Weak mixing angle measurement at SCT

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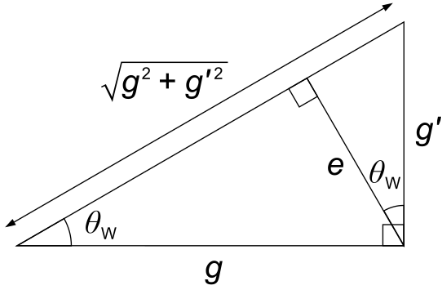
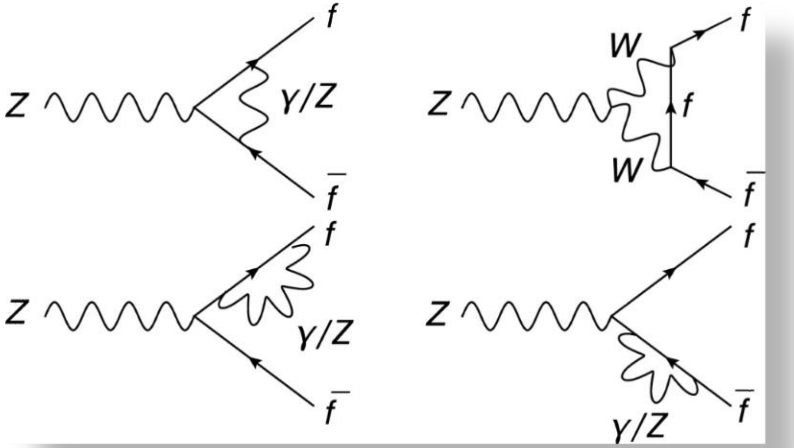
The weak mixing angle

- Electroweak model $SU(2)_L \times U(1)_Y$ (Glashow, 1961)

$$A_\mu = B_\mu^0 \cos\theta_W + W_\mu^0 \sin\theta_W$$
$$Z_\mu = W_\mu^0 \cos\theta_W - B_\mu^0 \sin\theta_W$$

Two independent coupling constants g and g'





- On-shell definition of the weak mixing angle

$$\sin^2\theta_W \equiv \frac{g'^2}{g^2 + g'^2} = 1 - \frac{m_W^2}{m_Z^2}$$

- Weak neutral current

$$\frac{g}{\cos\theta_W} Z_\mu \bar{f}\gamma^\mu\left(I_3^f - 2Q_f \sin^2\theta_W - I_3^f \gamma_5\right)f, \qquad I_3^f = 0, \pm 1/2$$

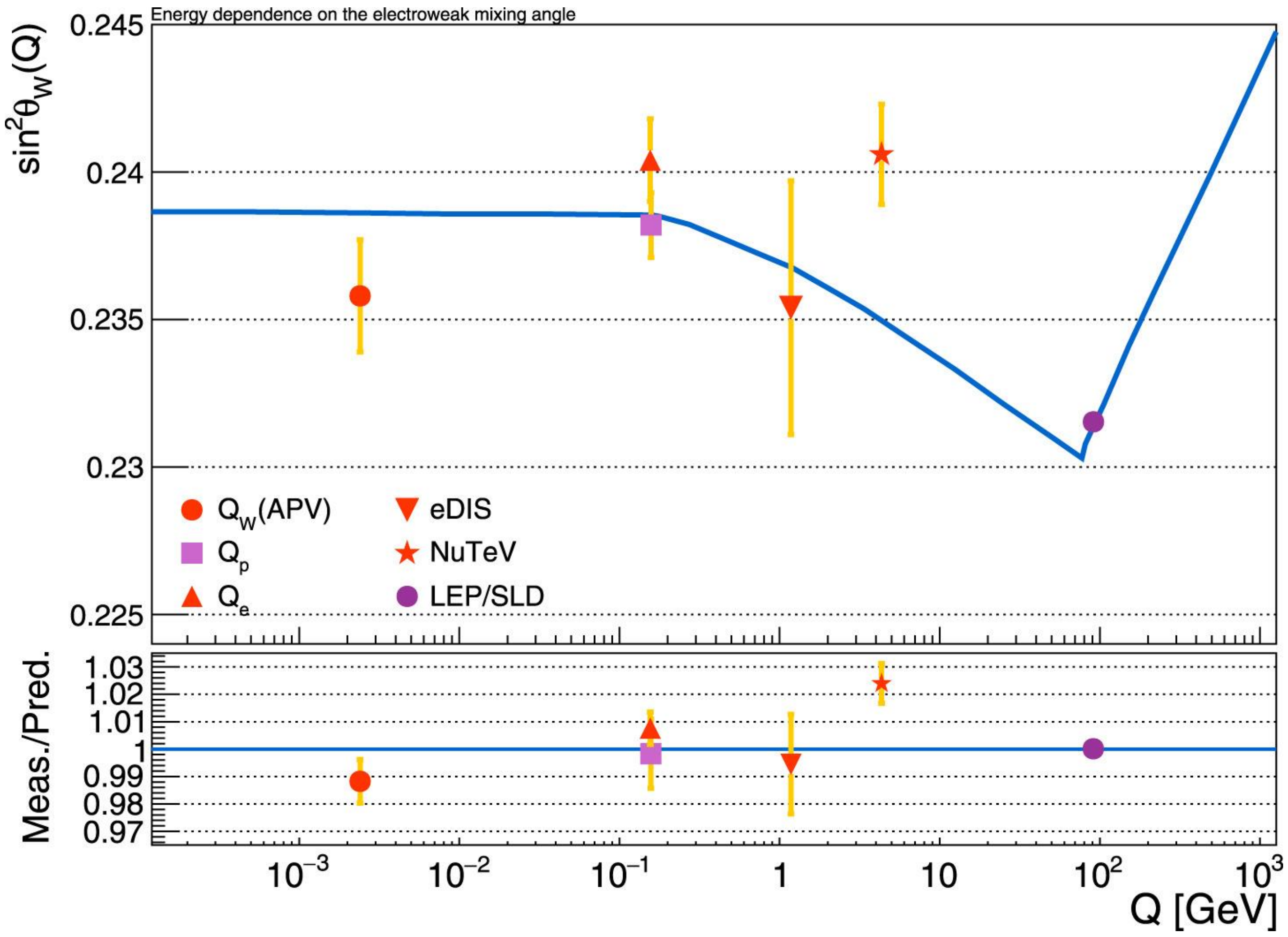
- Effective value due to radiative corrections

$$\sin^2\theta_{\text{eff}}^f \equiv \kappa_Z^f \sin^2\theta_W$$

Full two-loop EW fermionic and bosonic corrections completed recently

$\sin^2\theta_{\text{eff}}$ measurements

- A_{FB} close to the Z pole
  - $\delta(\sin^2\theta_{\text{eff}}) \approx 0.1\%$
  - $Q = m_Z = 91$ GeV
- Atomic parity violation
  - $\delta(\sin^2\theta_{\text{eff}}) \approx 0.4\%$
  - $Q \sim 10^{-3}$ GeV
- ν and polarized e^- scattering on fixed targets
  - $\delta(\sin^2\theta_{\text{eff}}) \approx 5\%$
  - $Q \sim 1$ GeV
- Planned experiments
  - P2 at MESA (Mainz)
  - Moller at JLab



$\sin^2\theta_{\text{eff}}$ at colliders

1. LEP
   - Unpolarized e^+e^- beams near Z pole, 17×10^6 Zs
   - Forward-backward asymmetry

2. SLAC Large Detector (SLD)
   - Polarized e^+e^- beams near Z pole, 50×10^3 Zs
   - Average beam polarization of 60%
   - Combinations of the forward-backward and left-right asymmetries

3. LHC: ATLAS, CMS, LHCb
   - Unpolarized proton beams
   - Tests of the $Z \to l\bar{l}$ couplings and measurement of $\sin^2\theta_{\text{eff}}^{l}$
   - Model-dependent

Left-right asymmetry at J/ψ

- Interference of γ^* and Z^* annihilation

$$A_{LR} = \frac{3/8 - \sin^2\theta^c_{\text{eff}}}{2\sin^2\theta^c_{\text{eff}}\left(1-\sin^2\theta^c_{\text{eff}}\right)}\left(\frac{m_{J/\psi}}{m_Z}\right)^2 \boxed{\xi} \approx 4.7\times 10^{-4}\xi$$

the average e^- polarization

- The expected statistical precision at SCT
  - Luminosity $L = 10^{35}\ \text{cm}^{-2}\text{s}^{-1}$
  - Cross-section $\sigma(e^+e^- \to J/\psi) \approx 10^{-30}\ \text{cm}^2$
  - One data-taking season $t = 10^7$ s
  - Fraction of J/ψ decays employed for the analysis $\varepsilon \approx 0.5$

$$A_{LR} \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}, \qquad \frac{\sigma(A_{LR})}{A_{LR}} \approx \frac{1}{A_{LR}\sqrt{L\sigma t\varepsilon}} \approx 5\times 10^{-3}$$

СЛАБЫЕ НЕЙТРАЛЬНЫЕ ТОКИ НОВЫХ КВАРКОВ В e^+e^--АННИГИЛЯЦИИ

Ю. И. СКОВПЕНЬ, И. Б. ХРИПЛОВИЧ

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

(Поступило в редакцию 11 апреля 1979 г.)

и при полной продольной поляризации обеих или хотя бы одной из начальных частиц находим для $q\bar{q}$-резонанса

$$\eta(1,-1) = \eta(1,0) = \eta(0,-1) = \frac{\sqrt{2}Gm^2}{8\pi\alpha|Q|}(1-4|Q|\sin^2\theta). \qquad (6)$$

При $\sin^2\theta = {}^1/_4$ [1] эта величина составляет соответственно для ψ- и Υ-пиков

$$\eta_\psi = \frac{\sqrt{2}\,Gm^2}{16\pi\alpha} \approx 4\cdot 10^{-4}, \quad \eta_\Upsilon = \frac{\sqrt{2}\,Gm^2}{4\pi\alpha} \approx 1{,}6\cdot 10^{-2}. \qquad (7)$$

$\sin^2(\theta_{\text{eff}}^c)$ at J/ψ

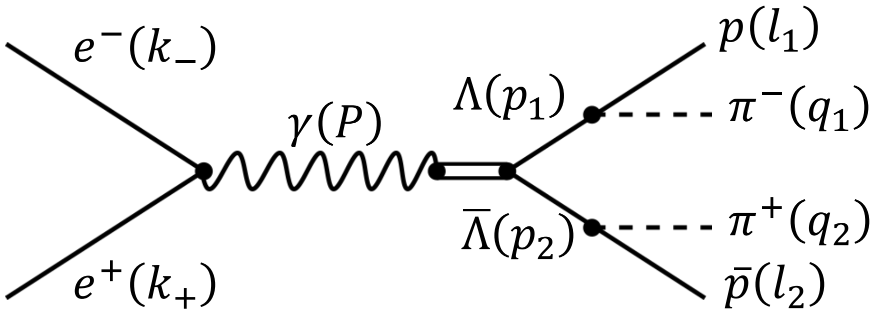
$$\frac{\sigma(\sin^2\theta_{\text{eff}}^c)}{\sin^2\theta_{\text{eff}}^c} \approx -0.44\frac{dA_{LR}}{A_{LR}} \oplus 0.44\frac{d\xi}{\xi} \approx 0.3\%$$

- The ultimate one-year absolute precision for $\sin^2\theta_{\text{eff}}^c$ at SCT is 5×10^{-4}
  - The average electron beam polarization ξ should be controlled with precision of 10^{-3}
- Polarization monitoring
  - On-line laser diagnostics
  - Off-line data-driven approach (this talk)
- Luminosity monitoring
- Careful experiment design to minimize systematic uncertainty

$e^+e^- \to J/\psi \to [\Lambda \to p\pi^-][\bar{\Lambda} \to \bar{p}\pi^+]$

- Leptonic current (z axis along Λ momentum)

$$j_e^\mu \equiv \bar{v}_{-\xi}\gamma^\mu u_\xi = \sqrt{s}(0, \xi\cos\theta\,, i, -\xi\sin\theta)$$



- The $J/\psi \to \Lambda\bar{\Lambda}$ vertex

$$-ie_g\bar{u}_\Lambda(p_1)\left[G_{\mathrm{M}}^{\psi}\gamma^\mu - \frac{2m_\Lambda}{Q^2}\left(G_{\mathrm{M}}^{\psi} - G_{\mathrm{E}}^{\psi}\right)Q^\mu\right]v_{\bar{\Lambda}}(p_2),$$

$$Q \equiv p_1 - p_2$$

- The $\Lambda \to p\pi^-$ ($\bar{\Lambda} \to \bar{p}\pi^+$) vertex

$$\bar{u}_p[A + B\gamma^5]u_\Lambda, \qquad \left(\bar{v}_{\bar{\Lambda}}[A' + B'\gamma^5]v_{\bar{p}}\right), \qquad |A| \sim |B|$$

- Four real form-factors

$$\alpha \equiv \frac{s\left|G_{\mathrm{M}}^{\psi}\right|^2 - 4m_\Lambda^2\left|G_{\mathrm{E}}^{\psi}\right|^2}{s\left|G_{\mathrm{M}}^{\psi}\right|^2 + 4m_\Lambda^2\left|G_{\mathrm{E}}^{\psi}\right|^2}, \qquad \Delta\Phi \equiv \arg\left(\frac{G_{\mathrm{E}}^{\psi}}{G_{\mathrm{M}}^{\psi}}\right), \qquad \boxed{\alpha_1, \alpha_2}$$

Λ and $\bar{\Lambda}$ decay form-factors. CP conservation implies $\alpha_1 = -\alpha_2$

Leptonic and hadronic tensors

- Leptonic tensor

$$L^{\mu\nu} \equiv (j_e^{\nu})^{\dagger} j_e^{\mu} = k_+^{\mu} k_-^{\nu} + k_-^{\mu} k_+^{\nu} - \frac{s}{2} g^{\mu\nu} - \boxed{\xi i \varepsilon^{\mu\nu\alpha\beta} k_{-\alpha} k_{+\beta}}$$

- Hadronic tensor: separate symmetric and anti-symmetric parts

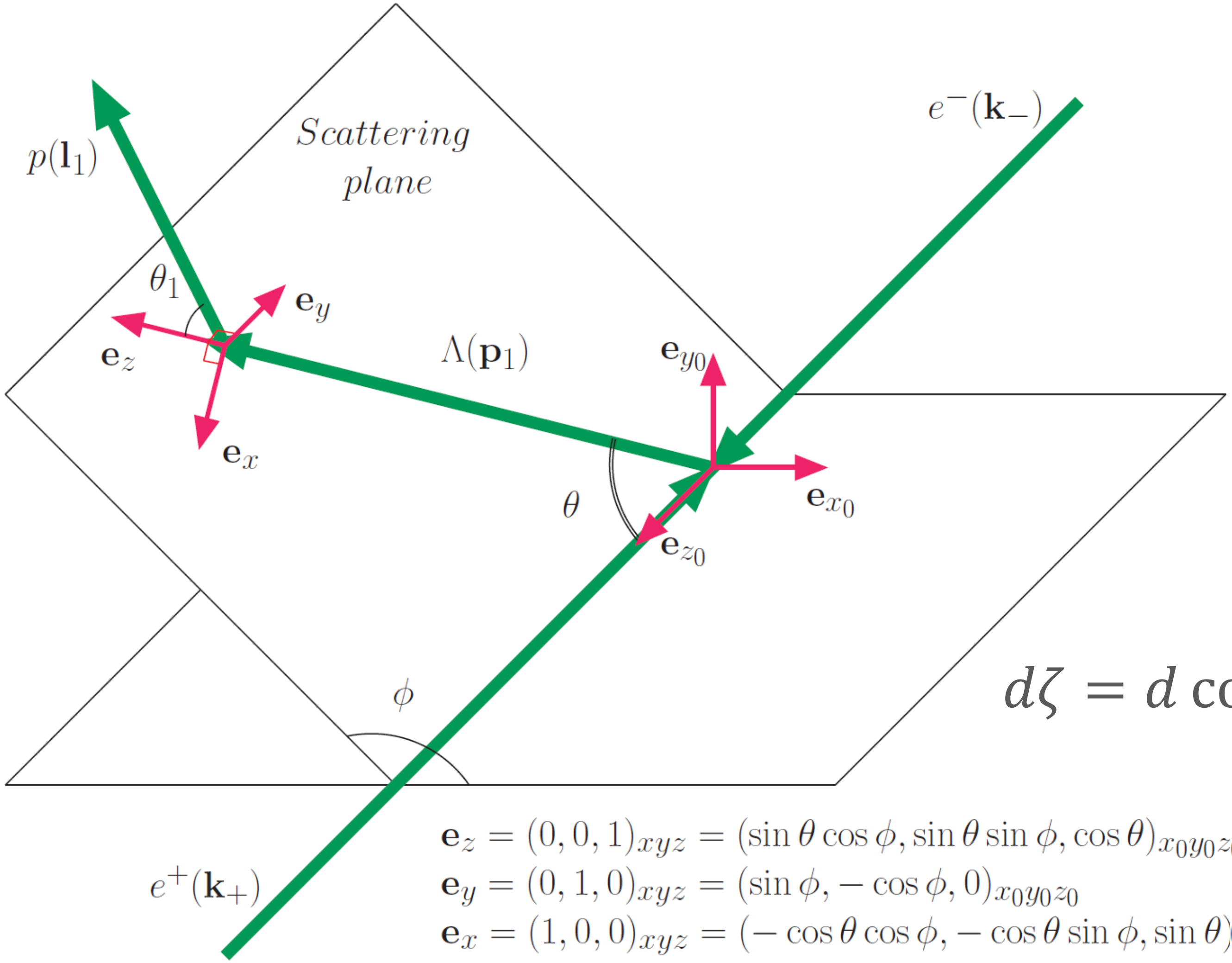
$$H_{\nu\mu} \equiv \widetilde{H}_{\nu\mu} + \overline{H}_{\nu\mu}, \qquad \widetilde{H}_{\nu\mu} \equiv \frac{H_{\nu\mu} + H_{\mu\nu}}{2}, \qquad \overline{H}_{\nu\mu} \equiv \frac{H_{\nu\mu} - H_{\mu\nu}}{2}$$

- Differential cross-section (5D)

$$d\sigma \propto W(\zeta) d\cos\theta \, d\Omega_1 d\Omega_2, \qquad W(\zeta) \propto L^{\mu\nu} H_{\nu\mu} = a + \xi b$$

- Symmetric part calculated in G. Fäldt, Eur. Phys. J. A 51 (2015) 74

Combined reference frame



$$\mathbf{e}_z = (0,0,1)_{xyz} = (\sin\theta\cos\phi, \sin\theta\sin\phi, \cos\theta)_{x_0y_0z_0}$$
$$\mathbf{e}_y = (0,1,0)_{xyz} = (\sin\phi, -\cos\phi, 0)_{x_0y_0z_0}$$
$$\mathbf{e}_x = (1,0,0)_{xyz} = (-\cos\theta\cos\phi, -\cos\theta\sin\phi, \sin\theta)_{x_0y_0z_0}$$

$$e_z = \frac{p}{|p|}$$

$$e_y = \frac{1}{\sin\theta}\left(\frac{p}{|p|} \times \frac{k}{|k|}\right)$$

$$e_x = e_y \times \frac{p}{|p|}$$

$$d\zeta = d\cos\theta\, d\cos\theta_1\, d\varphi_1 d\cos\theta_2\, d\varphi_2$$

Angular distribution

$$W(\zeta) = a + \xi b$$

$$a = F_0 + \alpha F_5 + \alpha_1 \alpha_2 \left(F_1 + \sqrt{1-\alpha^2} \cos(\Delta\Phi) F_2 + \alpha F_6 \right) + \sqrt{1-\alpha^2} \sin(\Delta\Phi) (\alpha_1 F_3 + \alpha_2 F_4)$$

$$b = (1+\alpha)(\alpha_1 G_1 + \alpha_2 G_2) + \sqrt{1-\alpha^2} \cos(\Delta\Phi) (\alpha_1 G_3 + \alpha_2 G_4) + \sqrt{1-\alpha^2} \alpha_1 \alpha_2 \sin(\Delta\Phi) G_5$$

$$\begin{aligned}
\mathcal{F}_0 &= 1, \\
\mathcal{F}_1 &= \sin^2\theta \sin\theta_1 \sin\theta_2 \cos\phi_1 \cos\phi_2 + \cos^2\theta \cos\theta_1 \cos\theta_2, \\
\mathcal{F}_2 &= \sin\theta \cos\theta \left(\sin\theta_1 \cos\theta_2 \cos\phi_1 + \cos\theta_1 \sin\theta_2 \cos\phi_2\right), \\
\mathcal{F}_3 &= \sin\theta \cos\theta \sin\theta_1 \sin\phi_1, \\
\mathcal{F}_4 &= \sin\theta \cos\theta \sin\theta_2 \sin\phi_2, \\
\mathcal{F}_5 &= \cos^2\theta, \\
\mathcal{F}_6 &= \cos\theta_1 \cos\theta_2 - \sin^2\theta \sin\theta_1 \sin\theta_2 \sin\phi_1 \sin\phi_2,
\end{aligned}$$

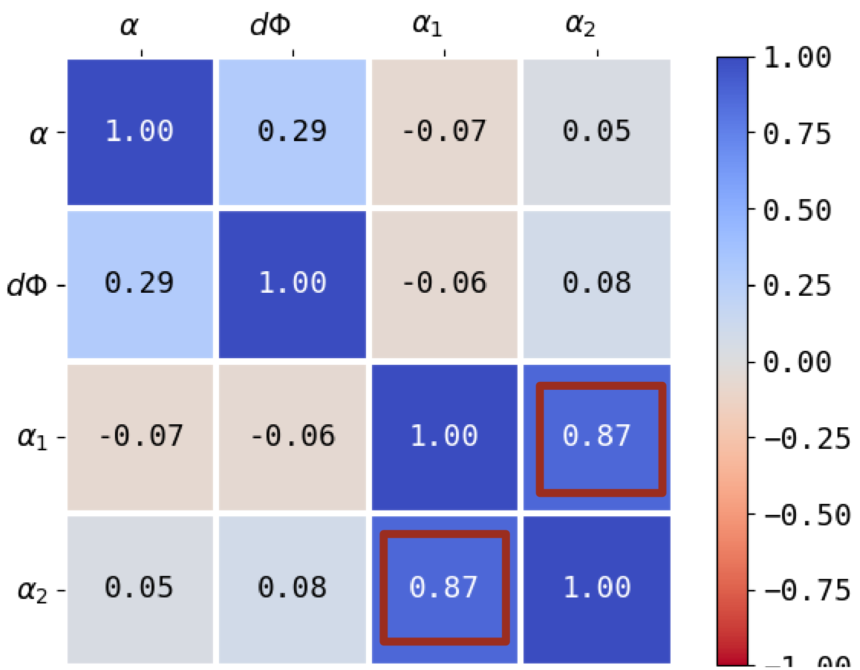
$$\begin{aligned}
\mathcal{G}_1 &= \cos\theta \cos\theta_1, \\
\mathcal{G}_2 &= \cos\theta \cos\theta_2, \\
\mathcal{G}_3 &= \sin\theta \sin\theta_1 \cos\phi_1, \\
\mathcal{G}_4 &= \sin\theta \sin\theta_2 \cos\phi_2, \\
\mathcal{G}_5 &= \sin\theta \left(\sin\theta_1 \cos\theta_2 \sin\phi_1 + \cos\theta_1 \sin\theta_2 \sin\phi_2\right).
\end{aligned}$$

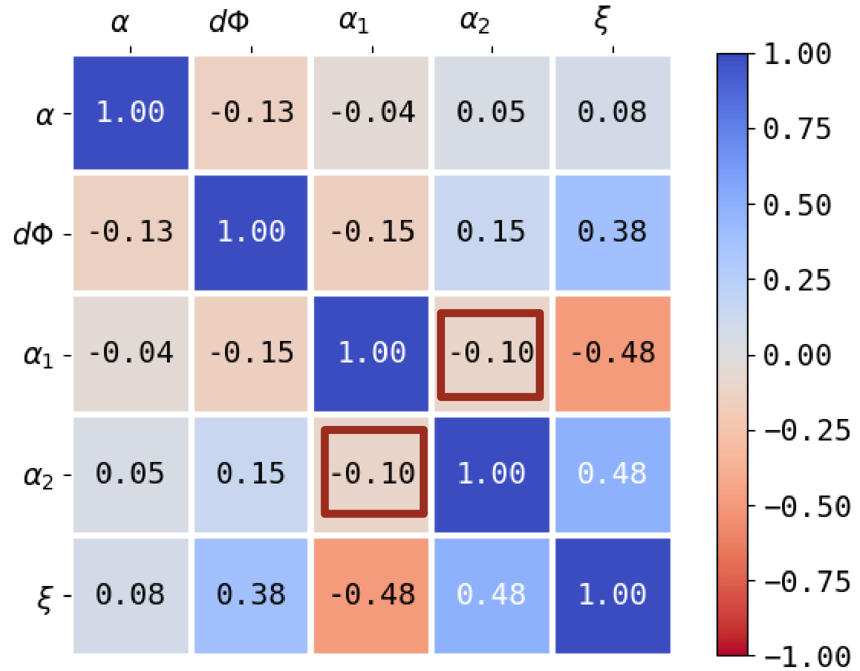
New!

Feasibility study: 5D Fit

Setup	SCT one-year σ (10^{-4})			
	ξ	α	$\Delta\Phi$ (rad)	α_i
$\xi = 0$	Fixed	1.5	3.1	2.8
$\xi = 0.8$	1.3	1.2	1.6	0.9

- The expected one-year signal yield at SCT
$$N_{\text{sig}} = 0.8 \times 10^9 \varepsilon_{\text{det}}$$
- ξ_+ and ξ_- are independent fit parameters
- Sensitivity to the *CP*-violating combination $\alpha_1 + \alpha_2$ is increased dramatically due to the beam polarization
  - SM expectation
$$A_\Lambda \equiv \left|\frac{\alpha_1 + \alpha_2}{\alpha_1 - \alpha_2}\right| \lesssim 5 \times 10^{-5}$$
Expected precision: $\sigma(A_\Lambda) = 1.2 \times 10^{-4}$





Single-side observables

- 3D single-side angular distribution

$$\frac{d\sigma}{d\cos\theta\ d\Omega_1} \propto a + \xi b$$

$$a = 1 + \alpha\cos^2\theta + \alpha_1\sqrt{1-\alpha^2}\sin\Delta\Phi\sin\theta\cos\theta\sin\theta_1\sin\phi_1$$

$$b = (1+\alpha)\alpha_1\cos\theta\cos\theta_1 + \alpha_1\sqrt{1-\alpha^2}\cos\Delta\Phi\sin\theta\sin\theta_1\cos\phi_1$$

- The form factors and average beam polarization can be measured using single-side reconstructed events

Setup	SCT one-year σ (10^{-4})			
	ξ	α	$\Delta\Phi$ (rad)	α_i
5D $\xi = 0$	Fixed	1.5	3.1	2.8
5D $\xi = 0.8$	1.3	1.2	1.6	0.9
3D $\xi = 0.8$	4.3	1.2	2.4	3.4

1D Distributions

- Proton azimuth angle ϕ_1 in Λ frame

$$\frac{d\sigma}{d\phi_1} \propto 1 + \frac{\alpha}{3} + \xi \frac{\pi^2}{16} \alpha_1 \sqrt{1-\alpha^2} \cos\Delta\Phi \cos\phi_1$$

  - Corresponding integral asymmetry

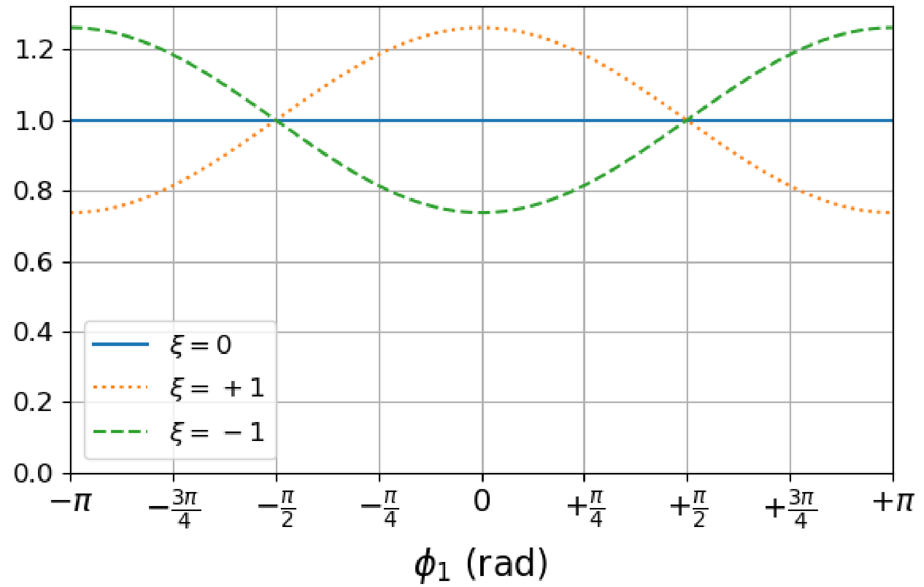
$$A_{\mathrm{LR}} = \xi \frac{3\pi}{8} \frac{\sqrt{1-\alpha^2}}{\alpha+3} \alpha_1 \cos\Delta\Phi \approx 0.17\xi$$

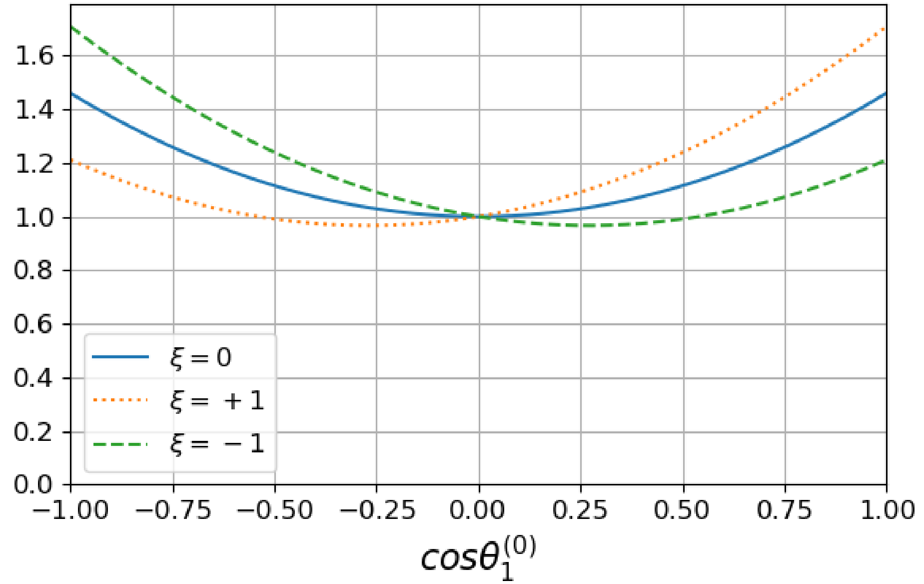
- Proton polar angle in the lab frame

$$\frac{d\sigma}{d\cos\theta_1^{(0)}} \propto 1 + \alpha\cos^2\theta_1^{(0)} + \xi\alpha_1\cos\theta_1^{(0)} [0.203(1+\alpha) + 0.054\sqrt{1-\alpha^2}\cos\Delta\Phi + \underline{\mathcal{O}(10^{-2})}]$$

  - Integral asymmetry $A_{\mathrm{FB}}^{(0)} \approx 0.11\xi$

can be improved





Feasibility study: summary

1. The process $e^+e^- \to J/\psi \to [\Lambda \to p\pi^-][\bar{\Lambda} \to \bar{p}\pi^+]$ can be used to control the average beam polarization precisely enough for measurement of the $\sin^2\theta_{\text{eff}}^c$

$$\sigma_{\text{stat}}(\xi) \sim 10^{-4}$$

   Systematic uncertainty is to be considered

2. Longitudinal polarization of electron beam
   - improves Λ baryon formfactors measurement accuracy
   - improves sensitivity to the CP symmetry breaking in Λ decays
   - enriches physics of charmed baryons at SCT (this item is to be further developed)

Subtleties and difficulties

1. Luminosity monitoring
2. Effect of the detector magnetic field
3. Effect of the bunch magnetic field
4. Effect of (non-zero) bunch crossing angle
5. Not equal average positive and negative beam polarization $\xi_+ \neq -\xi_-$
6. Accounting the $e^+e^- \to Z \to J/\psi \to \Lambda\bar{\Lambda}$ amplitude contribution
7. Effect of natural polarization of positrons
8. …

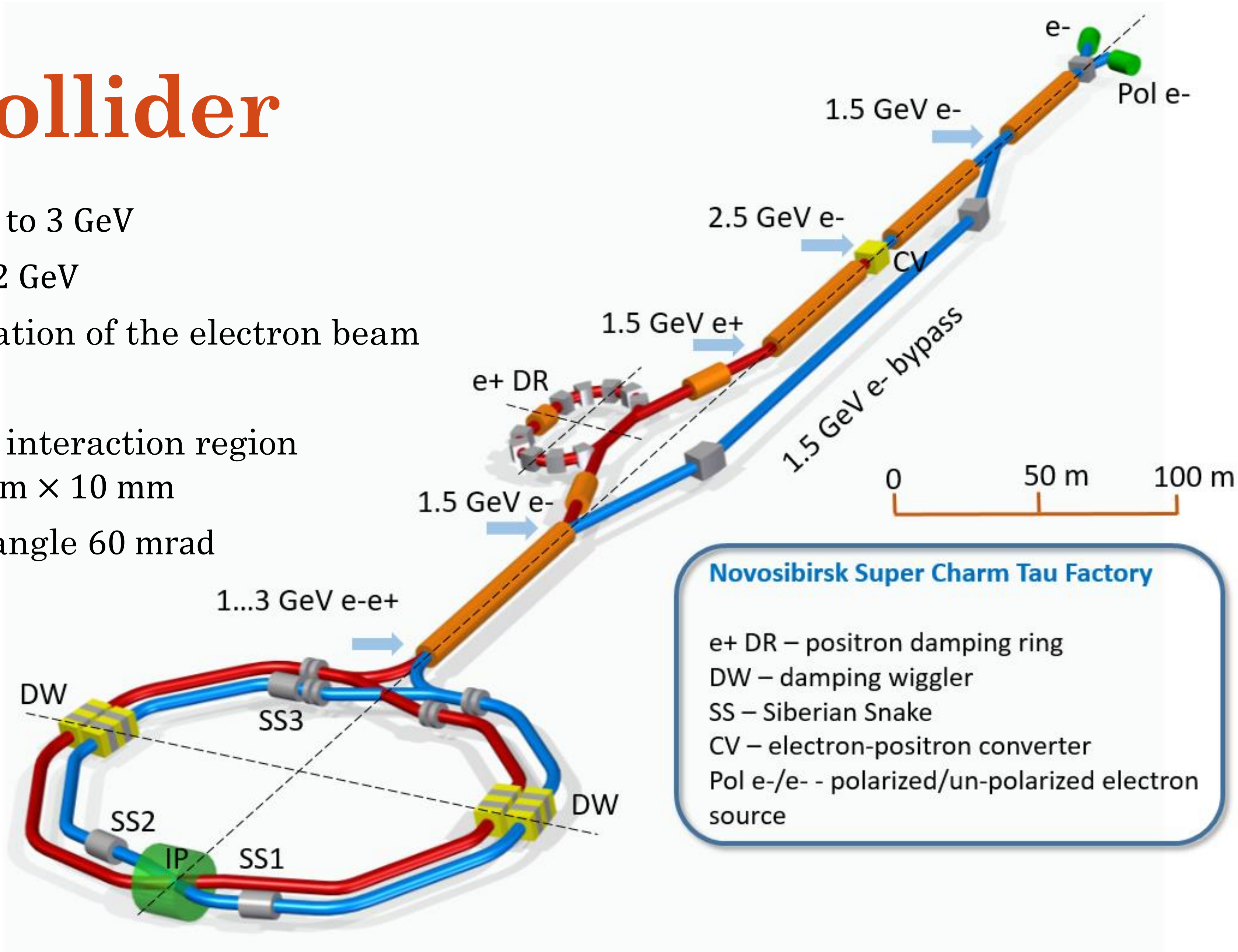
Conclusions

1. SCT with polarized electron beam is a unique experiment to study neutral weak coupling of charm quark and to measure $\sin^2\theta^c_{\text{eff}}$
2. Luminosity control at the 10^{-6} precision level requires dedicated low-angle Bhabha events detector
3. The decay $J/\psi \to \Lambda\bar{\Lambda}$ can be used as a precise monitor of the average beam polarization ξ
4. Baryon physics at SCT with polarized electrons seems attractive and needs to be considered in detail
5. Reaching new precision frontiers will require consideration of new subtle effects

Backup

SCT collider

- Beam energy: from 1 to 3 GeV
- $\mathcal{L} = 10^{35}\ \mathrm{cm^{-2}s^{-1}}$ @ 2 GeV
- Longitudinal polarization of the electron beam
- Crab-waist collisions
  - Beam size in the interaction region
    20 µm × 0.2 µm × 10 mm
  - Beams crossing angle 60 mrad



A_{FB} at LEP

- Annihilation process $e^+e^- \to Z \to f\bar{f}$, unpolarized cross-section

$$\frac{d\sigma}{d\cos\theta} \propto A(1+\cos^2\theta) + B\cos\theta$$

- Forward-backward asymmetry

$$A_{FB}^f \equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4} A_e A_f,$$

$$A_f \equiv \frac{2 g_v^f g_a^f}{\left(g_a^f\right)^2 + \left(g_v^f\right)^2} = \frac{1 - 4|Q_f| \sin^2\theta_{\text{eff}}^f}{1 - 4|Q_f| \sin^2\theta_{\text{eff}}^f + 8|Q_f| \sin^4\theta_{\text{eff}}^f}$$

- Counting experiment

SLC Experiment

- Polarized beam gives access to the left-right asymmetry

$$A_{LR} \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = A_e \xi$$

ξ is the average polarization of the electron beam

- Forward-backward asymmetry with polarized beam

$$A_{FB}^f = \frac{3}{4} A_f \frac{A_e + \xi}{1 + A_e \xi}$$

- Left-right forward-backward cross-section ratio

$$A_f = \frac{4}{3} \frac{\sigma_{LF}^f + \sigma_{RB}^f - \sigma_{LB}^f - \sigma_{RF}^f}{\sigma_{LF}^f + \sigma_{RB}^f + \sigma_{LB}^f + \sigma_{RF}^f}$$

Counting experiment with direct measurement of A_f

BESIII analysis

- $1.31 \times 10^9\ J/\psi$ events
- $J/\psi \rightarrow [\Lambda \rightarrow p\pi^-][\bar{\Lambda} \rightarrow \bar{p}\pi^+]$ signal yield 0.42×10^6 (with 400 background events)
- The results

$$\Delta\Phi = (42.4 \pm 0.6 \pm 0.5)^\circ$$
$$\alpha = 0.461 \pm 0.006 \pm 0.007$$
$$\alpha_1 = +0.750 \pm 0.009 \pm 0.004$$
$$\alpha_2 = -0.758 \pm 0.010 \pm 0.007$$

nature > nature physics > letters > article

nature physics

Letter | Published: 06 May 2019

Polarization and entanglement in baryon–antibaryon pair production in electron–positron annihilation

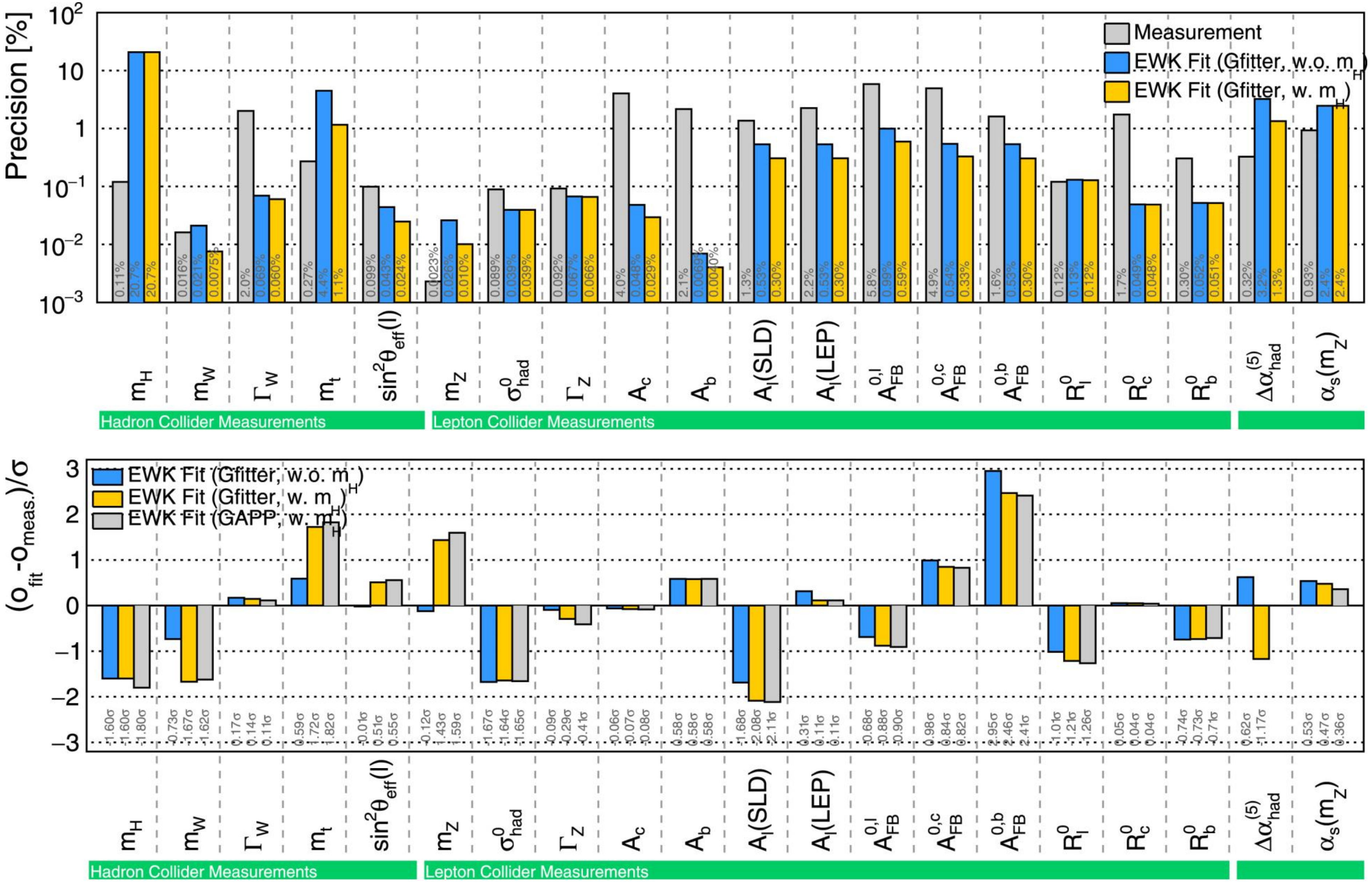
The BESIII Collaboration

Nature Physics **15**, 631–634 (2019) | Download Citation

Table 3.8
Overview of the measured asymmetries at the Z pole from the LEP and SLD experiments [19]. The values are compared to the SM prediction and a pull value for each observable, $(\mathcal{O}_{\text{measured}} - \mathcal{O}_{\text{predicted}})/\Delta\mathcal{O}$, is calculated. In addition, the corresponding effective weak mixing angle $\sin^2\theta^l_{\text{eff}}$ is given. The values indicated with an asterisk have been derived within this work.

Observable	Collider	Value	Total unc.	SM expectation	Pull	Corresponding $\sin^2\theta^l_{\text{eff}}$
A_e	LEP	0.1498	0.0049	0.1473 ± 0.0012	0.5	$0.23117 \pm 0.00062^*$
A_τ	LEP	0.1439	0.0043	0.1473 ± 0.0012	−0.8	0.23192 ± 0.00055
$A^{0,e}_{FB}$	LEP	0.0145	0.0025	0.01627 ± 0.00027	−0.7	$0.23254 \pm 0.0015^*$
$A^{0,\mu}_{FB}$	LEP	0.0169	0.0013	0.01627 ± 0.00027	0.5	$0.23113 \pm 0.0007^*$
$A^{0,\tau}_{FB}$	LEP	0.0188	0.0017	0.01627 ± 0.00027	1.5	$0.23000 \pm 0.0009^*$
$A^{0,l}_{FB}$	LEP	0.0171	0.001	0.01627 ± 0.00027	0.8	0.23099 ± 0.00053
$A^{0,c}_{FB}$	LEP	0.0699	0.0036	0.07378 ± 0.00068	−1.1	0.23220 ± 0.00081
$A^{0,b}_{FB}$	LEP	0.0992	0.0017	0.10324 ± 0.00088	−2.4	0.23221 ± 0.00029
A_e	SLD	0.1516	0.0021	0.1473 ± 0.0012	2.0	$0.23094 \pm 0.00027^*$
A_μ	SLD	0.142	0.015	0.1473 ± 0.0012	−0.4	$0.23216 \pm 0.002^*$
A_τ	SLD	0.136	0.015	0.1473 ± 0.0012	−0.8	$0.23259 \pm 0.002^*$
A_l	SLD	0.1513	0.0021	0.1473 ± 0.0012	1.9	0.23098 ± 0.00026
A_c	SLD	0.67	0.027	0.66798 ± 0.00055	0.1	$0.231 \pm 0.008^*$
A_b	SLD	0.923	0.02	0.93462 ± 0.00018	−0.6	$0.25 \pm 0.03^*$

https://doi.org/10.1016/j.ppnp.2019.02.007



Global EW fit

p-value is 0.24

https://doi.org/10.1016/j.ppnp.2019.02.007

Experiment at SCT

1. Set beam energy at $\sqrt{s} \approx m(J/\psi)$, about 400 bunches circulate simultaneously
2. Set *random* polarization 0, ξ_+ or ξ_-, $\xi_+ \approx -\xi_-$, for each e^- bunch
3. Count numbers of $J/\psi \to$ hadrons events N_+ and N_- for the positive and negative polarizations ξ_+ and ξ_-

$$N_\pm \sim 10^{12}, \qquad \text{event rate} \approx 100\ \text{kHz}$$

4. Calculate the cross sections and left-right asymmetry

$$\sigma_\pm = \frac{N_\pm}{\mathcal{L}_\pm \varepsilon_{\text{det}}}, \qquad A_{LR} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- Luminosity monitoring and backgrounds
  - Statistical precision $\sigma_{\mathcal{L}}/\mathcal{L} \sim 10^{-6}$ is needed
  - Multiplicative bias $\mathcal{L}'_\pm = (1+\kappa)\mathcal{L}_\pm$ vanishes
  - Additive bias δN should be controlled at the level of 10^{-3}

Table 3.9
Overview of selected measurements at LEP, SLD, Tevatron and the LHC of the effective leptonic electroweak mixing angle $\sin^2\theta^l_{\text{eff}}$ using different observables including a breakdown of different sources of uncertainties. Values which are indicated with an asterisk have not been published and hence only estimated within this work.

$\sin^2\theta^l_{\text{eff}}$	Value	Stat. unc.	Syst. unc.	PDF unc.	Model unc.	Total unc.	Reference
DØ	0.23095	0.00035	0.00007	0.00019	0.00008	0.00047	[223]
CDF	0.23221	0.00043	0.00003	0.00016	0.00006	0.00046	[224]
Tevatron (combined)	0.23148	0.00027	0.00005	0.00018	0.00006	0.00033	[225]
CMS	0.23101	0.00036	0.00018	0.00030	0.00016	0.00053	[226]
ATLAS (central)	0.23119	0.00031	0.00018	0.00033	0.00006	0.00049	[227]
ATLAS (forward)	0.23166	0.00029	0.00021	0.00022	0.00010	0.00043	[227]
ATLAS (combined)	0.23140	0.00021	0.00014	0.00024	0.00007	0.00036	[227]
LHCb	0.23142	0.00073	0.00052	0.00043*	0.00036*	0.00106	[228]
A_{FB}^{had} (LEP)	0.23240	0.00070	0.00100	–	–	0.00120	[19]
A_l (LEP)	0.23099	0.00042*	0.00032*	–	–	0.00053	[19]
$A_\tau + A_e$ (LEP)	0.23159	0.00037*	0.00018*	–	–	0.00041	[19]
A_{FB}^b (LEP)	0.23221	0.00023*	0.00017*	–	–	0.00029	[19]
A_l (SLD)	0.23098	0.00024	0.00013	–	–	0.00026	[19]

https://doi.org/10.1016/j.ppnp.2019.02.007

Lambda decay form factor

- $\Lambda \to p\pi^-$ decay with Λ polarization $\boldsymbol{\omega}$ and π^- momentum $\boldsymbol{q}$:
$$\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_1 \boldsymbol{\omega} \cdot \boldsymbol{q}$$
- $\bar{\Lambda} \to \bar{p}\pi^+$:
$$\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_2 \boldsymbol{\omega} \cdot \boldsymbol{q}$$
- CP symmetry implies $\alpha_1 = -\alpha_2$. CP asymmetry
$$A_\Lambda \equiv \frac{\alpha_1 + \alpha_2}{\alpha_1 - \alpha_2}$$
is about 5×10^{-5} within the standard model

Feasibility study: the procedure

1. Generate phase-space distributed events with EvtGen
2. Accept-reject algorithm with probability proportional to $W(\zeta)$
3. Simple detection efficiency (min $p_t = 60\ MeV$, min $\theta = 10°$), perfect momentum resolution and perfect identification
4. Maximum likelihood fit with likelihood function

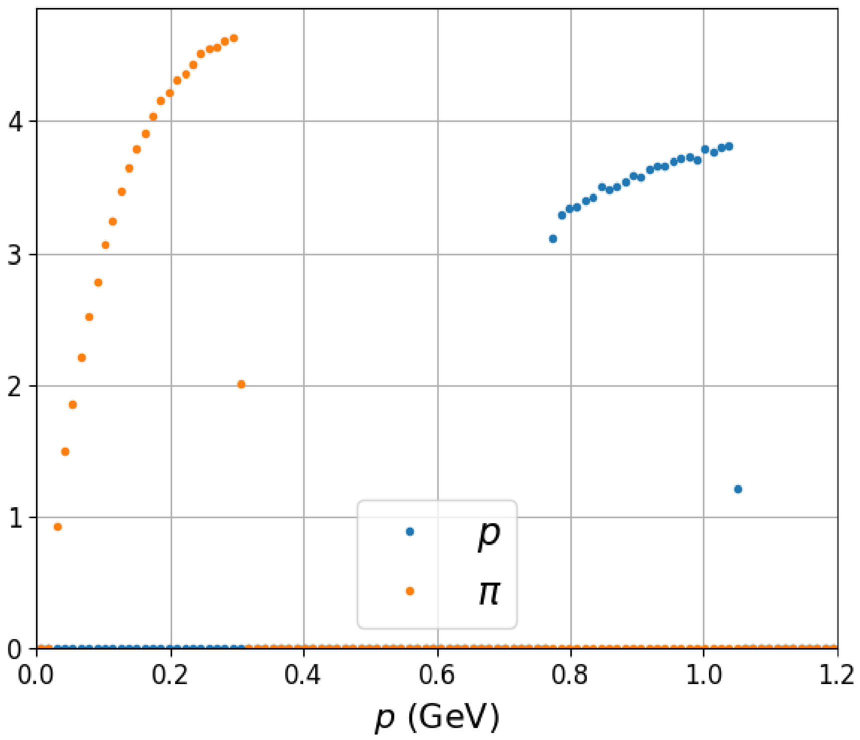
$$-2\ln\mathcal{L} = -2\sum_{i=1}^{N}\ln W(\zeta_i) + 2N\ln\sum_{j=1}^{M}\ln W\left(\tilde{\zeta}_j\right), \qquad M \gg N$$

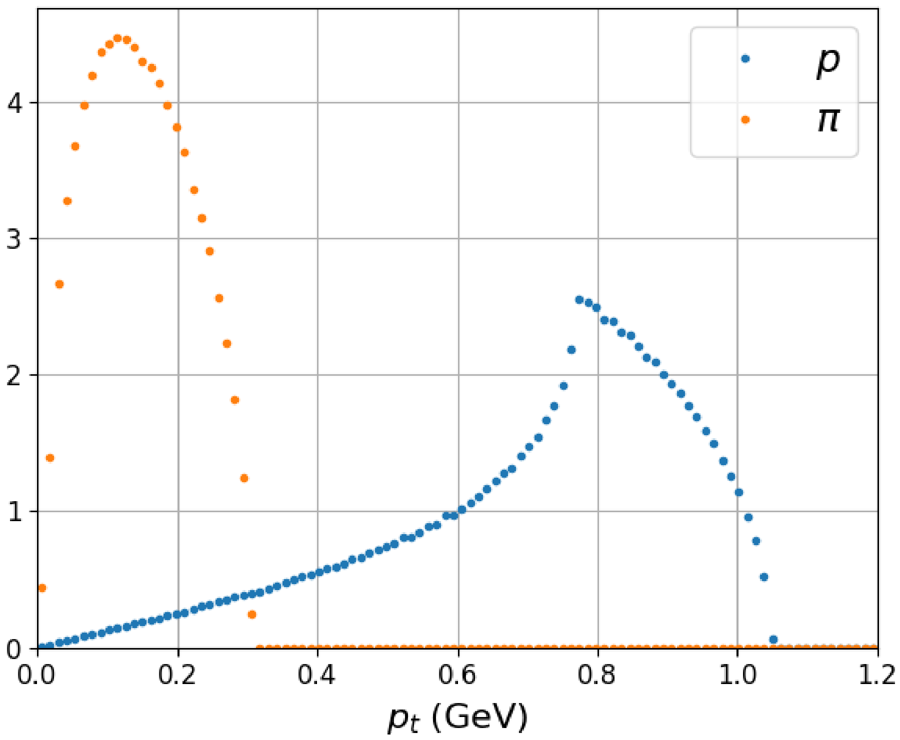
Signal events

PHSP normalization events

Signal yield and Detection efficiency

$J/\psi \to [\Lambda \to p\pi^-][\overline{\Lambda} \to \bar{p}\pi^+]$





- $p_t > 60$ MeV and $\theta > 10°$ give
  - Double-side detection efficiency $\varepsilon_{\text{det}} = 0.72$
  - Single-side detection efficiency $\varepsilon_{\text{det}}^{\text{ss}} = 0.84$

- $\mathcal{B}_1 \equiv \mathcal{B}(J/\psi \to \Lambda\overline{\Lambda}) = 1.9 \times 10^{-3}$
- $\mathcal{B}_2 \equiv \mathcal{B}(\Lambda \to p\pi^-) = 0.64$
- $N_{\text{sig}}^0 = 10^{12} \times \mathcal{B}_1 \times \mathcal{B}_2^2 \approx 0.8 \times 10^9$

2D Distribution

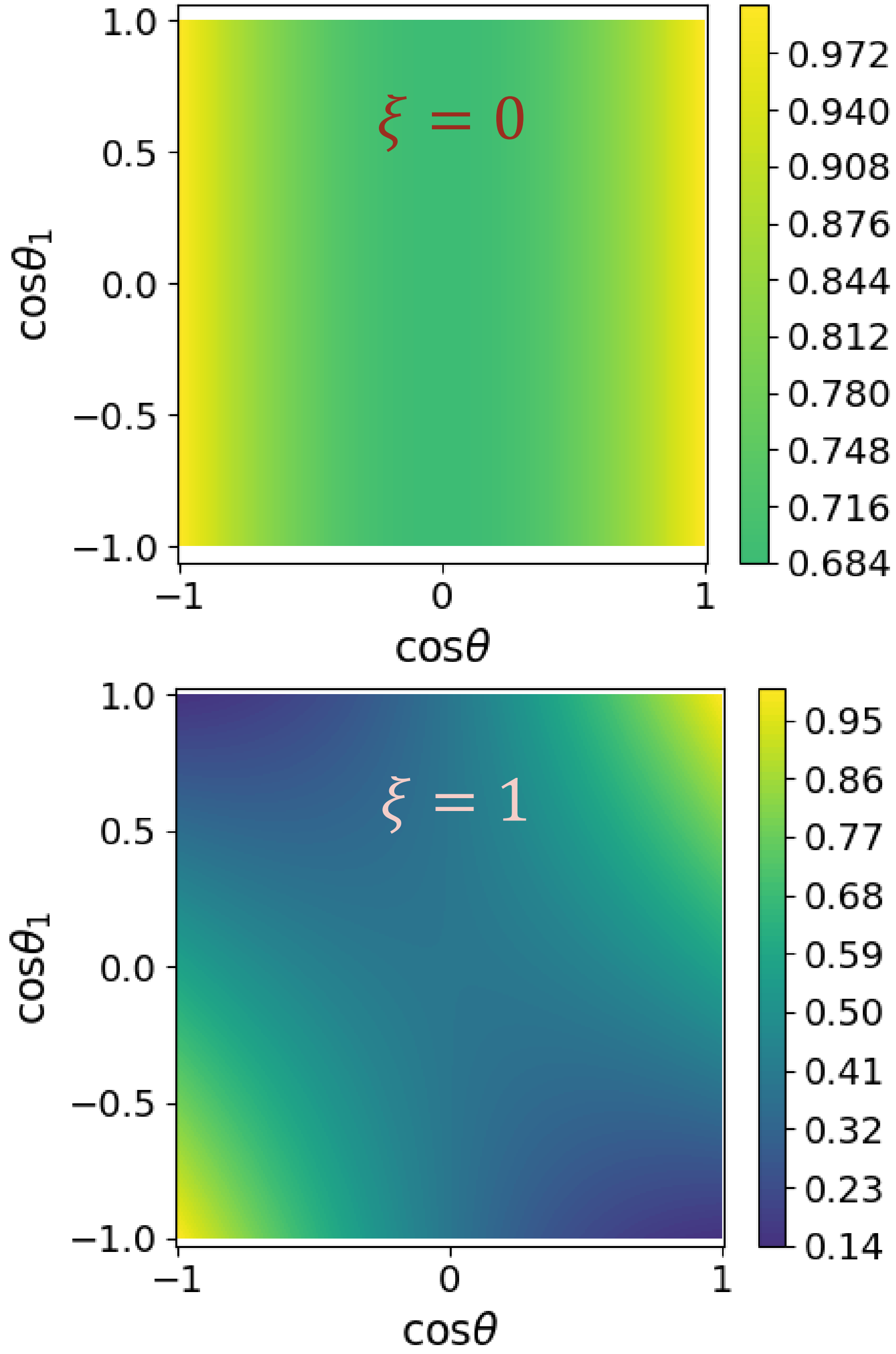
$$\frac{d\sigma}{d\cos\theta\, d\cos\theta_1} \propto 1 + \alpha\cos^2\theta + \xi(1+\alpha)\alpha_1\cos\theta\cos\theta_1$$

- Polarization makes $\cos\theta$ and $\cos\theta_1$ correlated
- Asymmetry can be formed

$$A_{\mathrm{FB}} \equiv \frac{\sigma_{\mathrm{fwd}} - \sigma_{\mathrm{bwd}}}{\sigma_{\mathrm{fwd}} + \sigma_{\mathrm{bwd}}} = \xi\frac{3\alpha_1}{4}\frac{\alpha+1}{\alpha+3} \approx 0.24\xi$$

$$\sigma_{\mathrm{fwd}} \equiv \int_{\cos\theta\cos\theta_1>0} \frac{d\sigma}{d\cos\theta\, d\cos\theta_1} d\cos\theta\, d\cos\theta_1$$

$$\sigma_{\mathrm{bwd}} \equiv \int_{\cos\theta\cos\theta_1<0} \frac{d\sigma}{d\cos\theta\, d\cos\theta_1} d\cos\theta\, d\cos\theta_1$$



Two-step procedure

- Data set composition:
  - $\frac{1}{3}N_0$ events with unpolarized beam
  - $\frac{1}{3}N_0$ events with $+\xi$
  - $\frac{1}{3}N_0$ events with $-\xi$
- **Step 1**: measure form factors with the unpolarized beam data
- **Step 2**: measure ξ with polarized beam data and externally constrained form factors

Setup ($\xi = 0.8$)	SCT one-year $\sigma(\xi)$ (10^{-4})	
	Nuisance FFs	Fixed FFs
3D	1.6	1.2
2D	1.9	1.6
1D azimuth	4.5	2.5
1D polar lab		
A_{BF}		5.2
A_{LR}		10
$A_{BF}^{(0)}$		24

Luminosity monitoring

$$\sigma_{\pm} = \frac{N_{\pm}}{\mathcal{L}_{\pm}\varepsilon_{\text{eff}}}$$

- Statistical accuracy $\sigma_{\mathcal{L}}/\mathcal{L} \sim 10^{-6}$ is needed
  - Multiplicative systematic uncertainties vanish in asymmetry
- $\mathcal{L}$ monitoring with Bhabha events

$$\sigma(e^{+}e^{-} \to e^{+}e^{-})_{\theta>10^{\circ}} \approx 1 \times 10^{-30}\ \text{cm}^{2} \approx \sigma(e^{+}e^{-} \to J/\psi)$$

  - Bhabha events statistics will limit precision
- $\mathcal{L}$ monitoring with dedicated device at low angle
  - Would provide good support for the $\sin^{2}\theta_{\text{eff}}$ measurement
  - The device should be able to measure bunch-by-bunch luminosity

Detector magnetic field

- $c\tau(\Lambda) = 7.90$ mm
- Λ spin rotation in magnetic field

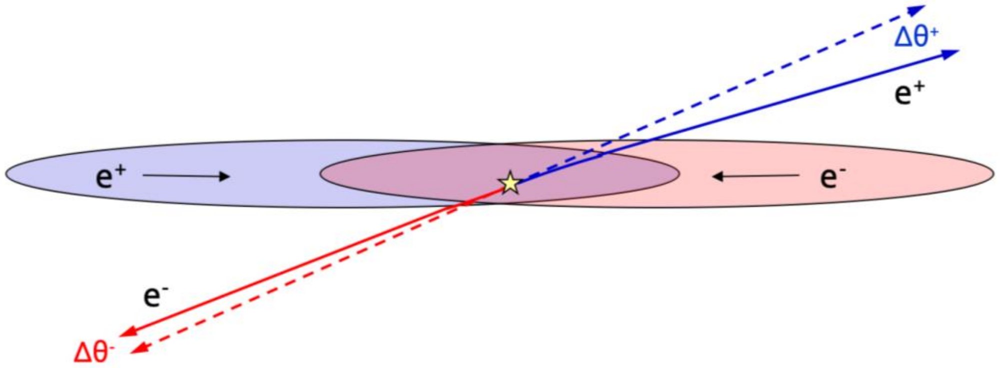
$$\omega = \frac{-2B\mu_\Lambda\mu_N}{\hbar}, \qquad \mu_\Lambda = -0.613$$

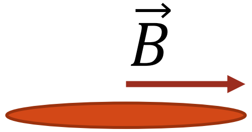
- Λ spin rotation in 1.5 T magnetic field is about 30 mrad
  - A $\sim 10^{-3}$ effect, probably should be considered
- Λ flight length-dependent correction
  - Requirements for the spatial and vertex resolution

[H.-B. Li, X.-X. Ma, PRD 100 (2019) 076007]

Bunch magnetic field at SCT

- Bunch current 4.2 mA
- Beam size 0.178μm × 17.8μm × 10mm
- Magnetic field at bunch surface is about 0.01 T
- Correction for the effect of bunch magnetic field should be considered in the Bhabha-measured luminosity





G. Voutsinas et al., arXiv:1908.01698 [hep-ex]