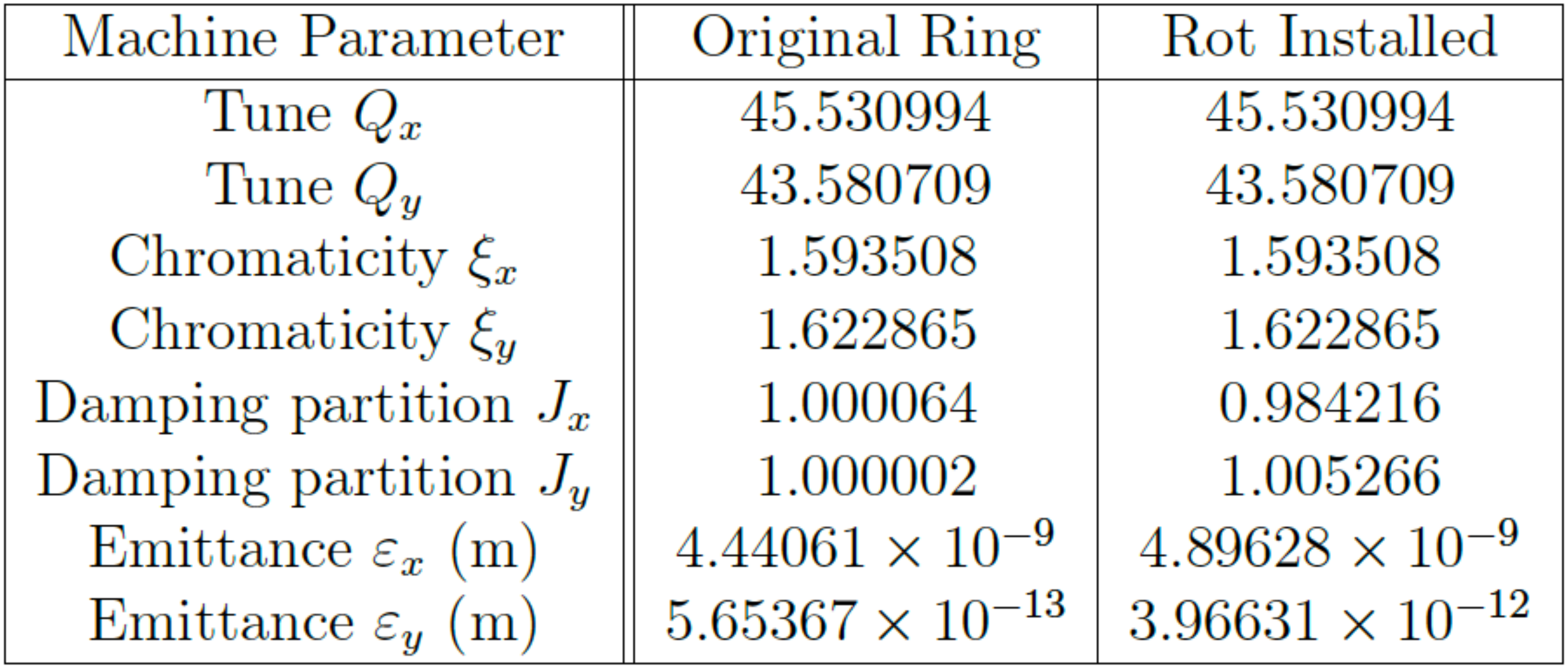
Rotator Ring

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



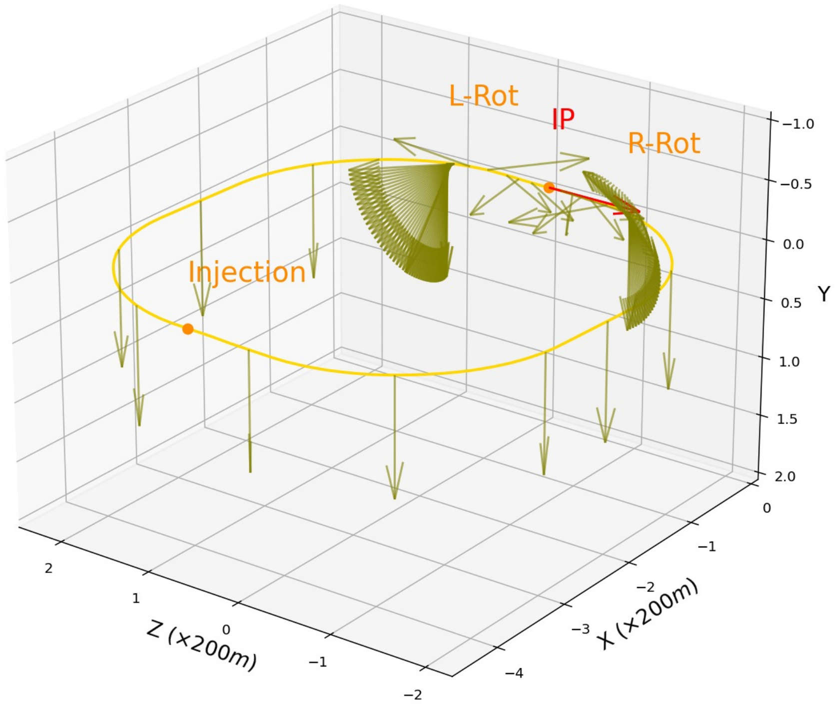
Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}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

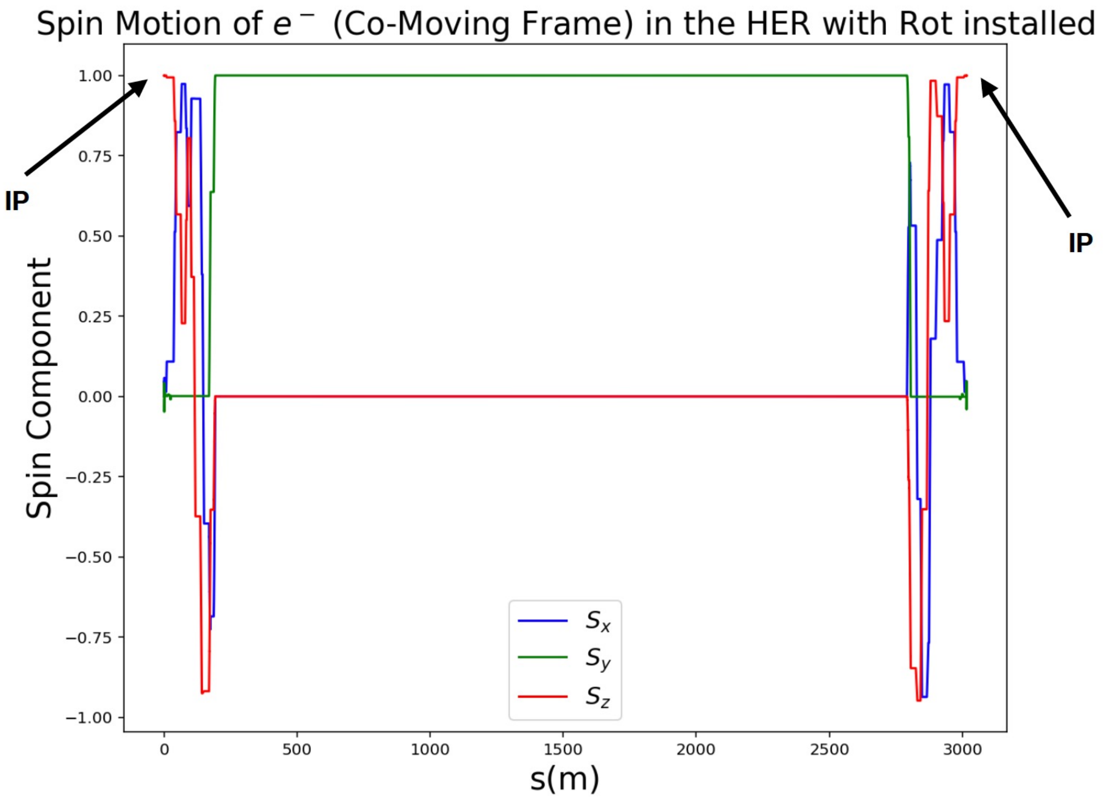
Compact spin rotator

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




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

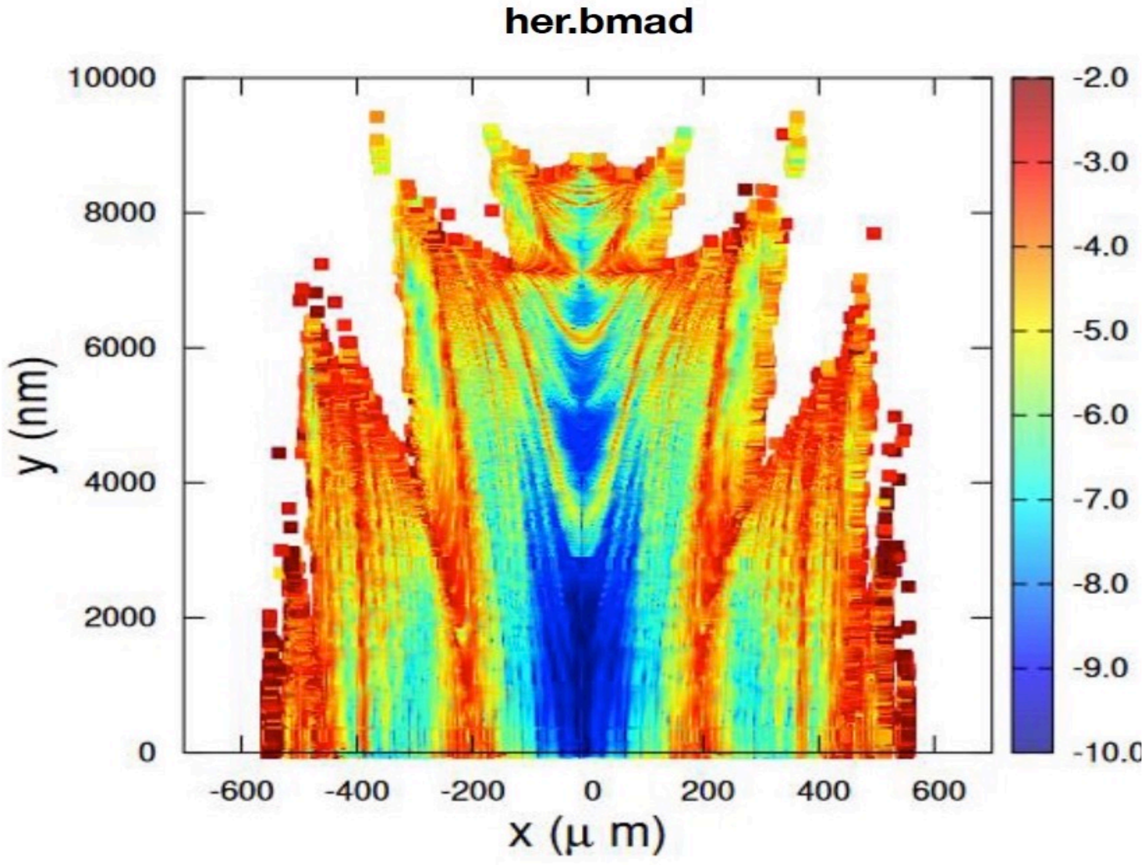
Compact spin rotator

Frequency Map Analysis (FMA)

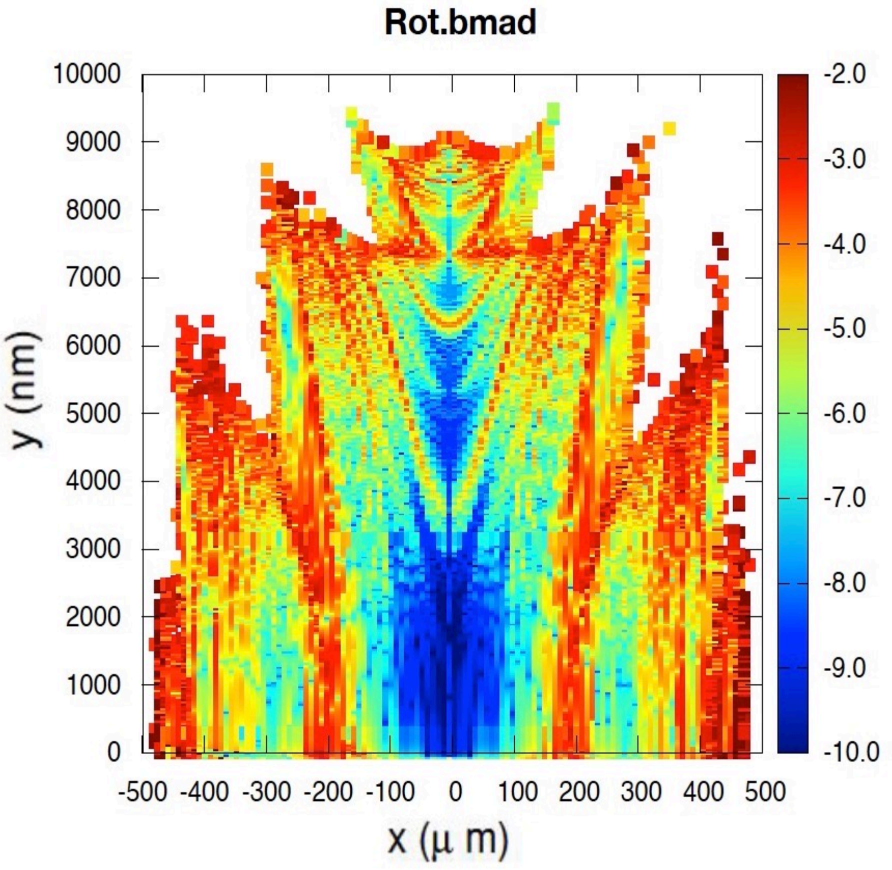
dynamic aperture studies using BMAD – show no large changes

work by Noah Tessema (UVictoria)

Original HER Lattice



HER Lattice with spin rotator



Compact spin rotator

Frequency Map Analysis (FMA)

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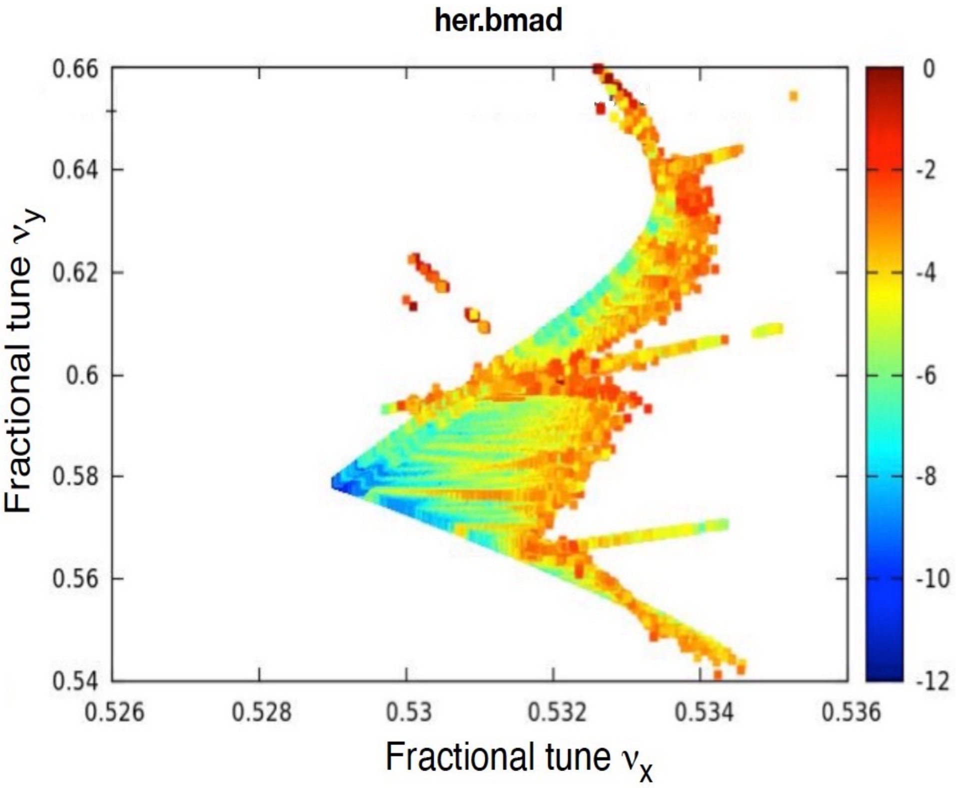
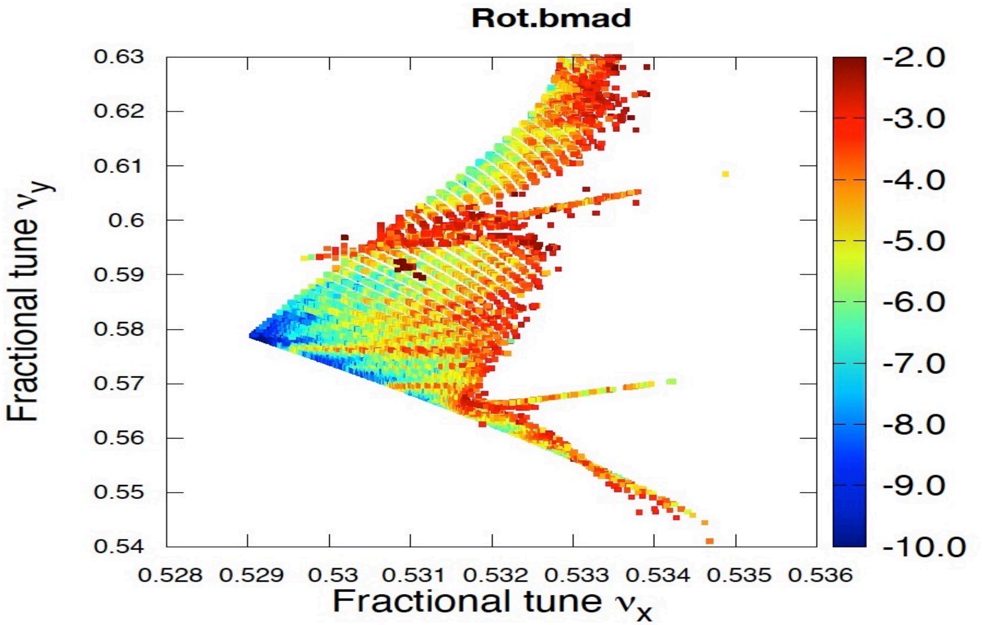
Original HER Lattice



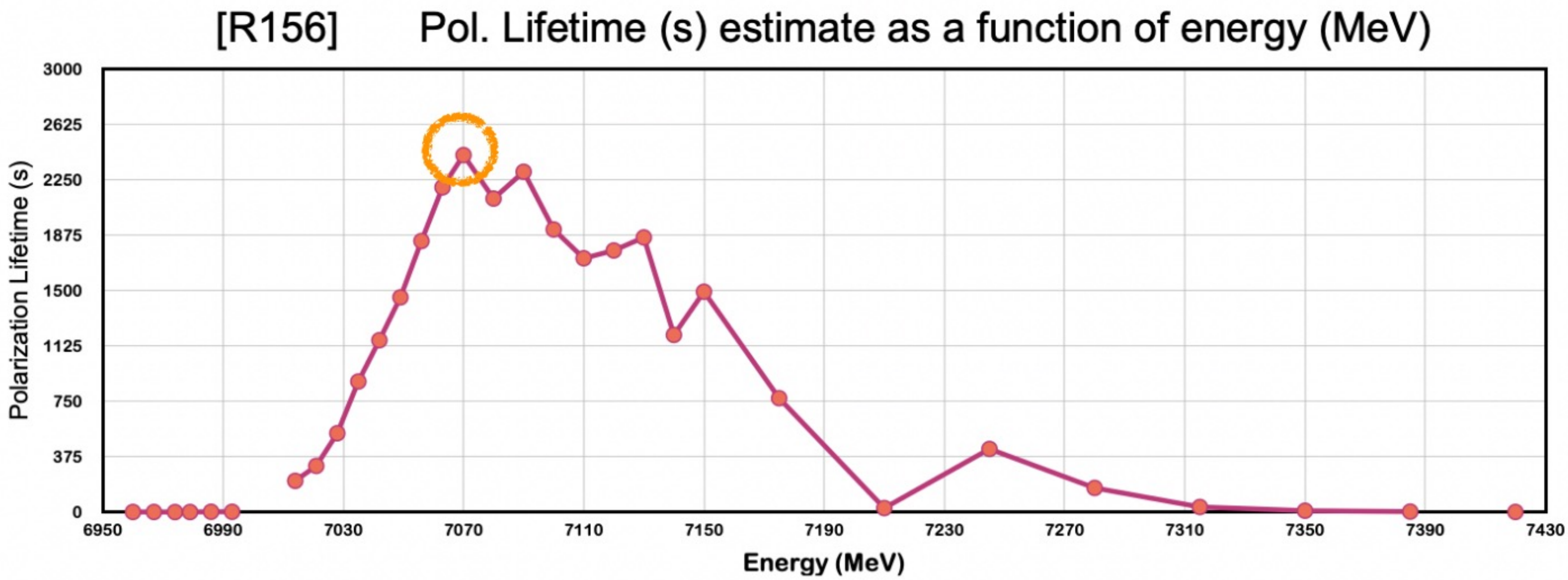
HER Lattice with spin rotator



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**

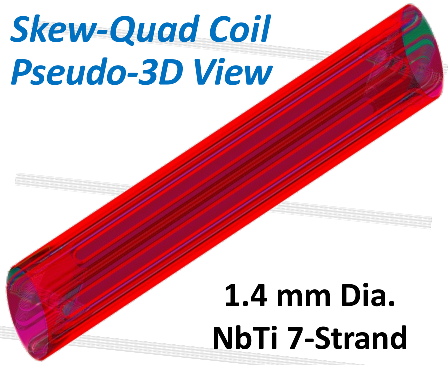
Compact Spin Rotator provides solution to transparency with minimal changes to lattice AND ability to have SuperKEKB with no spin rotator when we do not run with polarized beams – LTT studies show minimal impact on beam & polarization lifetimes

Compact Spin Rotator – Coil Feasibility

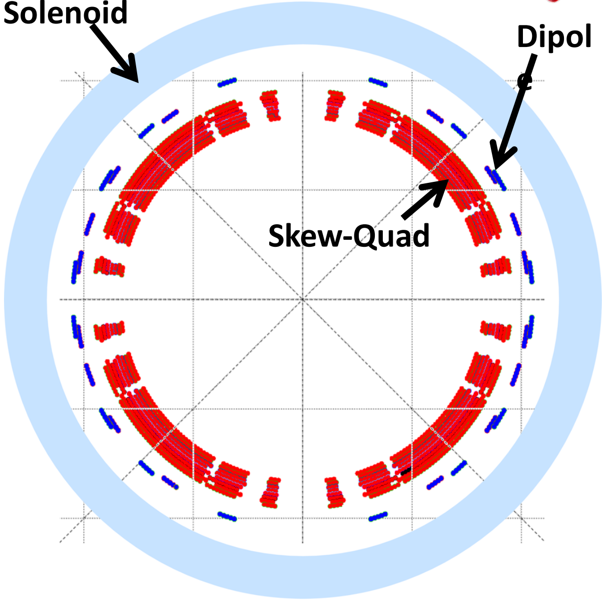
Brett Parker (BNL)

BNL Direct Wind Coil Production

Skew-Quad Coil Pseudo-3D View



1.4 mm Dia. NbTi 7-Strand Cable



Coil Cross Section at Skew-Quad Center

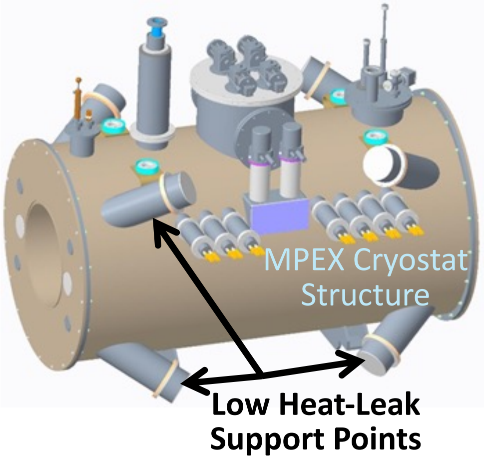
Solenoid Field 4.85 T
Skew Gradient 24 T/m
Dipole Field 0.2 T

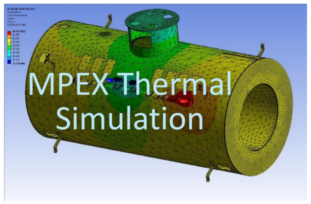
Combined Field @ Skew-Quad is 6.15 T
I_{op} = 729 A
I_q = 1050 A
for 69% Short Sample

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

Compact Spin Rotator – Cryostat System Feasibility

Brett Parker (BNL)





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

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

Compact Spin Rotator

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

BNL Side Responsibilities:

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


AGS Snake in Tunnel


HER Warm Dipoles in Tunnel at KEK.

KEK Side Responsibilities:

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

Polarization in SuperKEKB

Hardware needs

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

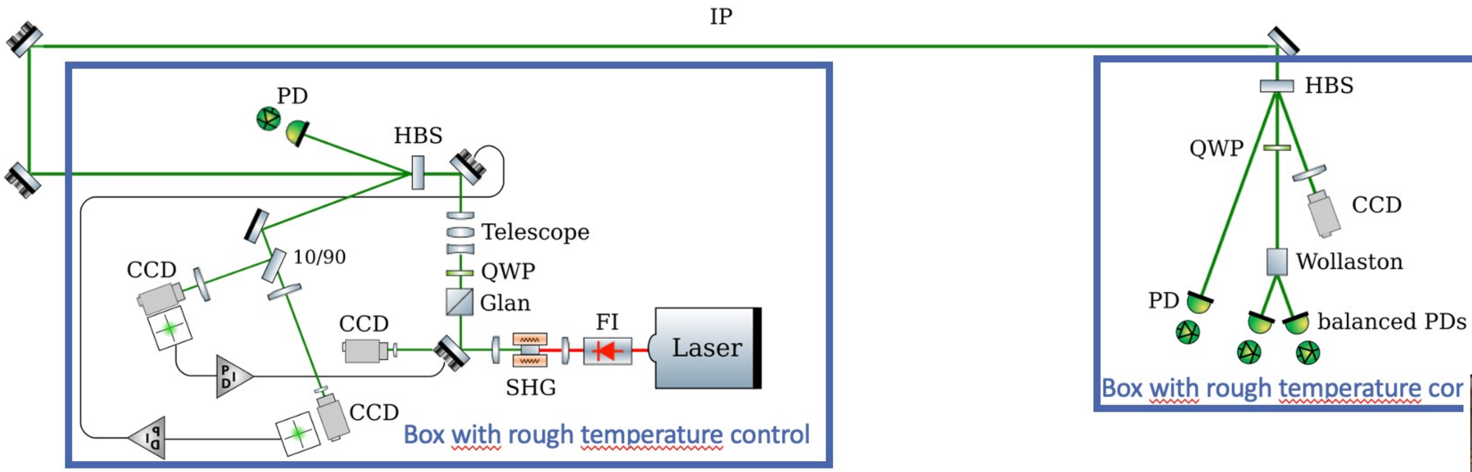
Figure 1: SuperKEKB left side cryostat at KEK.

Space is available outside
Cryostats for the final focusing quads

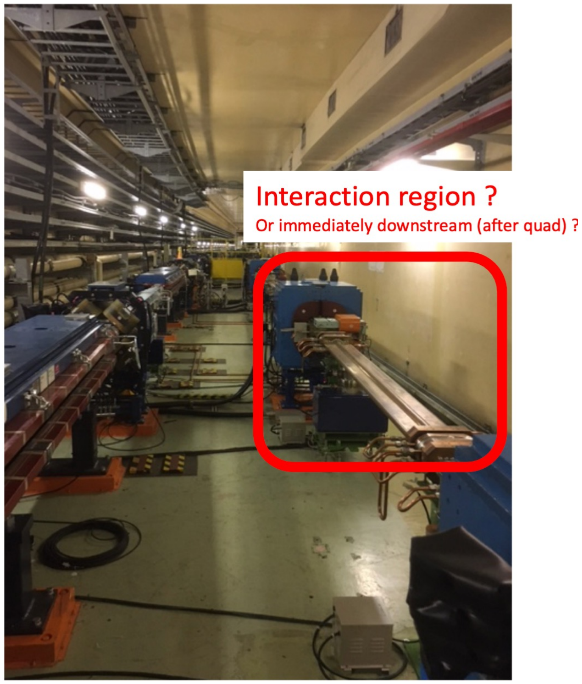
LAL Orsay and U. Manitoba groups

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**

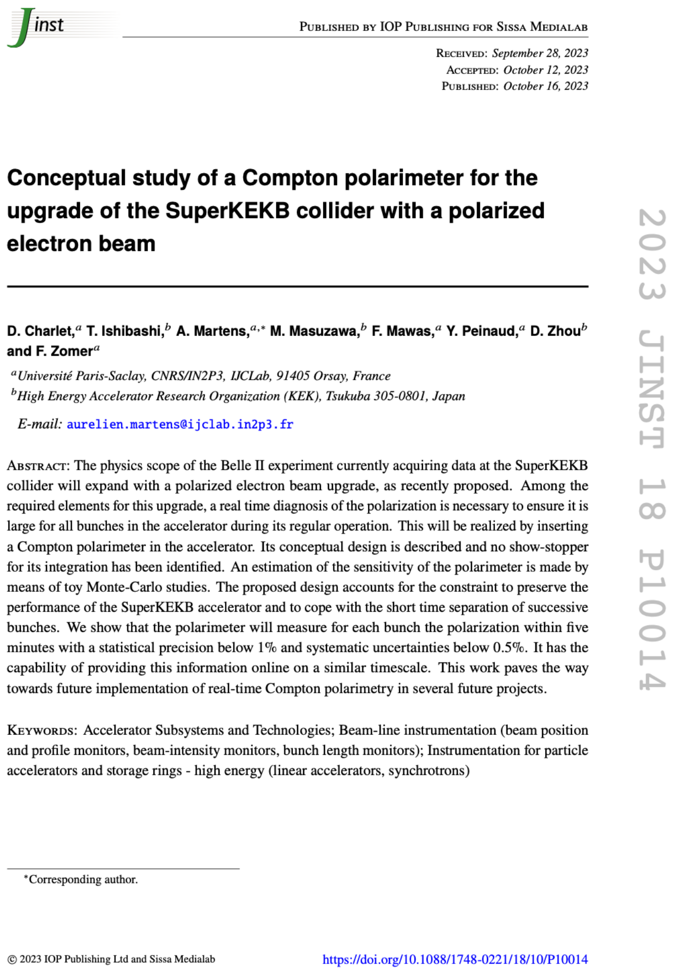


Main challenges -> laser integration in pre-defined environment
High rep-rate (250MHz) laser considered --> detection capabilities
Polarization control and accurate monitoring being worked on at IJCLab


Interaction region ?
Or immediately downstream (after quad) ?

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**



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

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

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

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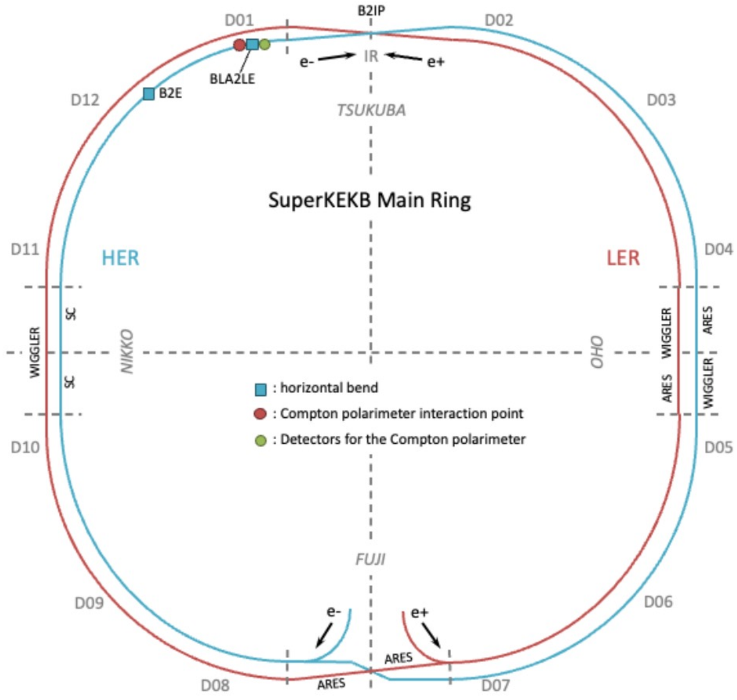
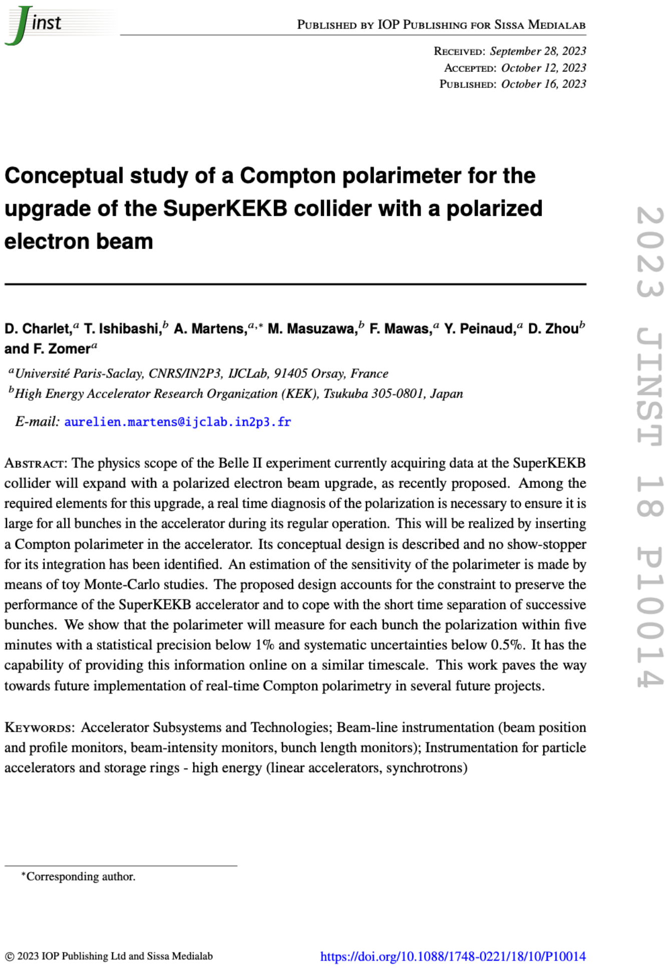


Figure 1. Schematic drawing of the main SuperKEKB ring, where the current B2E dipole to be replaced by spin rotators is identified. The location of the Compton polarimeter is also shown as well as Belle II interaction point.

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**



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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)

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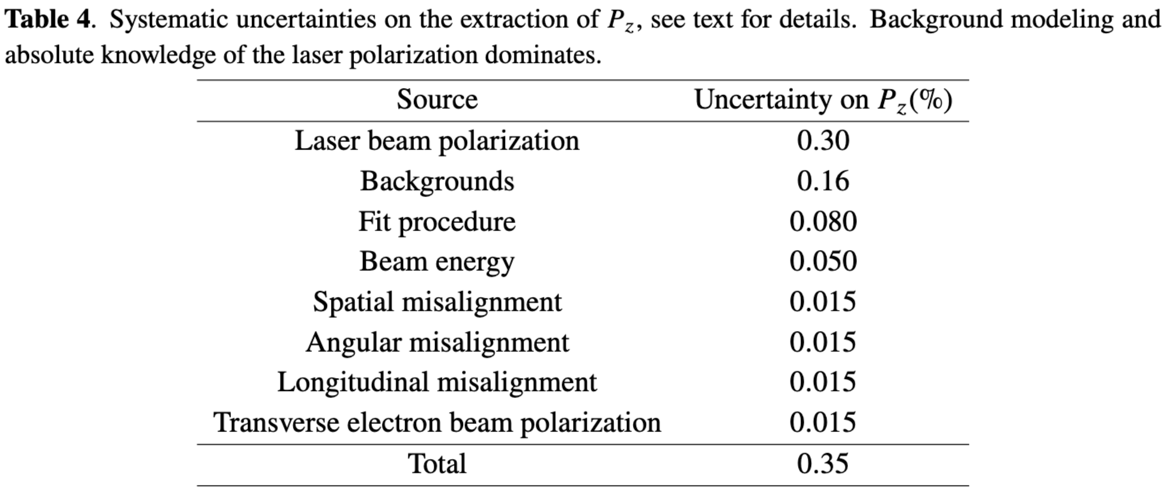

Table 4. Systematic uncertainties on the extraction of P_z, see text for details. Background modeling and absolute knowledge of the laser polarization dominates.

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

Polarization in SuperKEKB: Compton polarimeter

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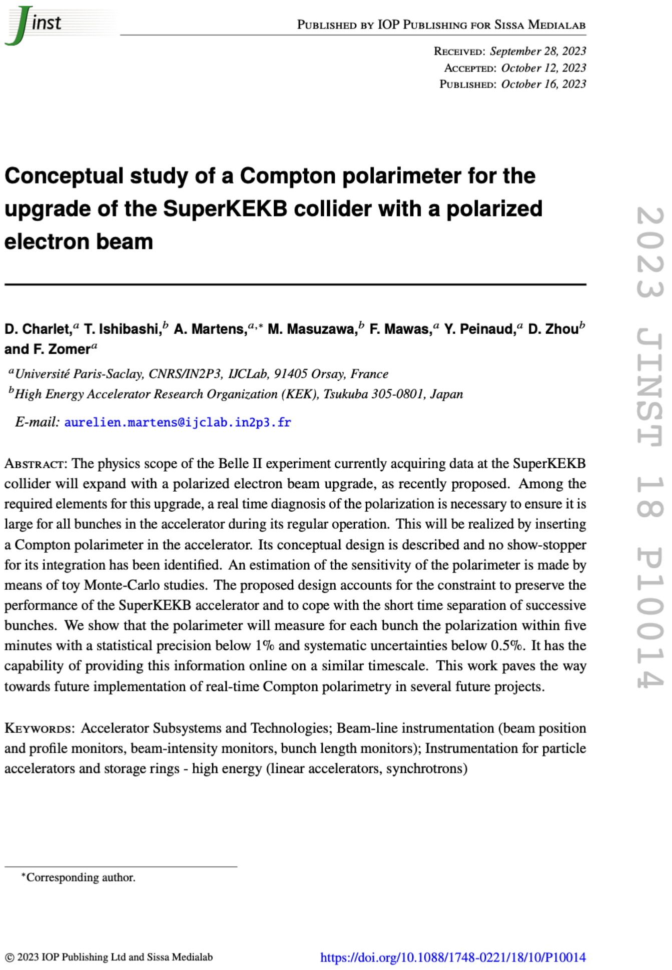

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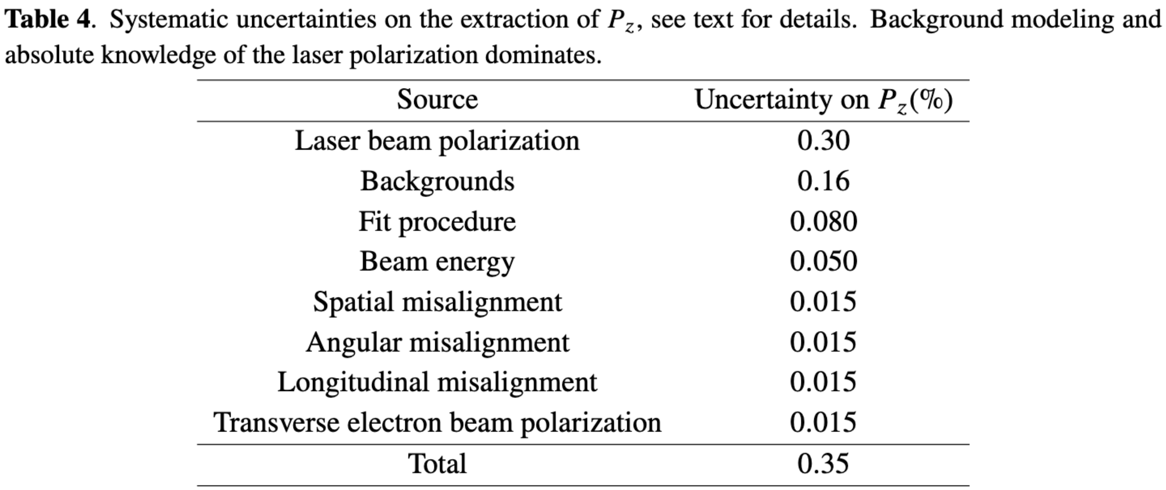

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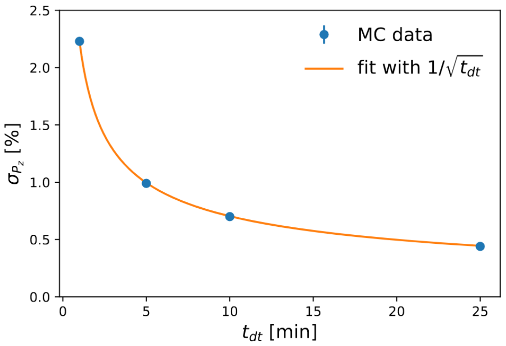


Figure 7. Statistical precision of the Compton polarimeter as a function of the duration of the data taking t_{dt} for a single bunch. For 25 minutes of data taking, a 0.5% statistical precision is obtained. Monte Carlo uncertainties on the points are negligible and smaller than the size of the points.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

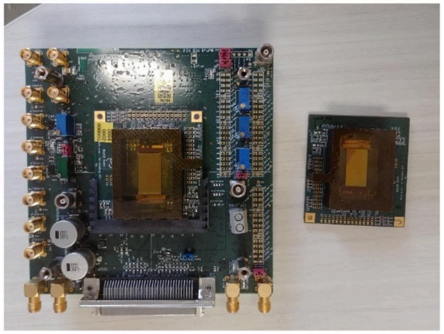
Using HPVMAPs as Compton e- Detector at MOLLER

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).

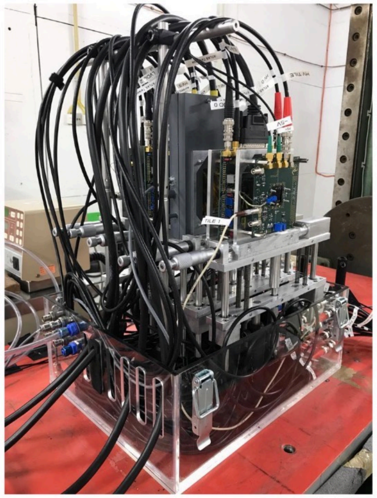
If it performs well, version 11 (2020 submission) will be the production chip we use for MOLLER.



Version 8 at UofM

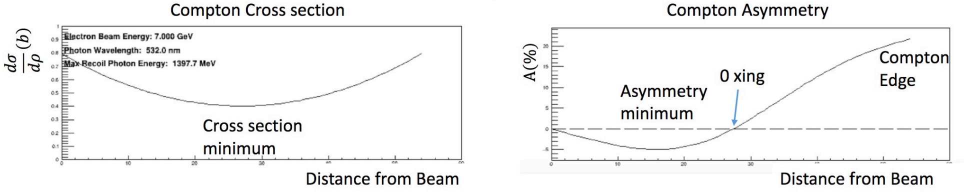
The chip is primarily developed by groups at the U. of Heidelberg and the Karlsruhe Institute of Technology, and intended for various experiments:

- ATLAS
- Mu3e
- PANDA
- P2
- MOLLER



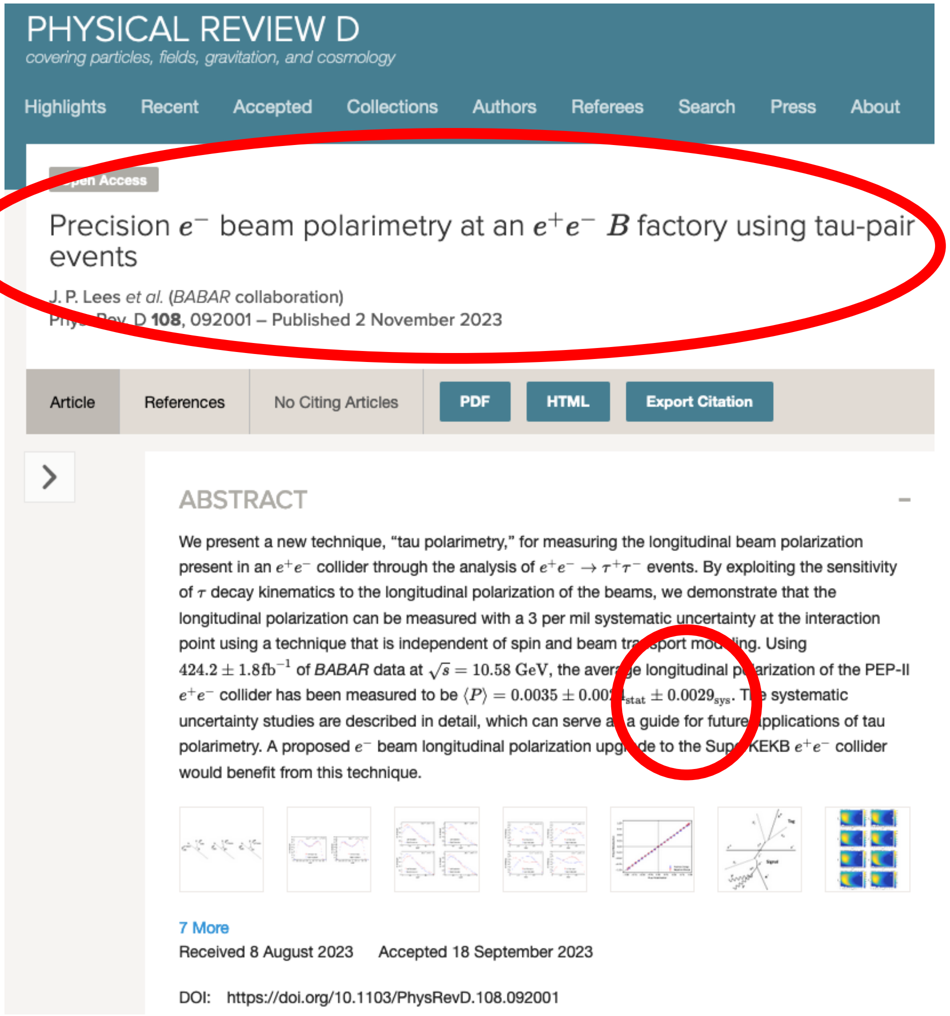
The implementation as a Compton detector is done by the Manitoba group.

Calculations/Simulations



Beam Polarization: Can be measured to < 0.005

BABAR paper


PHYSICAL REVIEW D

covering particles, fields, gravitation, and cosmology

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

J. P. Lees *et al.* (*BABAR* collaboration)

Phys. Rev. D **108**, 092001 – Published 2 November 2023

ABSTRACT

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

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Tau Polarization as Beam Polarimeter

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

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

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

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

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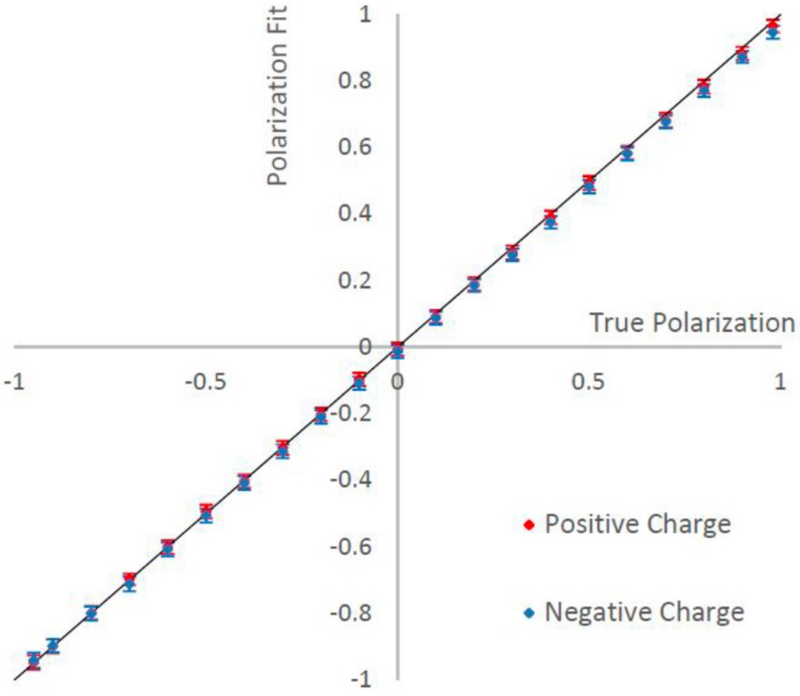
Beam Polarization MC “Measurement”

- 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

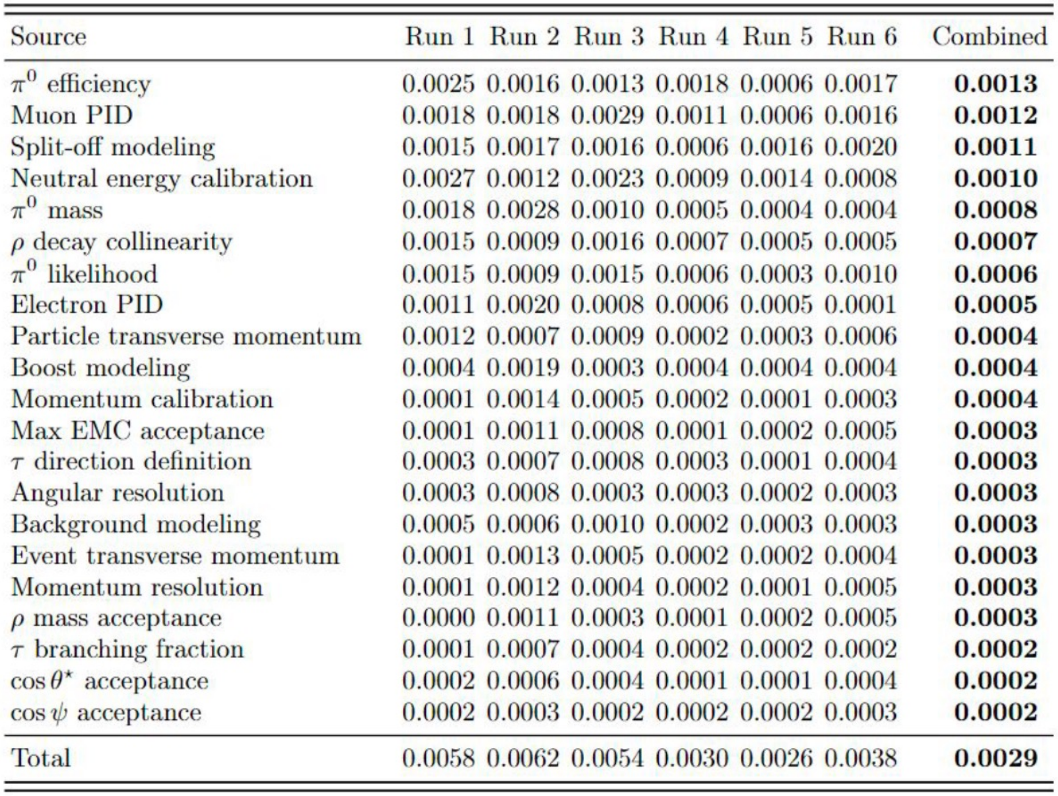
Full Measurement

- 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 Υ(1S) where CM is precisely known to also calibrate LER e+ energy; would provide precision CM energies above the Υ(4S)

Stage 2: implement spin rotators and longitudinal Compton polarimeters

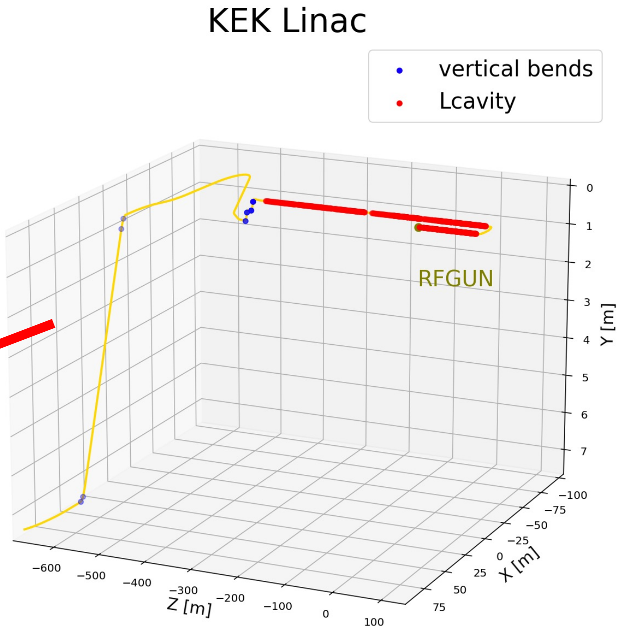
- Initially with dedicated polarization runs and start Chiral Belle electroweak physics program

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}.

Next step: 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



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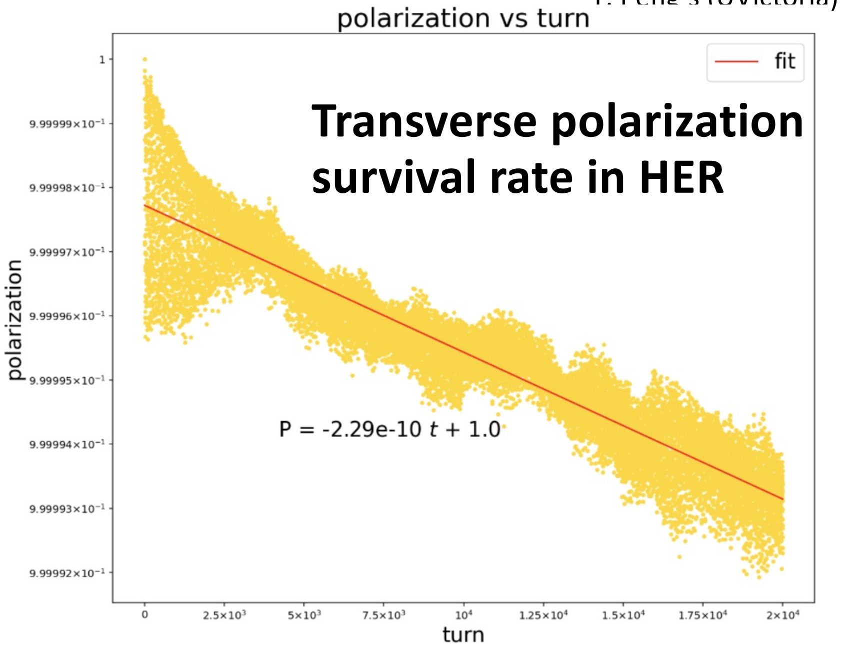


Transverse polarization survival rate in HER

$P = -2.29\text{e-}10\ t + 1.0$

Tracking 100 particles for 20000 turns in the HER with BMAD

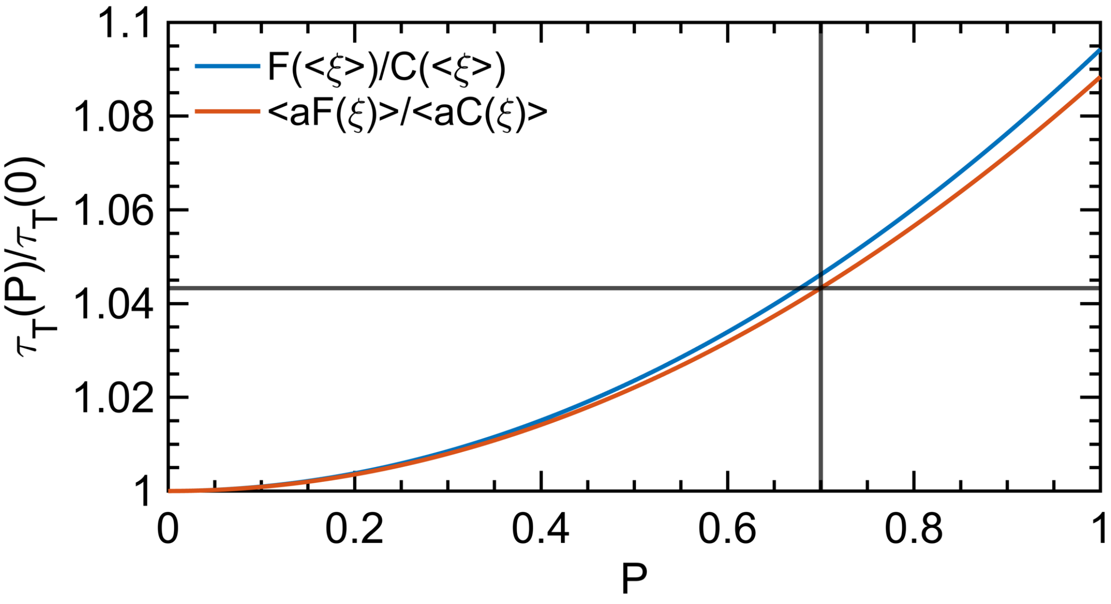
This study estimates polarization lifetime > 10 hours

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%

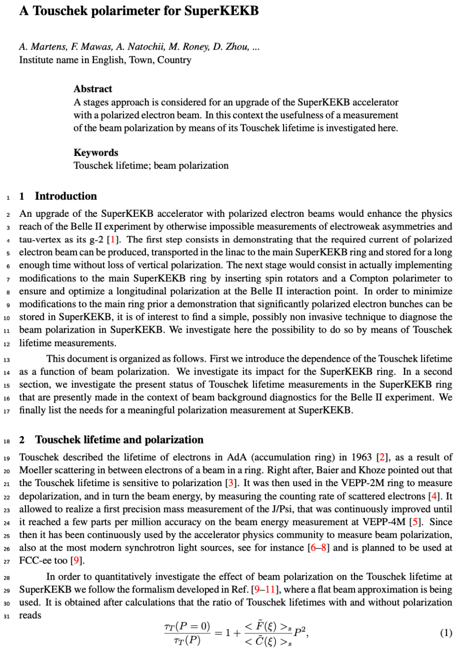
[Aurélien Martens (IJCLab) presentation in Feb 2023 B2GM and described in current draft of Chiral Belle CDR]

Touschek Lifetime Studies

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

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

[Andrii Natochii (BNL) presentation in Oct 2023 Belle II General Meeting



A Touschek polarimeter for SuperKEKB

A. Martens, F. Mawas, A. Natochii, M. Roney, D. Zhou, ...
Institute name in English, Town, Country

Abstract
A stages approach is considered for an upgrade of the SuperKEKB accelerator with a polarized electron beam. In this context the usefulness of a measurement of the beam polarization by means of its Touschek lifetime is investigated here.

Keywords
Touschek lifetime; beam polarization

1 Introduction

An upgrade of the SuperKEKB accelerator with polarized electron beams would enhance the physics reach of the Belle II experiment by otherwise impossible measurements of electroweak asymmetries and tau-vertex as its g-2 [1]. The first step consists in demonstrating that the required current of polarized electron beam can be produced, transported in the linac to the main SuperKEKB ring and stored for a long enough time without loss of vertical polarization. The next stage would consist in actually implementing modifications to the main SuperKEKB ring by inserting spin rotators and a Compton polarimeter to ensure and optimize a longitudinal polarization at the Belle II interaction point. In order to minimize modifications to the main ring prior a demonstration that significantly polarized electron bunches can be stored in SuperKEKB, it is of interest to find a simple, possibly non invasive technique to diagnose the beam polarization in SuperKEKB. We investigate here the possibility to do so by means of Touschek lifetime measurements.

This document is organized as follows. First we introduce the dependence of the Touschek lifetime as a function of beam polarization. We investigate its impact for the SuperKEKB ring. In a second section, we investigate the present status of Touschek lifetime measurements in the SuperKEKB ring that are presently made in the context of beam background diagnostics for the Belle II experiment. We finally list the needs for a meaningful polarization measurement at SuperKEKB.

2 Touschek lifetime and polarization

Touschek described the lifetime of electrons in AdA (accumulation ring) in 1963 [2], as a result of Moeller scattering in between electrons of a beam in a ring. Right after, Baier and Khoze pointed out that the Touschek lifetime is sensitive to polarization [3]. It was then used in the VEPP-2M ring to measure depolarization, and in turn the beam energy, by measuring the counting rate of scattered electrons [4]. It allowed to realize a first precision mass measurement of the J/Psi, that was continuously improved until it reached a few parts per million accuracy on the beam energy measurement at VEPP-4M [5]. Since then it has been continuously used by the accelerator physics community to measure beam polarization, also at the most modern synchrotron light sources, see for instance [6–8] and is planned to be used at FCC-ee too [9].

In order to quantitatively investigate the effect of beam polarization on the Touschek lifetime at SuperKEKB we follow the formalism developed in Ref. [9–11], where a flat beam approximation is being used. It is obtained after calculations that the ratio of Touschek lifetimes with and without polarization reads

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

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

Period	Experimental Touschek Lifetime (minutes)
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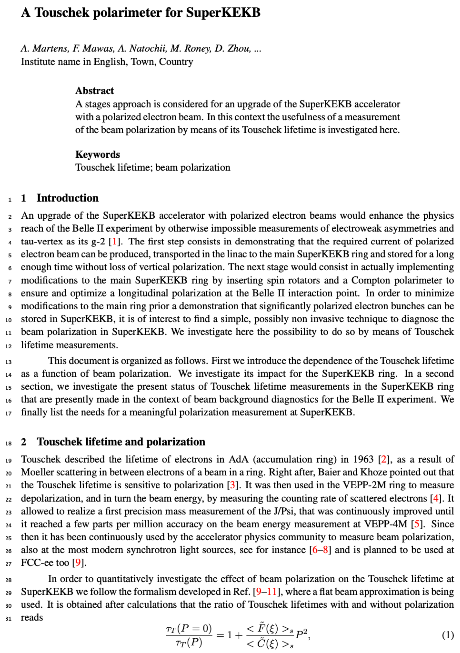

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Touschek lifetime; beam polarization

1 Introduction

An upgrade of the SuperKEKB accelerator with polarized electron beams would enhance the physics reach of the Belle II experiment by otherwise impossible measurements of electroweak asymmetries and tau-vertex as its g-2 [1]. The first step consists in demonstrating that the required current of polarized electron beam can be produced, transported in the linac to the main SuperKEKB ring and stored for a long enough time without loss of vertical polarization. The next stage would consist in actually implementing modifications to the main SuperKEKB ring by inserting spin rotators and a Compton polarimeter to ensure and optimize a longitudinal polarization at the Belle II interaction point. In order to minimize modifications to the main ring prior a demonstration that significantly polarized electron bunches can be stored in SuperKEKB, it is of interest to find a simple, possibly non invasive technique to diagnose the beam polarization in SuperKEKB. We investigate here the possibility to do so by means of Touschek lifetime measurements.

This document is organized as follows. First we introduce the dependence of the Touschek lifetime as a function of beam polarization. We investigate its impact for the SuperKEKB ring. In a second section, we investigate the present status of Touschek lifetime measurements in the SuperKEKB ring that are presently made in the context of beam background diagnostics for the Belle II experiment. We finally list the needs for a meaningful polarization measurement at SuperKEKB.

2 Touschek lifetime and polarization

Touschek described the lifetime of electrons in AdA (accumulation ring) in 1963 [2], as a result of Moeller scattering in between electrons of a beam in a ring. Right after, Baier and Khoze pointed out that the Touschek lifetime is sensitive to polarization [3]. It was then used in the VEPP-2M ring to measure depolarization, and in turn the beam energy, by measuring the counting rate of scattered electrons [4]. It allowed to realize a first precision mass measurement of the J/Psi, that was continuously improved until it reached a few parts per million accuracy on the beam energy measurement at VEPP-4M [5]. Since then it has been continuously used by the accelerator physics community to measure beam polarization, also at the most modern synchrotron light sources, see for instance [6–8] and is planned to be used at FCC-ee too [9].

In order to quantitatively investigate the effect of beam polarization on the Touschek lifetime at SuperKEKB we follow the formalism developed in Ref. [9–11], where a flat beam approximation is being used. It is obtained after calculations that the ratio of Touschek lifetimes with and without polarization reads

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

Working with KEK source team & team members at Hiroshima, Nagoya, Victoria, BNL

Proposing 2 day experiment following SuperKEKB autumn 2025 run

- **Transverse polarization lifetime measurements with and without collisions; measure beam-beam effects on polarization**

Summary

Chiral Belle Physics Program

Unique New Physics Probe into Dark Sector via Precision measurement of weak mixing angle @ 10GeV with e, μ, τ, c and b
5x precision of EIC

Going beyond muon g-2 Measured at BNL & FERMILAB:
Tau g-2
>100x more precise than can be reached elsewhere

Worlds Highest Precision Weak Neutral Current Measurements with μ, c and b
Many times more precise than World Average of CERN & SLAC measurements
Avoids LHC hadronization uncertainties

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

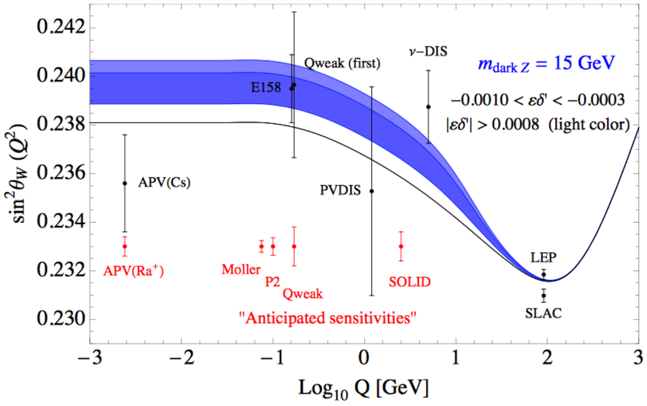
Summary

- 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 Parity Violation experiemnts
  - 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

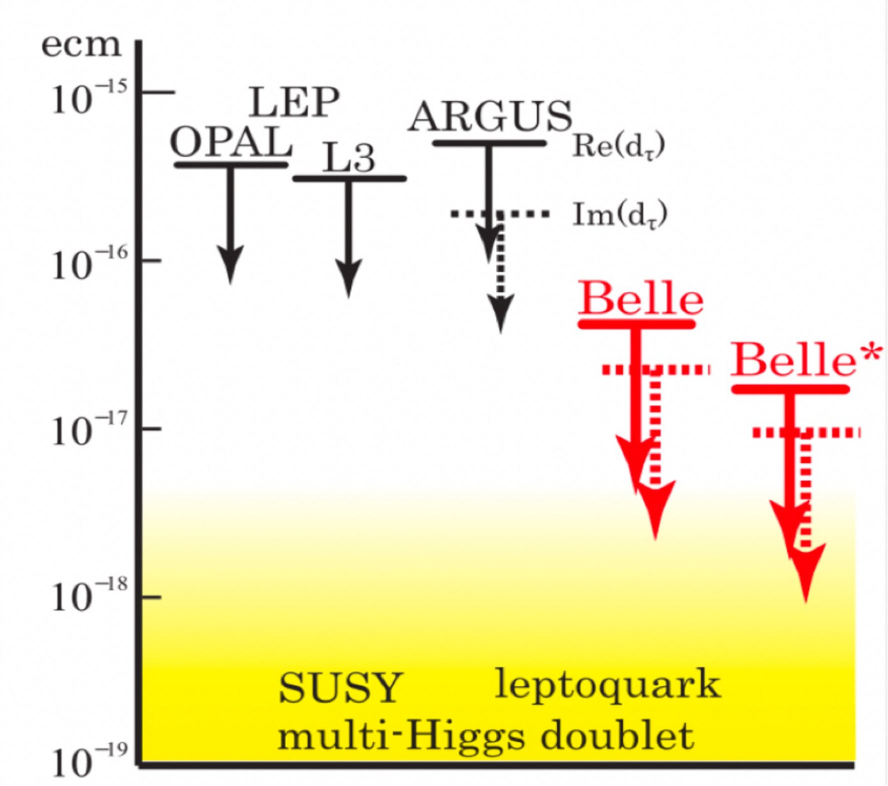
- Canada: TRIUMF, UVic, Manitoba, UBC/IPP
- France: LAL/Orsay
- KEK & Hiroshima Univ. + Oide-san (CERN)
- Russia: BINP
- USA: ANL, BLN, Louisville, Duke

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.

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)

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;

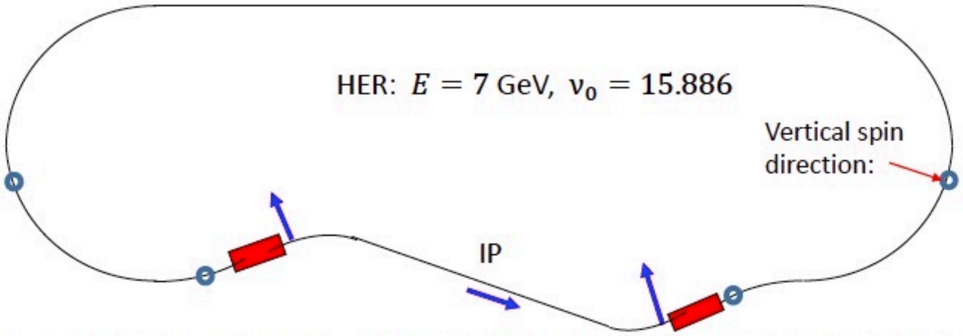
ii) second approach makes use of combined function solenoid-quadrupole magnets

This is favoured as it involves lower solenoid fields

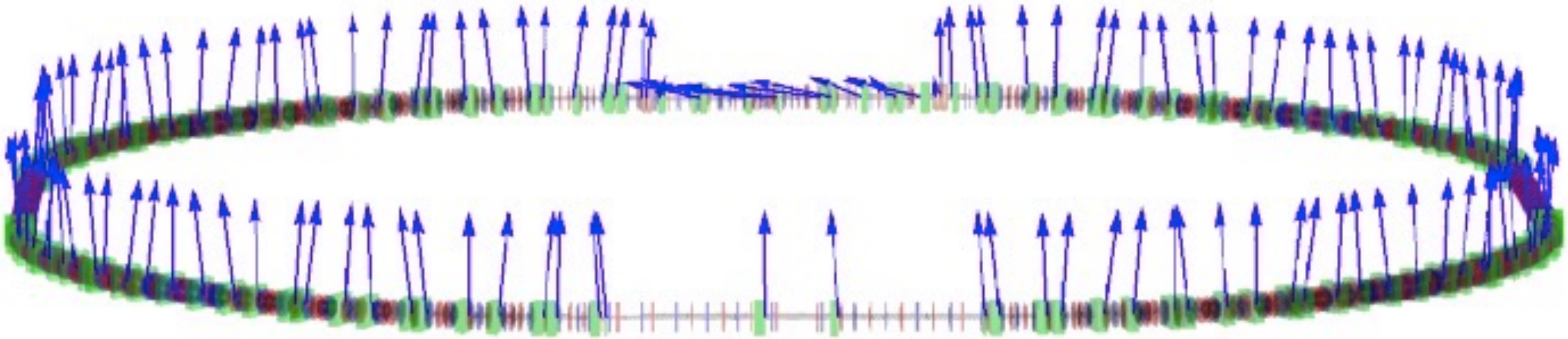
From I. Koop, A.Otboev and Yu.Shatunov, BINP, Novosibirsk preliminary considerations on the longitudinal polarization at SuperKEKB

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)

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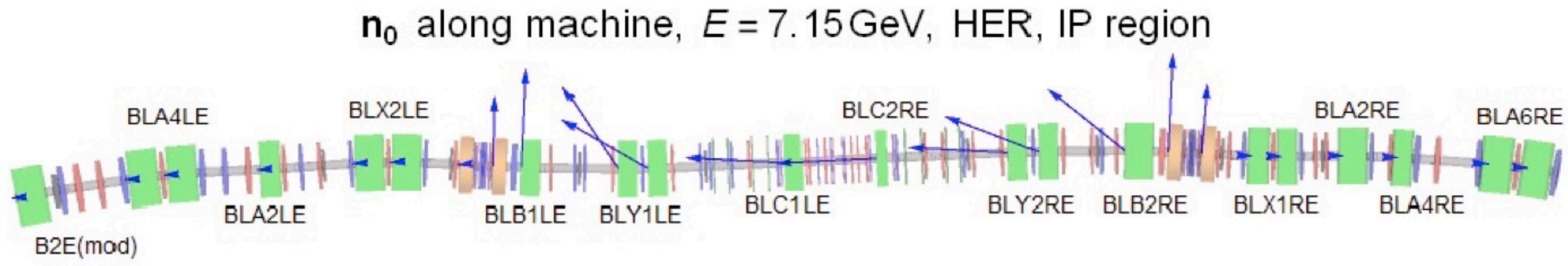
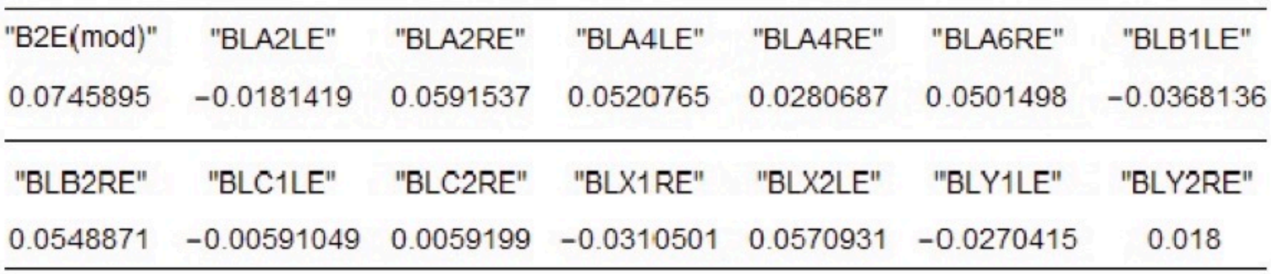
Preliminary studies by BINP group





"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.

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Preliminary studies by BINP group

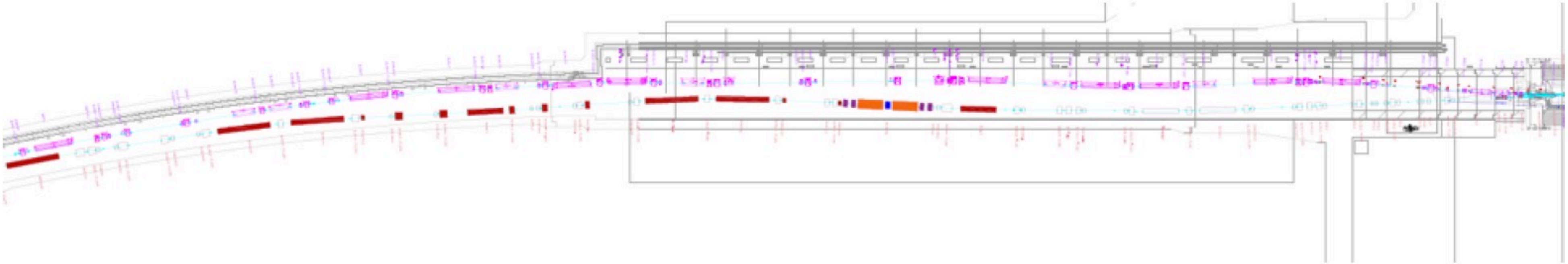


Figure 18: To the left from the IP half of experimental straight section. The modified magnetic elements of the HER ring are painted in dark brown, and the solenoids of the spin rotator are painted in dark yellow. The distance between the rings is great

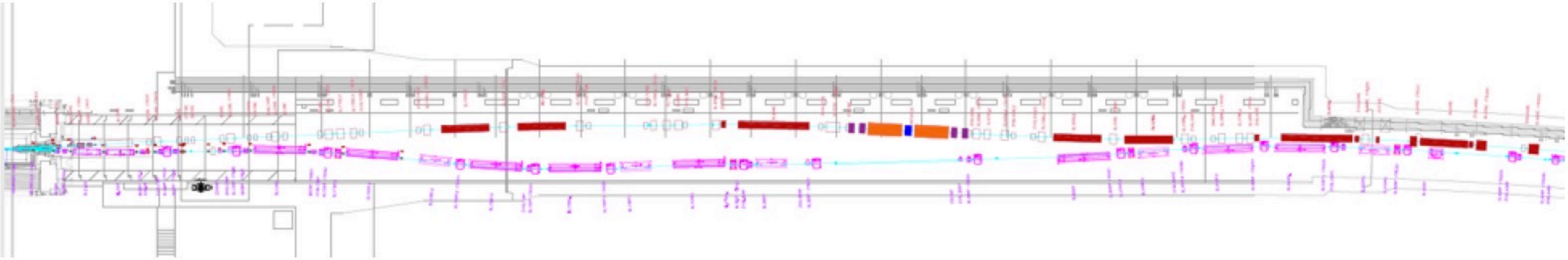
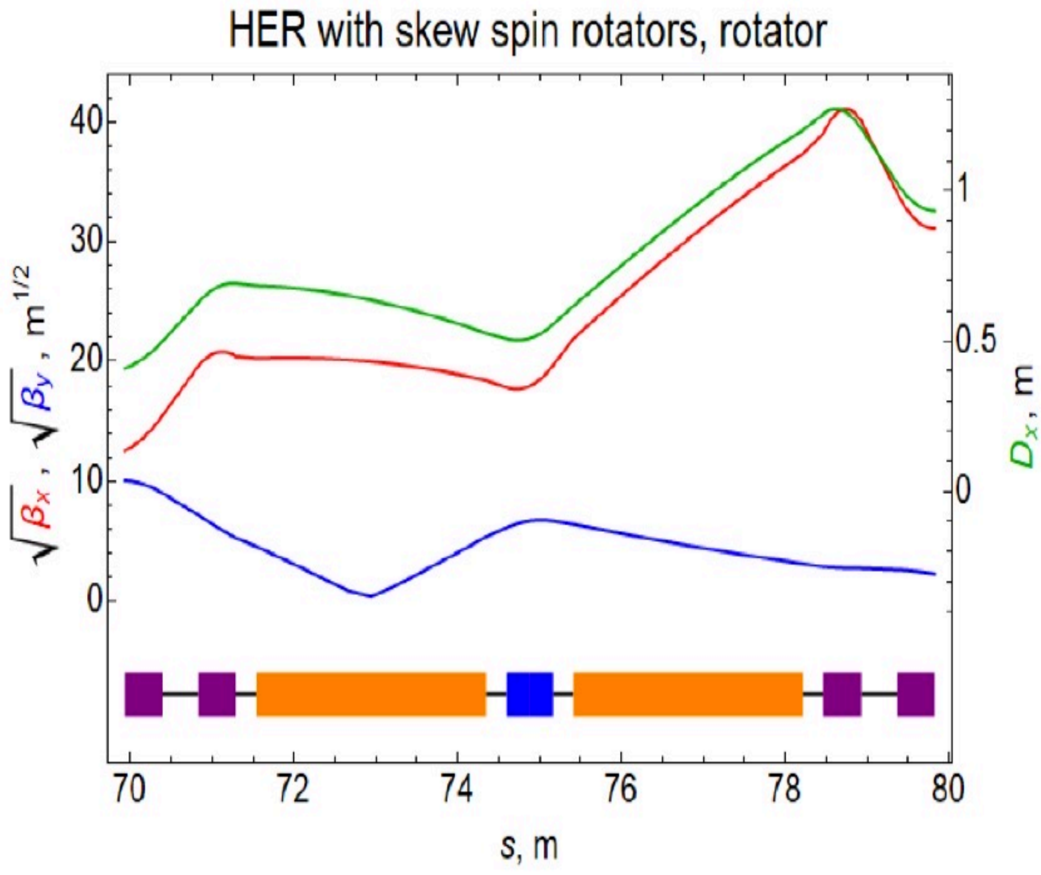


Figure 19: To the right from the IP half of straight section. At the entrance to the tunnel, the magnets of the rings are very close, but such technical problems can be solved.

Preliminary studies by BINP group



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

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

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Preliminary studies by BINP group: option (i)

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

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.

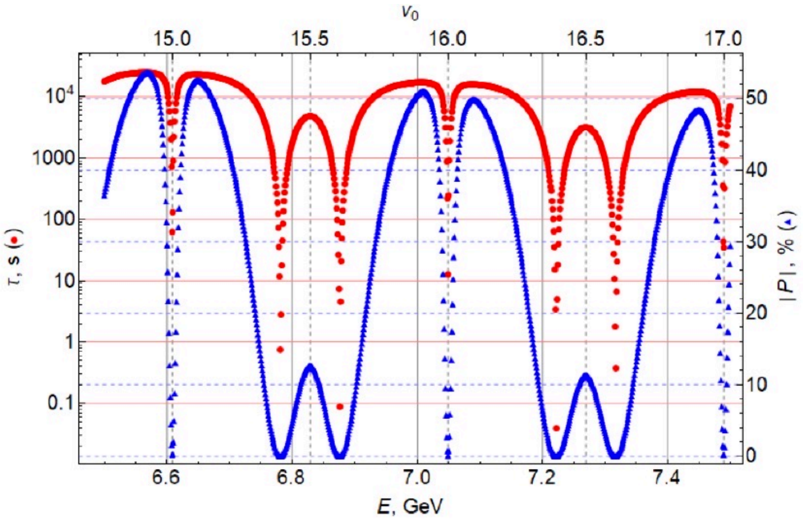

Figure 23: Dependence of the radiation spin relaxation time on energy with the rotator version from Table 12 with rotated extreme doublets of the lenses, see Fig. 21.

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

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

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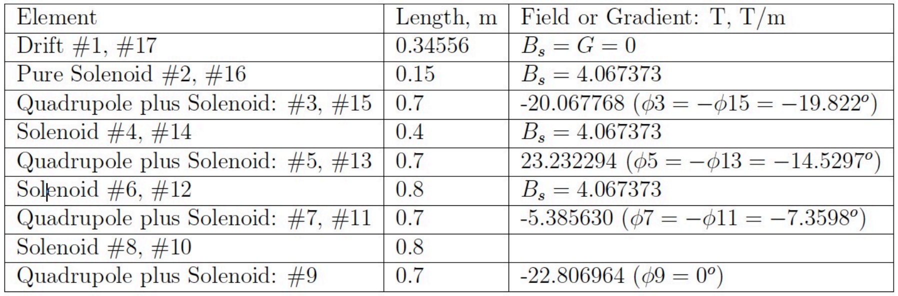
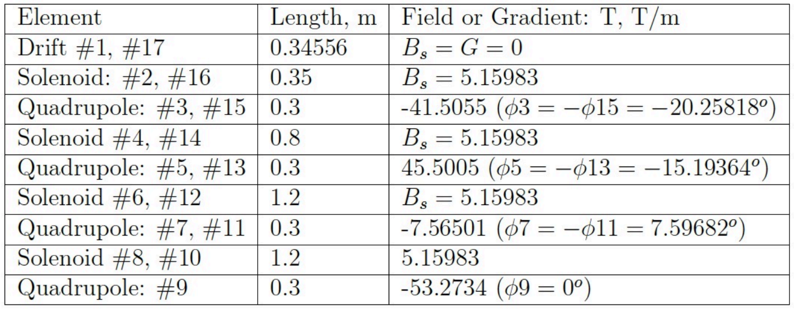
Preliminary studies by BINP group: option (ii)



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 ($\phi 3 = -\phi 15 = -19.822^o$)
Solenoid #4, #14	0.4	$B_s = 4.067373$
Quadrupole plus Solenoid: #5, #13	0.7	23.232294 ($\phi 5 = -\phi 13 = -14.5297^o$)
Solenoid #6, #12	0.8	$B_s = 4.067373$
Quadrupole plus Solenoid: #7, #11	0.7	-5.385630 ($\phi 7 = -\phi 11 = -7.3598^o$)
Solenoid #8, #10	0.8	
Quadrupole plus Solenoid: #9	0.7	-22.806964 ($\phi 9 = 0^o$)

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 ($\phi 3 = -\phi 15 = -20.25818^o$)
Solenoid #4, #14	0.8	$B_s = 5.15983$
Quadrupole: #5, #13	0.3	45.5005 ($\phi 5 = -\phi 13 = -15.19364^o$)
Solenoid #6, #12	1.2	$B_s = 5.15983$
Quadrupole: #7, #11	0.3	-7.56501 ($\phi 7 = -\phi 11 = 7.59682^o$)
Solenoid #8, #10	1.2	5.15983
Quadrupole: #9	0.3	-53.2734 ($\phi 9 = 0^o$)

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).

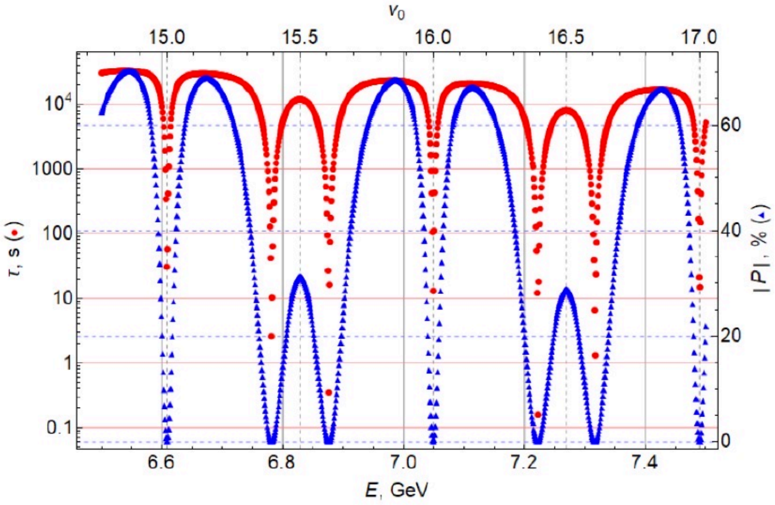


Figure 26: Radiation spin relaxation time and equilibrium degree of polarization versus energy for the rotator optics option from Table 14.

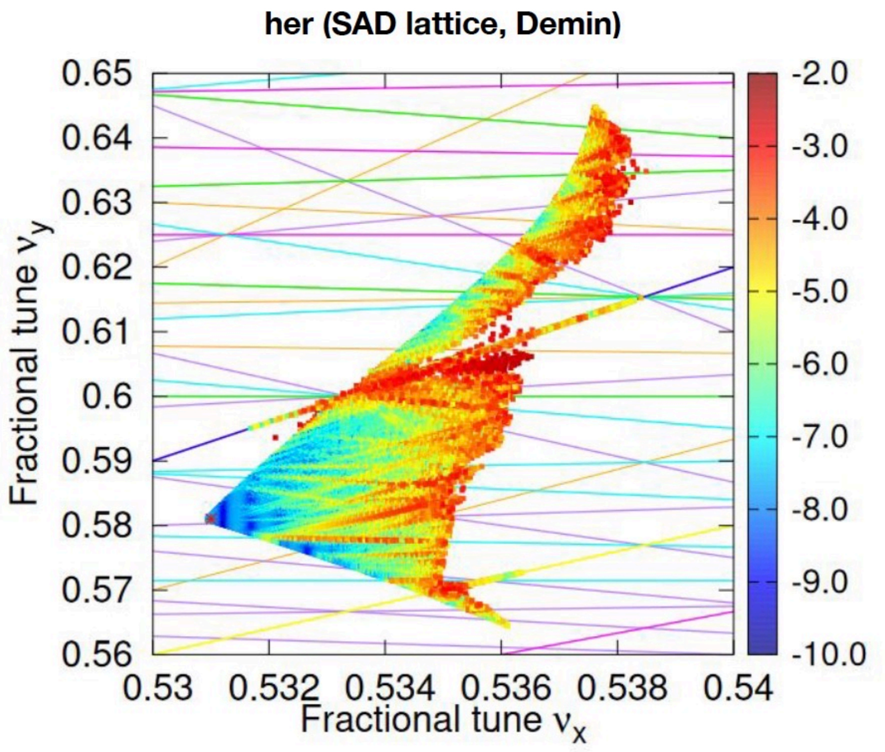
Depolarization lifetime at E=7.15GeV is ~19000s

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

Comparing SAD FMA to BMAD FMA in original HER Lattice

Original HER Lattice with SAD



Original HER Lattice with BMAD
Noah Tessema (UVictoria)