Chiral Belle

Polarized electron beam at SuperKEKB

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21 July 2020

On behalf of Canadian Chiral Belle Group

Chiral Belle → Left-Right Asymmetries in e+e- at 10.58GeV

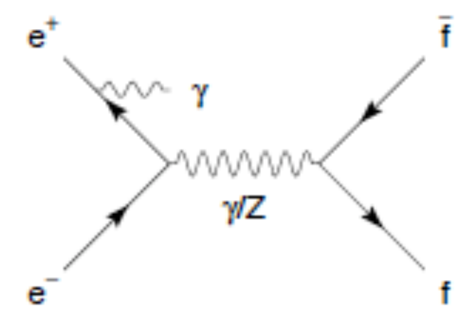
- Measure difference between cross-sections with left-handed beam electrons and right-handed beam electrons
- Same technique as SLD A_{LR} measurement at the Z-pole giving single most precise measurement of :

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

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

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

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



New and Unique Windows for Discovery

A New Path in World-wide Precision Neutral Current Electroweak Precision Program

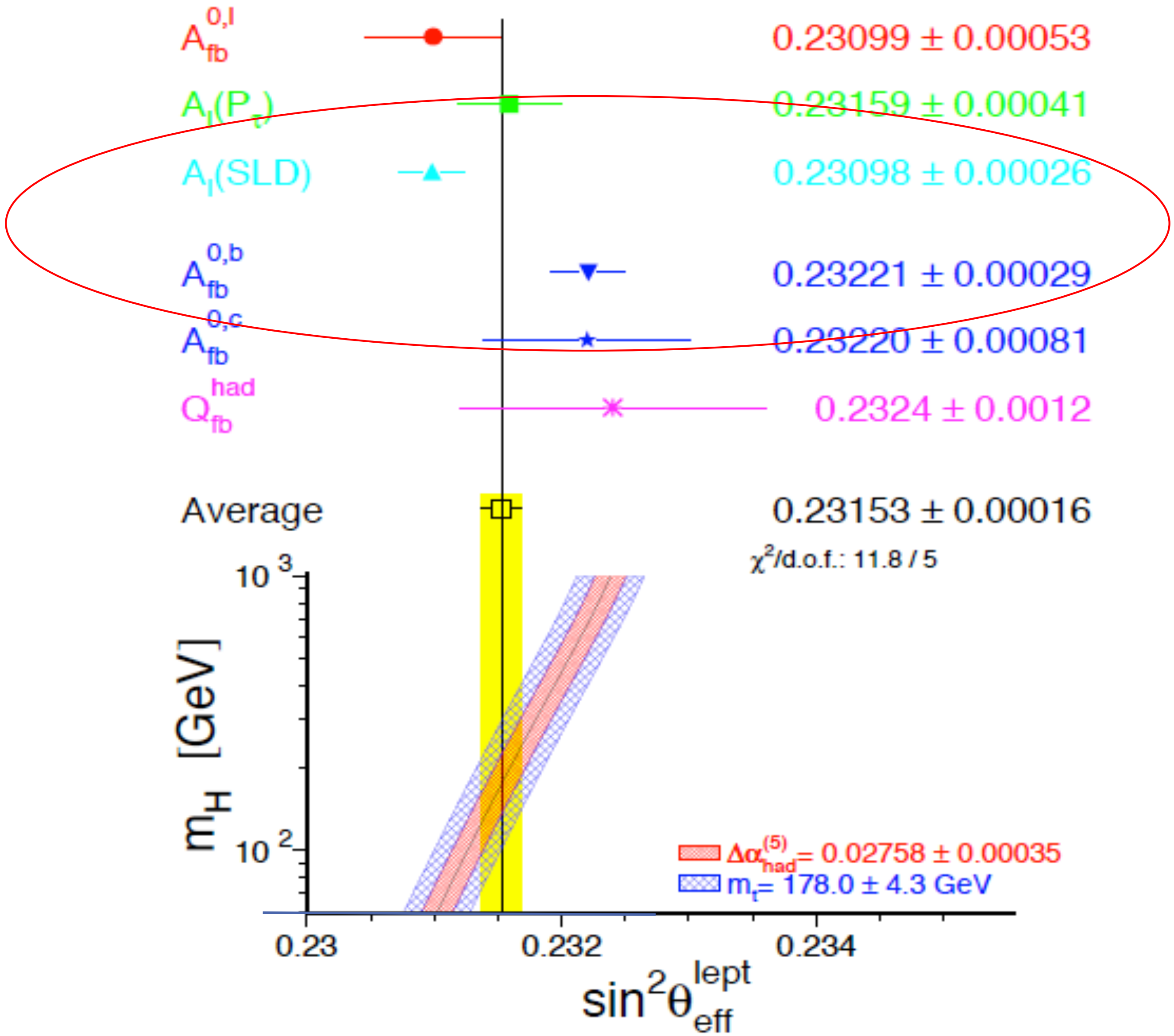
- Left-Right Asymmetries (A_{LR}) yield measurements of unprecedented precision of the neutral current vector couplings (g_V) to each of five fermion flavours, *f* :
    - beauty (D-type)
    - charm (U-type)
    - tau
    - muon
    - electron

  as well as light quarks

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

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

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)

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 (selection 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)	0.0007	0.0004
Muon (eff. = 0.5)	-0.0371 ±.0003	-0.03667 ±0.0023	0.0007 Improve x3	0.0005	0.0003
Electron (eff. = 0.015)	-0.0371 ±.0003	-0.03816 ±0.00047	0.0007	0.0005	0.0003 *(all leptons will give ~current WA error)*

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

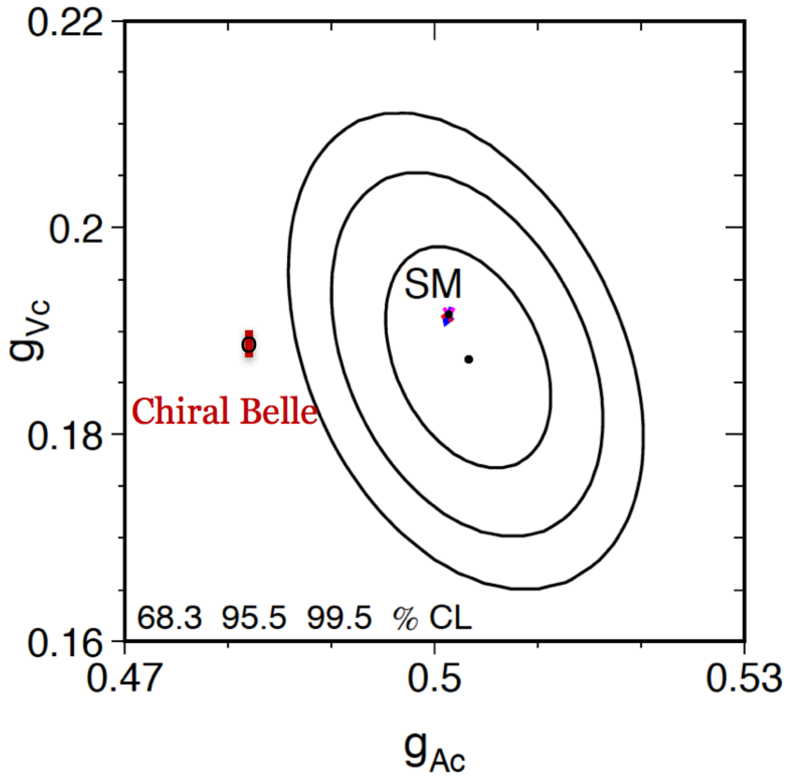
Chiral Belle probes both high and low energy scales

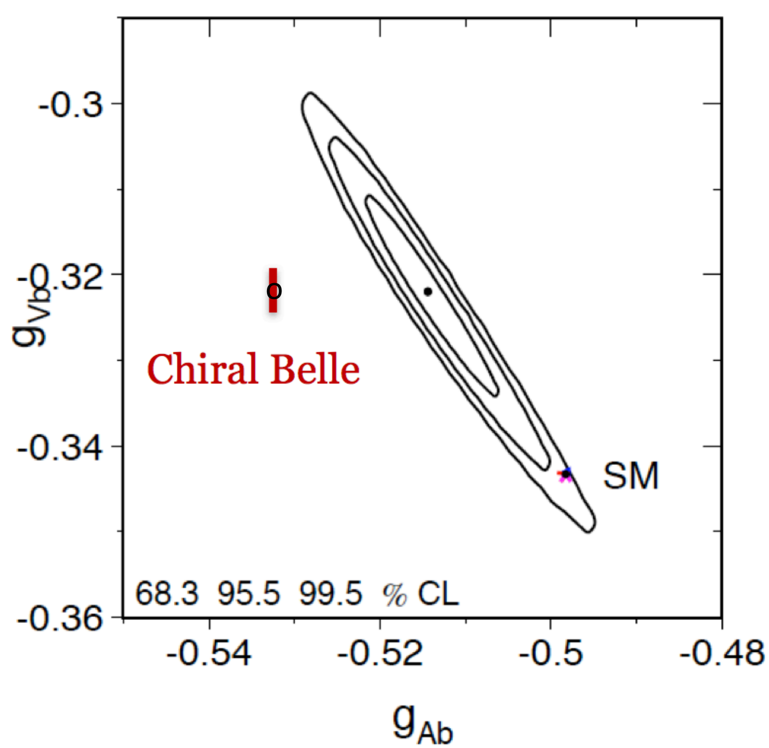
Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD

c-quark:
Chiral Belle ~7 times more precise

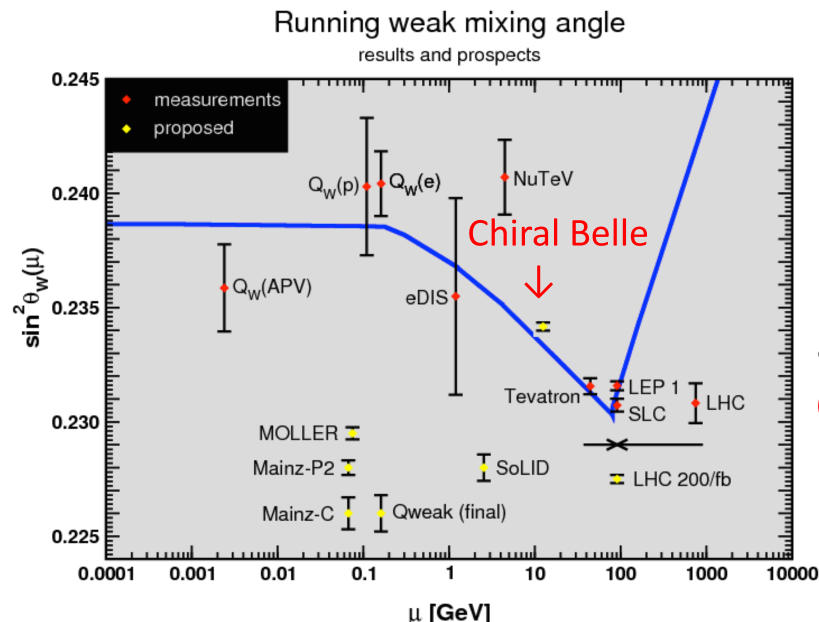
b-quark:
Chiral Belle ~4 times more precise

with 20 ab^{-1}





Chiral Belle probes both high and low energy scales



Erler, Moriond 2017

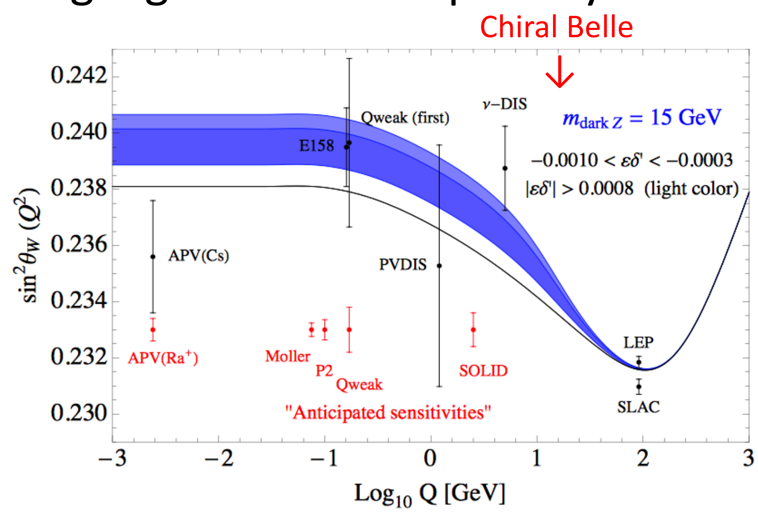
arXiv:1704.08330 [hep-ph]

Chiral Belle: σ ~ 0.00018

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

Chiral Belle probes both high and low energy scales

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



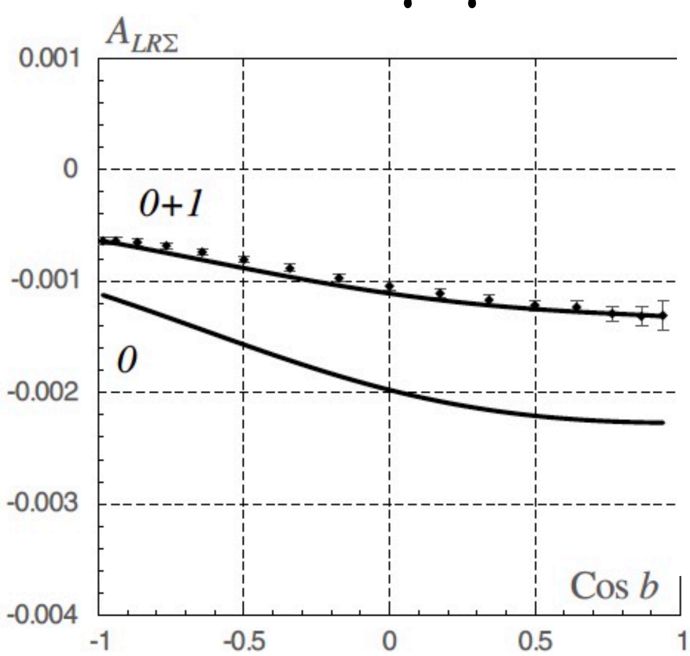
- Global interest in this EW physics:
  - LHC experiments
  - APV measurements at lower energy scales
  - Moller Experiment at Jefferson Lab which will measure $\sin^2\theta_{eff}^{electron}$ below 100MeV with similar precision (note: Moller is only sensitive to electron couplings.)
  - Next generation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

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) **(see Ruban Sandapen's talk)**

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

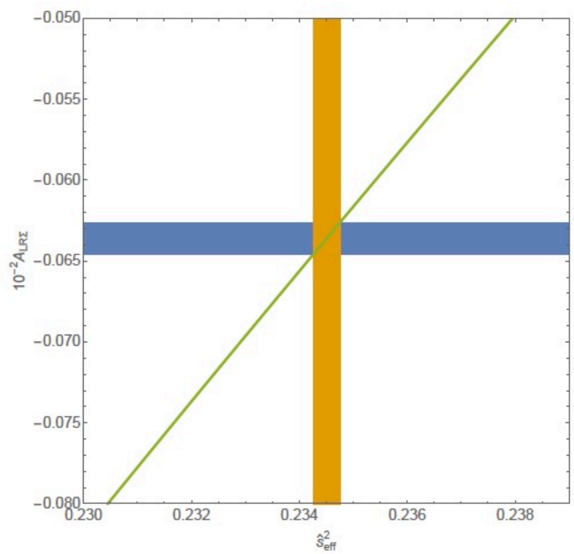


$$\Sigma_L^C = \int_{\cos b}^{\cos a} \sigma_L^C \cdot d(\cos\theta), \quad \Sigma_R^C = \int_{\cos b}^{\cos a} \sigma_R^C \cdot d(\cos\theta)$$

a=10^o & energy of photons < 2GeV

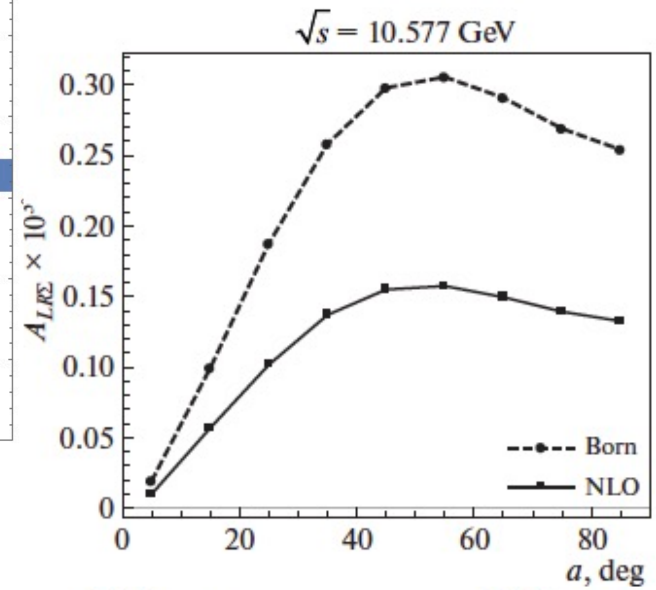
Phys.Rev. D101 (2020) no.5, 053003

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



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

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



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

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Chiral Belle also provides

- Improved precision measurements of τ electric dipole moment (EDM) and $(g\text{-}2)_\tau$
  - See J. Bernabéu, G. A. Gonzalez-Sprinberg, and J. Vidal, "CP violation and electric dipole moment at low energy tau production with polarized electrons", Nucl. Phys. B763:283–292, 2007, hep-ph/0610135.

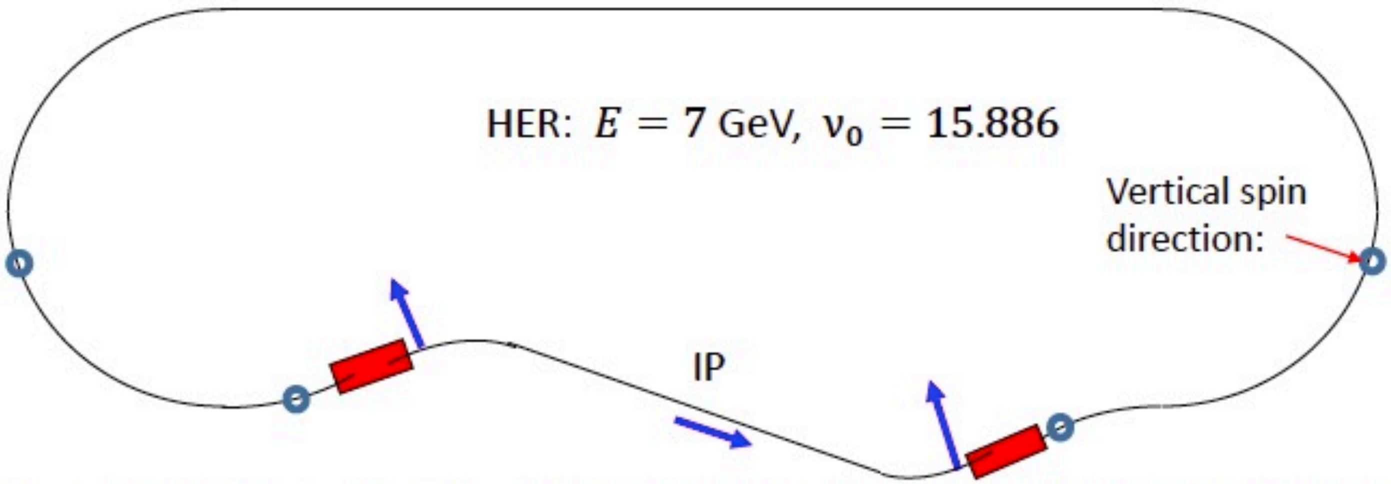
- e^- beam polarization can be used to reduce backgrounds in $\tau \to \mu\gamma$ and $\tau \to e\gamma$ – leading to improved sensitivities; also electron beam polarization and can be used to distinguish Left and Right handed New Physics currents.
  - See: arXiv:1008.1541v1 [hep-ex]
- Polarized e+e- annihilation into a polarized Λ or a hadron pair experimentally probes dynamical mass generation in QCD

Polarization in SuperKEKB

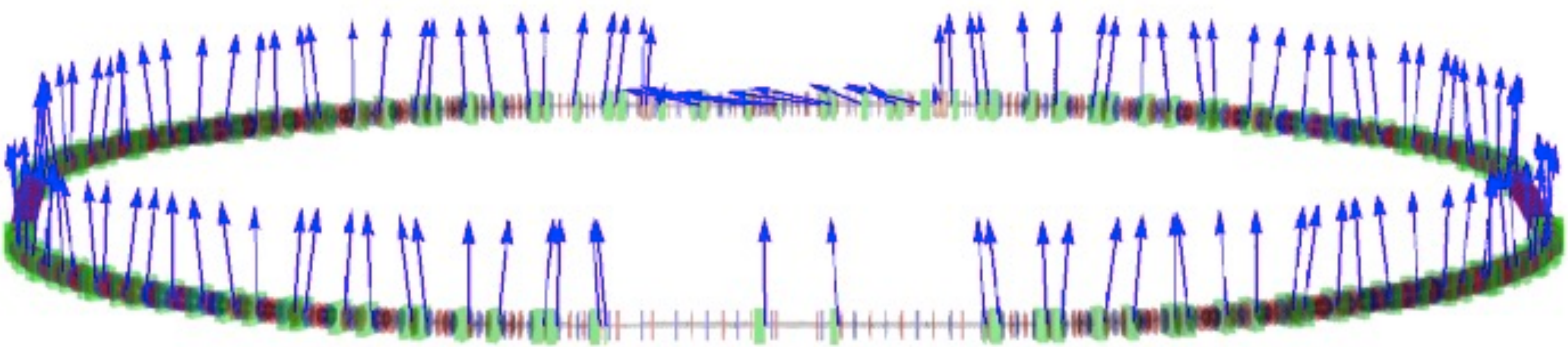
- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source)
- Inject vertically polarized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

Spin Rotator

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.



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

Polarization in SuperKEKB

Hardware needs

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

Current source photo-cathode

With 5 nC/bunch

20 mm-mrad vertical emittance

50 mm-mrad horizontal emittance

KEK and Hiroshima Groups

M. Satoh et al, IPAC 2016 Proceedings

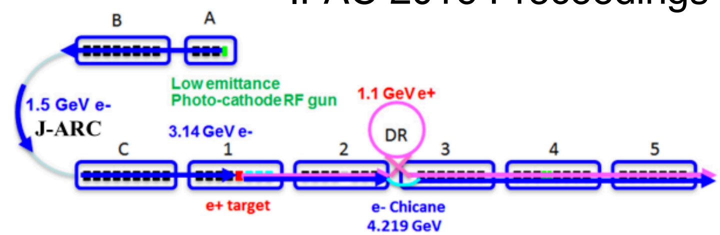


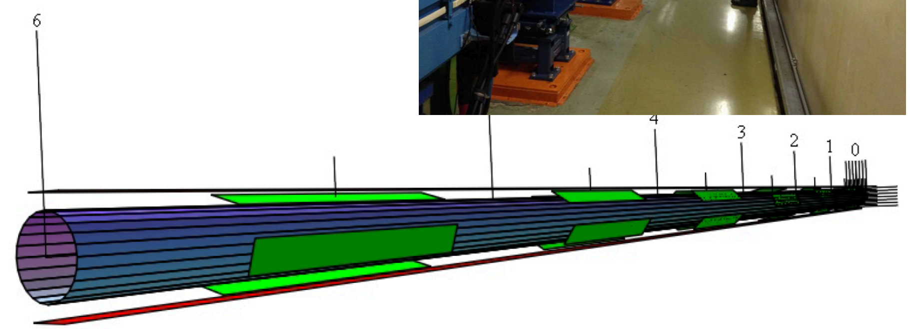
Figure 1: Schematic drawing of the SuperKEKB injector linac.

Table 1: Main Parameters of SuperKEKB Injector Linac

	KEKB		SuperKEKB (Phase III)	
	e-	e+	e-	e+
Beam energy (GeV)	8	3.5	7	4
Bunch charge (nC)	1	$1\ (10^{*})$	5	$4\ (10^{*})$
Normalized vertical emittance (mm·mrad)	100	2100	20	20
Normalized horizontal emittance (mm·mrad)	100	2100	50	100
Energy spread (%)	0.05	0.125	0.08	0.07
Bunch length (mm)	1.3	2.6	1.3	0.7
# of bunch	2			
Maximum beam repetition (Hz)	50			

Polarization in SuperKEKB

Hardware needs



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

Consider using combined function magnets (the solenoid and dipole spin-rotator magnets, plus the quadrupoles) needed for decoupling, in three superconducting magnets on either side of the IP which would replace three existing bending magnets. 5.9m long, 150m on either side of interaction point

Potential CFI request

BINP, ANL, BNL, TRIUMF-Victoria Groups

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 just outside Cryostats for the final focusing quads

Potential CFI request

U. Manitoba and LAL Orsay groups

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

- Canada: M. Roney, C. Miller, Y. Peng, Tobi Junginger (UVic); S. Koscielniak, R. Baartman, T. Planche (TRIUMF); J. Mammei, M. Gericke, W. Deconinck (Manitoba); C. Hearty (UBC/IPP); A. Aleksejevs, S. Barkanova (MUN)
- France: A. Martens, Y. Peinaud,F. Zomer, P. Bambade,F. Le Diberder, K. Trabselsi (LAL, Orsay)
- KEK & Japanese universities: D. Zhou, consulting with K. Ohmi, E. Forest connecting to overall SuperKEKB team - Y.Ohnishi and T.Miyajima; Katsunobu Oide (CERN/KEK)
- Japanese universities: M. Kuriki and Z. Liptack (Hiroshima Univ.)
- Russia: Ivan Koop, A.Otboev and Yu.Shatunov (BINP, Novosibirsk), V. Zykunov, Yu. M. Bystritskiy (DUBNA)
- USA: U. Wienands (ANL), Brett Parker et al (BNL – N.B. synergies with EIC), S. Banerjee (Louisville), Anselm Vossen (Duke), A. Signori (Pavia, Jlab)

Preparing White Paper as basis for LOI, followed by CDR & TDR, then construction.

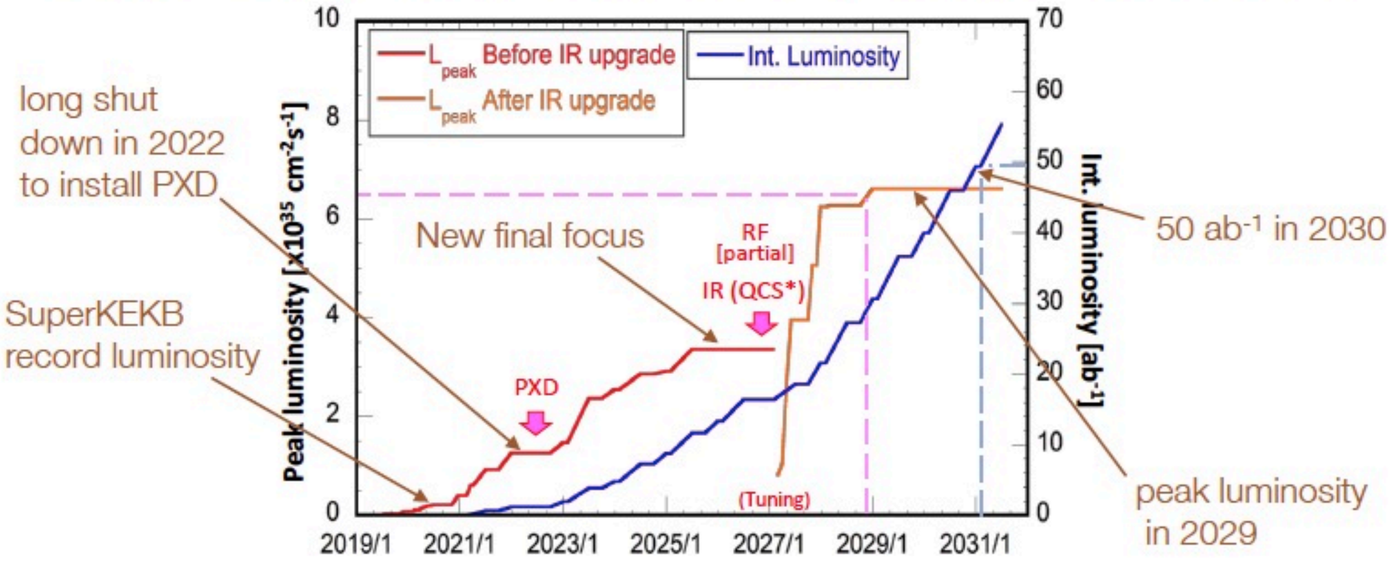
Additional Attraction: Opportunity not just for physics, but serves as real-world project to develop technologies for learning and training for future e+e- polarization projects

SuperKEKB polarization upgrade

- Aim to install polarization in shutdown for new final focus in 2026 – preparing for MEXT KEK Roadmap 2021-26

Longer term Belle II run plan

- Run through 2030 to get full data set.
- New 2-layer pixel detector in 2022; new final focus 2026.



C. Hearty | Belle II | IPP LRP July 2020 14

Chiral Belle: Polarization in SuperKEKB

HQP Opportunities

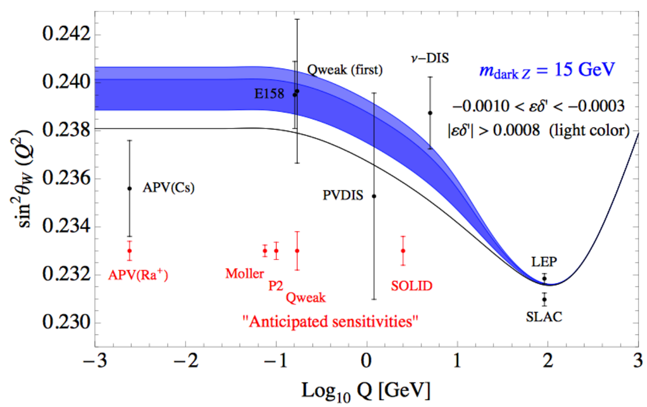
- Accelerator Physics – polarized source, spin rotators, beam dynamics
- Detector development and construction (Compton polarimeter)
- Data analysis with Belle II detector – tau polarimeter, signal selection algorithms, precision systematic error studies
- Experience working in international team of accelerator physicists, experimental and theoretical particle physicists
- Excellent training ground for generation who will build ILC and/or FCC

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

Summary

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



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

Summary

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

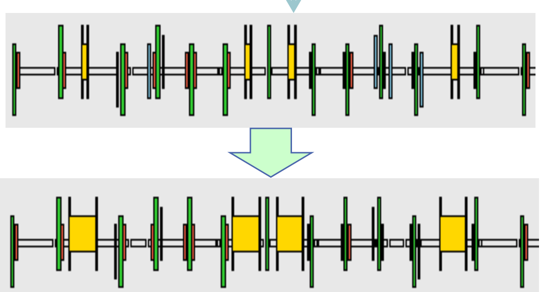
Thankyou for your attention…

…and consider taking the plunge and join Chiral Belle:
the SuperKEKB electron beam polarization project!

Additional Information

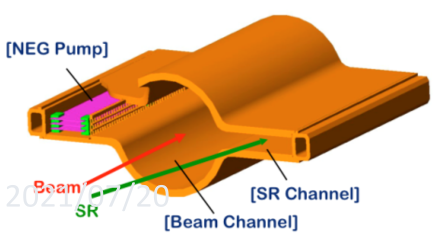
SuperKEKB in Japan

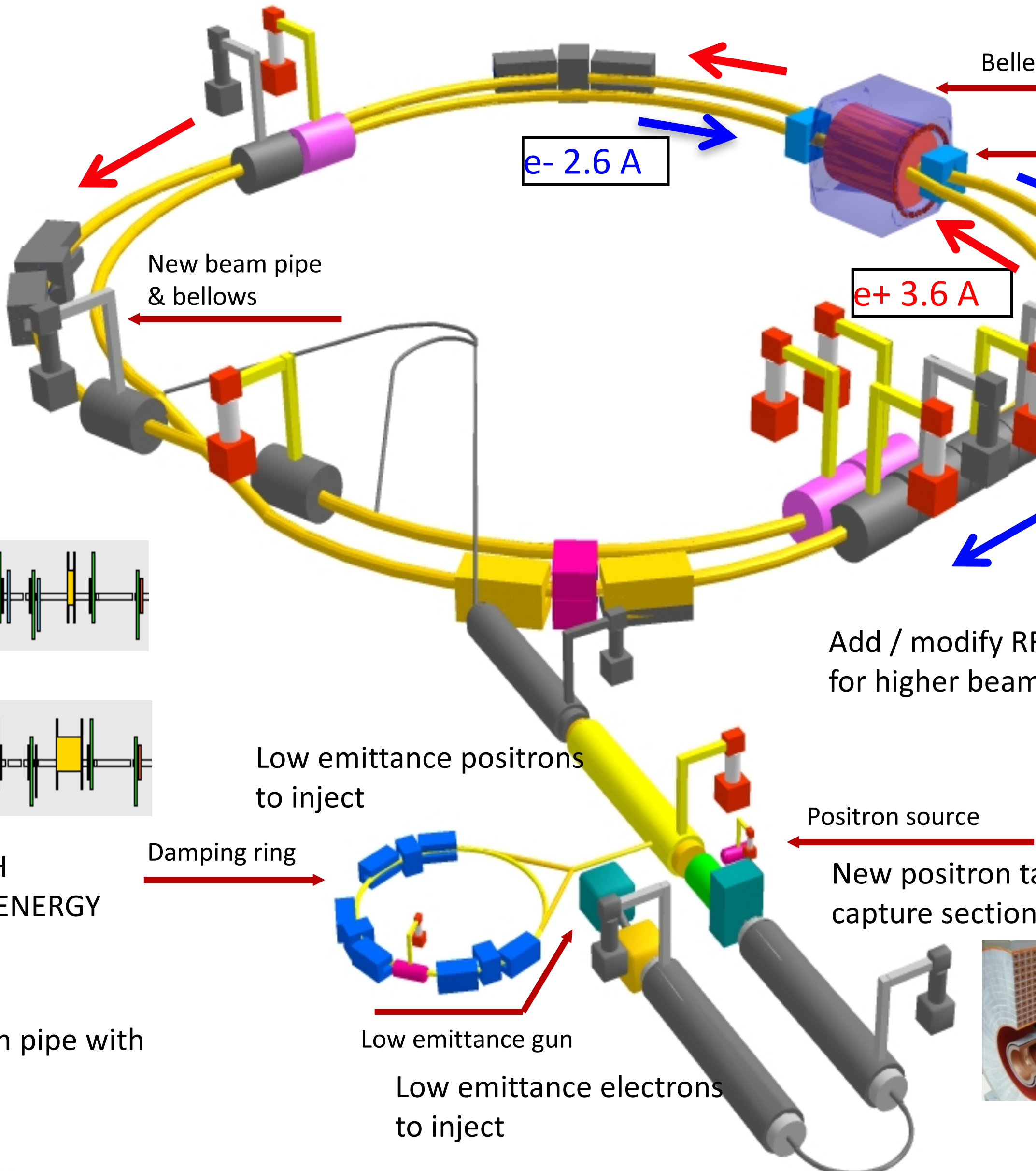
Replace short dipoles with longer ones (LER)



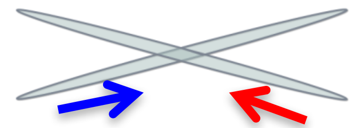
Redesign the lattices of HIGH ENERGY RING (HER) & LOW ENERGY RING (LER) to squeeze the emittance

TiN-coated beam pipe with antechambers

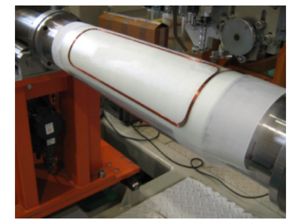




Colliding bunches

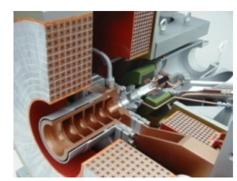


New superconducting /permanent final focusing quads near the IP



Add / modify RF systems for higher beam current

New positron target / capture section



To obtain x40 higher luminosity

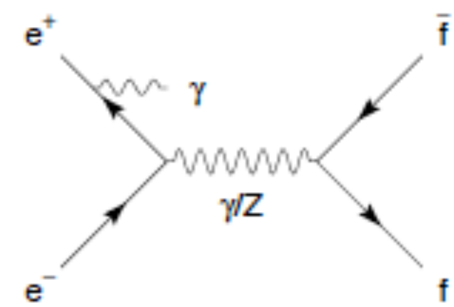
Chiral Belle → Left-Right Asymmetries

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

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

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

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



Source generates mainly right-handed electrons

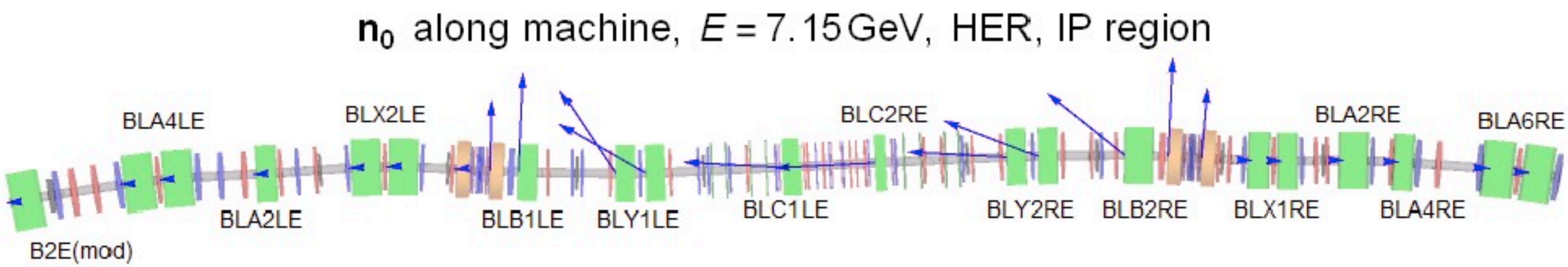
Source generates mainly left-handed electrons

Polarization in SuperKEKB

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

Recent studies by BINP group

Version 3: Bird view on the spin direction in the FF region



"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.

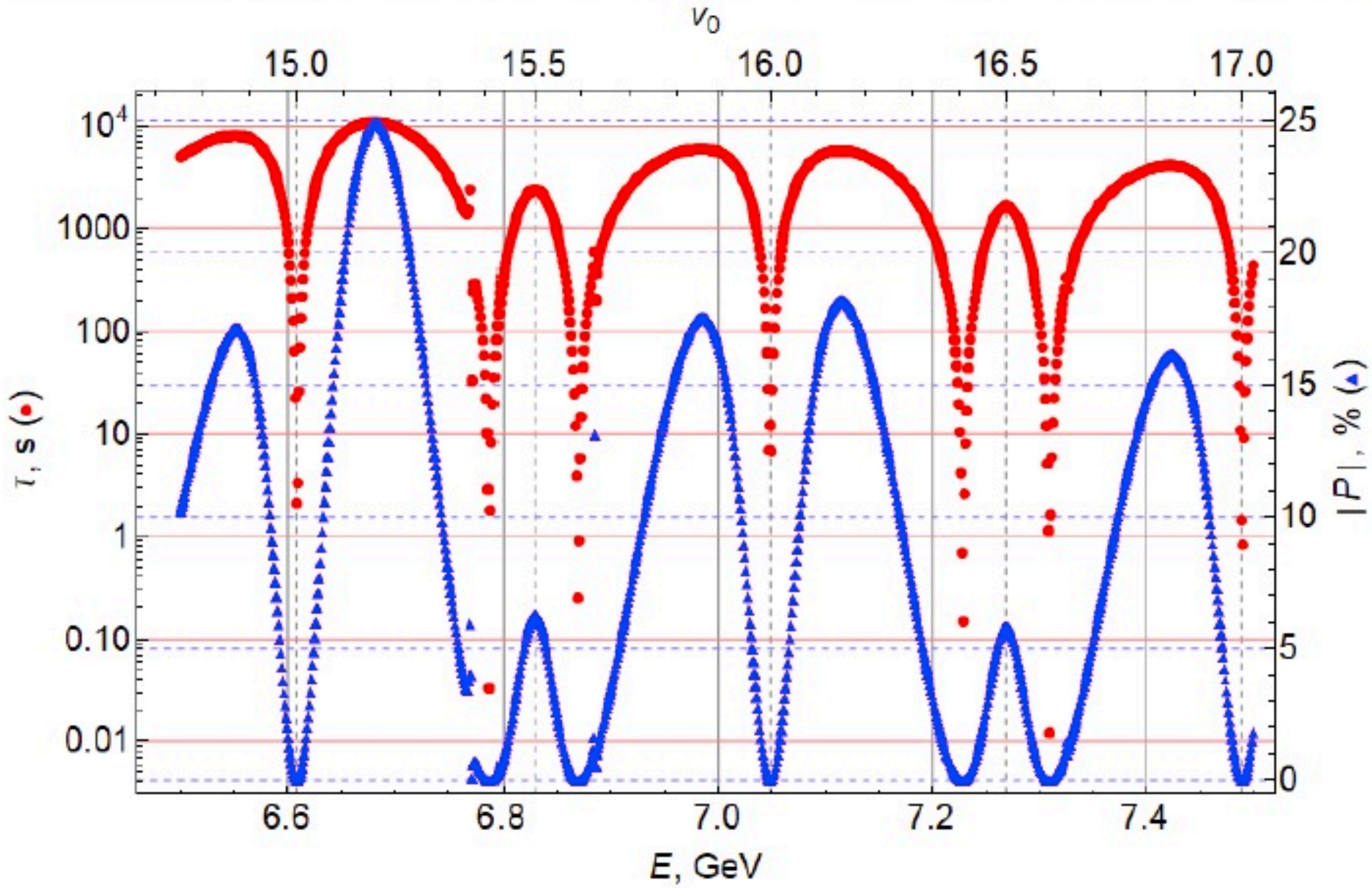
Recent studies by BINP group

Version 3 of the FF region geometry: Right half from IP

Koop, Long. Pol. 11

Recent studies by BINP group

Version 3: Energy dependence of the depolarization time



In this version 3 the depolarization time at 7.15 GeV is 4350 s – somewhat lower than in version 2.

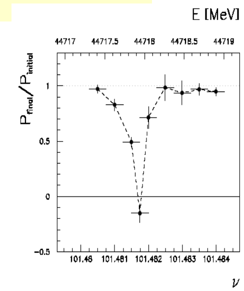
Will investigate why so!

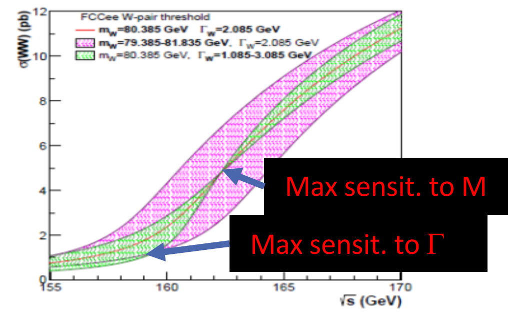
Koop, Long. Pol. 13

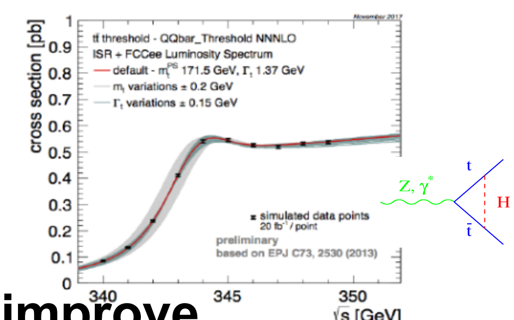
Precision Z EW is important part of FCCee program

observable	Physics	Present precision (PDG)		FCC-ee stat Syst Precision	FCC-ee key	Challenge
M_Z MeV/c2	Input	91187.5 ±2.1	Z Line shape scan	**0.004 MeV <±0.1 MeV**	**E_cal**	QED corrections
Γ_Z MeV/c2	$\Delta\rho$ (T) (no $\Delta\alpha$!)	2495.2 ±2.3	Z Line shape scan	**0.007 MeV <±0.1 MeV**	**E_cal**	QED corrections
$R_l \equiv \frac{\Gamma_h}{\Gamma_l}$	α_s, δ_b	20.767 (25) (α_s ±0.0011)	Z Peak	**0.0001 (2-20) (α_s ±0.00015)**	Statistics	QED corrections
N_ν	Unitarity of PMNS, sterile ν's	2.984 ±0.008	Z Peak Z+γ(161 GeV)	**0.00008 (40) 0.001**	->lumi meast Statistics	**QED corrections to Bhabha scat.**
R_b	δ_b	0.21629 (66)	Z Peak	**0.000003 (20-60)**	Statistics, small IP	Hem. correlations
A_{LR}	$\Delta\rho$, ε_3, $\Delta\alpha$ (T, S)	$\sin^2\theta_W^{eff}$ 0.23098(26)	Z peak, **Long. polarized**	$\sin^2\theta_W^{eff}$ **±0.000006**	4 bunch scheme	Design experiment
A_{FB}^{lept}	$\Delta\rho$, ε_3, $\Delta\alpha$ (T, S)	$\sin^2\theta_W^{eff}$ 0.23099(53)		$\sin^2\theta_W^{eff}$ **±0.000006**	**E_cal** & Statistics	
M_W MeV/c2	$\Delta\rho$, ε_3, ε_2, $\Delta\alpha$ (T, S, U)	80379 ± 12	Threshold (161 GeV)	**0.5 MeV <0.5 MeV**	**E_cal** & Statistics	QED corrections **Theory ~4-5 MeV**
m_{top} MeV/c2	Input	173300 ± 400± 500	Threshold scan	**m_{top} ~17 MeV Γ_{top} ~45 MeV**	**E_cal** & Statistics	Theory limit at **~40-50 MeV**?

Beam E cal. with reson. depolar.



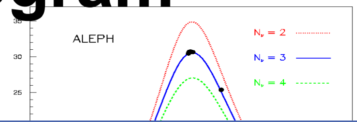




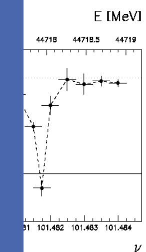
As important is the precision on SM parameters : FCCee will improve precision by > 1 order of magnitude Running at Z pole mandatory, as is progress in theory

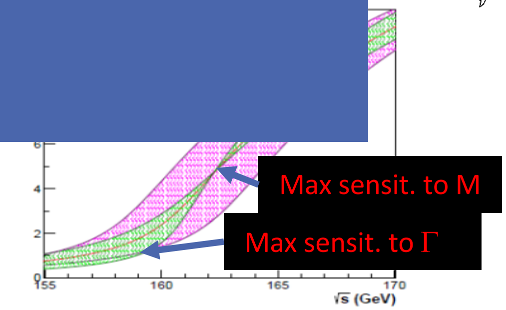
Precision Z EW is important part of FCCee program

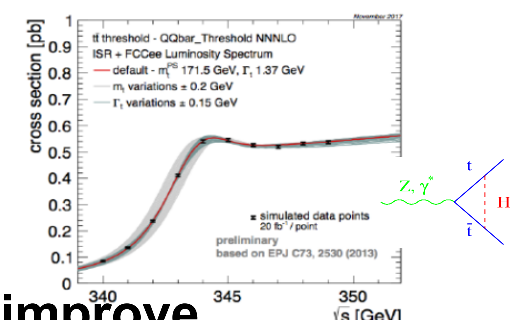
observable	Physics	Present precision		FCC-ee stat Syst Precision	FCC-ee key	Challenge
M_Z MeV/c2						
Γ_Z MeV/c2						
$R_l \equiv$						
N_ν						
R_b						
A_{LR}	$\Delta\rho, \varepsilon_3, \Delta\alpha$ (T, S)	$\sin^2\theta_w^{eff}$ 0.23098(26)	Z peak, **Long. polarized**	$\sin^2\theta_w^{eff}$ **±0.000006**	4 bunch scheme	Design experiment
A_{FB}^{lept}	$\Delta\rho, \varepsilon_3, \Delta\alpha$ (T, S)	$\sin^2\theta_w^{eff}$ 0.23099(53)		$\sin^2\theta_w^{eff}$ **±0.000006**	**E_cal** & Statistics	
M_W MeV/c2	$\Delta\rho, \varepsilon_3, \varepsilon_2, \Delta\alpha$ (T, S, U)	80379 ± 12	Threshold (161 GeV)	**0.5 MeV** **<0.5 MeV**	**E_cal** & Statistics	QED corrections **Theory ~4-5 MeV**
m_{top} MeV/c2	Input	173300 ± 400± 500	Threshold scan	**m_{top} ~17 MeV** **Γ_{top} ~45 MeV**	**E_cal** & Statistics	Theory limit at **~40-50 MeV**?



SuperKEKB with polarized beams probe Z physics at low energy much earlier







As important is the precision on SM parameters : FCCee will improve precision by > 1 order of magnitude Running at Z pole mandatory, as is progress in theory

Tau Polarization as Beam Polarimeter

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

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

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
- Experience from OPAL (at LEP) indicates a 0.2% on systematic error on the A^{pol}_{FB} is achievable, translates into 0.5% error on the beam polarization

- Now exploring this with BaBar data at UVic