Search for Hyperon CPV at BESIII and STCF

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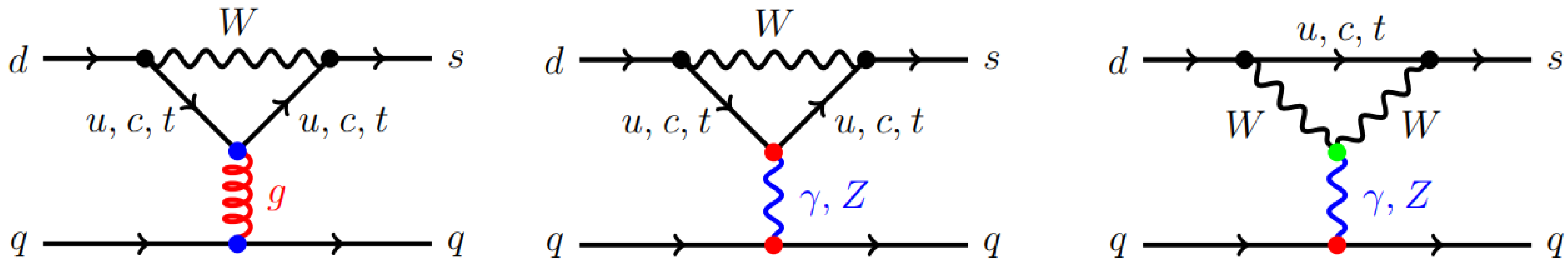
26/8/2023, USTC, Hefei

Direct CPV effect in strange-quark sector

- Direct CP-violation effects in kaon and hyperon decays in the SM are given by QCD and EW penguin operators.



- To generate a CP asymmetry, one needs two different amplitudes that contribute coherently.
- Direct CPV in $K_L \to \pi^+\pi^-$ arise from $\Delta I = 1/2$ and $\Delta I = 3/2$ amplitudes interference in S-wave decay.
- Direct CPV in $Y' \to Y\pi$ arise from S wave and P wave amplitudes interference.

Study of CPV in hyperon decay is a complementary approach in two-body non-leptonic ΔS = 1 transitions

Direct CPV effect in strange-quark sector

- For decay $A = A_1 e^{i\delta_s^1} e^{i\phi_w^1} + A_2 e^{i\delta_s^2} e^{i\phi_w^2}$

δ_s strong phase

ϕ_w weak phase

$\xrightarrow{CP}$ $\bar{A} = A_1 e^{i\delta_s^1} e^{-i\phi_w^1} + A_2 e^{i\delta_s^2} e^{-i\phi_w^2}$

Make $r = A_2/A_1$, $\delta = \delta_s^2 - \delta_s^1$, $\phi = \phi_w^2 - \phi_w^1$

$$\text{Thus } A_{CP} = \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2} = \frac{|A_1|^2 \left|1 + re^{i(\delta+\phi)}\right|^2 - |A_1|^2 \left|1 + re^{i(\delta-\phi)}\right|^2}{|A_1|^2 \left|1 + re^{i(\delta+\phi)}\right|^2 + |A_1|^2 \left|1 + re^{i(\delta-\phi)}\right|^2}$$

$$= \frac{2r\cos(\delta+\phi) - 2r\cos(\delta-\phi)}{2(1 + r^2 + r\cos(\delta+\phi) + r\cos(\delta-\phi))} = \frac{2r\sin\delta\sin\phi}{1 + r^2 + 2r\cos\delta\cos\phi}$$

$\neq 0$, if $\delta \neq 0$ and $\phi \neq 0$

Hyperon non-leptonic decays

- Effective Lagranian of the decay:

$$\mathcal{L} = \frac{eG_F}{2} \bar{B}_f (P + S\gamma_5)\sigma^{\mu\nu} B_i F_{\mu\nu}$$

$$S = \Sigma^i S_i e^{i(\phi_i^S + \delta_i^S)}$$

$$P = \Sigma^i P_i e^{i(\phi_i^P + \delta_i^P)}$$

Phys. Rev. 108, 1645 (1957)

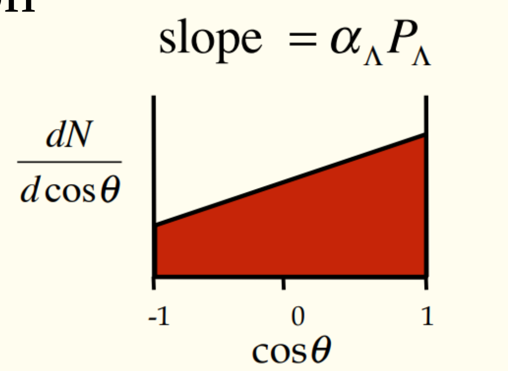
- Observables:

$$\Gamma = \frac{e^2 G_F^2}{\pi}(|S|^2 + |P|^2)$$

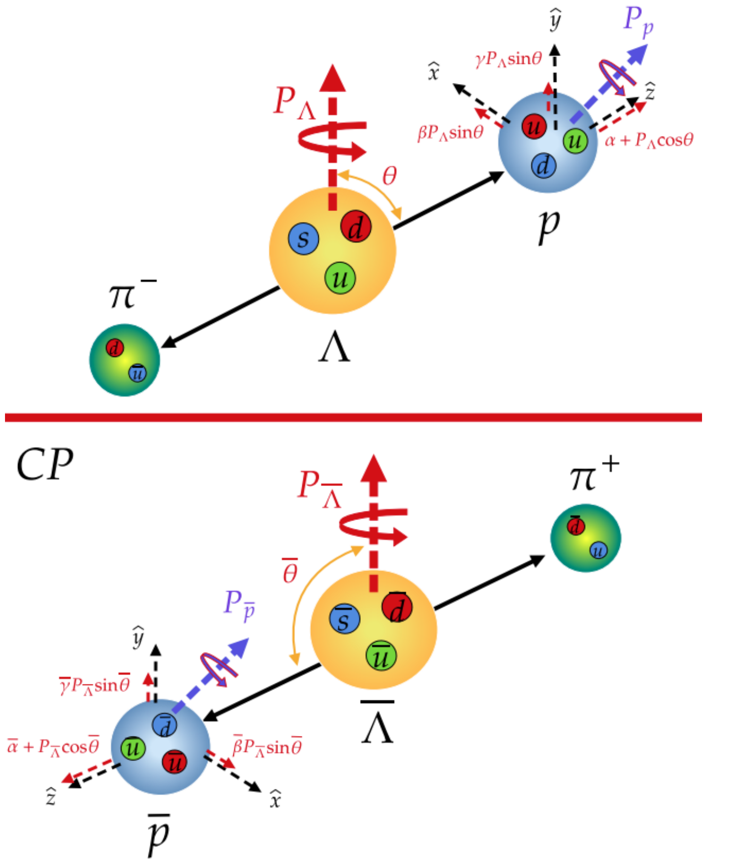
$$\alpha_Y = \frac{2\,\mathrm{Re}\,(S^* P)}{|S|^2 + |P|^2}, \quad \beta_Y = \frac{2\,\mathrm{Im}\,(S^* P)}{|S|^2 + |P|^2}, \quad \gamma_Y = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

- Anisotropic proton decay distribution

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1 + \alpha_\Lambda P_\Lambda \cos\theta)$$



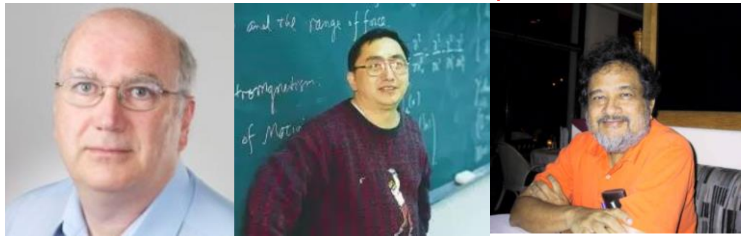
Construction of CP-odd observables



$$A = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}, \quad B = \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}}.$$

CPV observables and SM prediction

PRD 34,833 1986



John F. Donoghue   Xiao-Gang He   Sandip Pakvasa

PHYSICAL REVIEW D   VOLUME 34, NUMBER 3   1 AUGUST 1986

Hyperon decays and *CP* nonconservation

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(Received 7 March 1986)

We study all modes of hyperon nonleptonic decay and consider the *CP*-odd observables which result. Explicit calculations are provided in the Kobayashi-Maskawa, Weinberg-Higgs, and left-right-symmetric models of *CP* nonconservation.

Not sensitive to *CPV* → **Decay width difference** $\Delta = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}} \approx \sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}}\sin\Delta_s \sin\phi_{CP}$ $\mathbf{-5.4\times10^{-7}}$

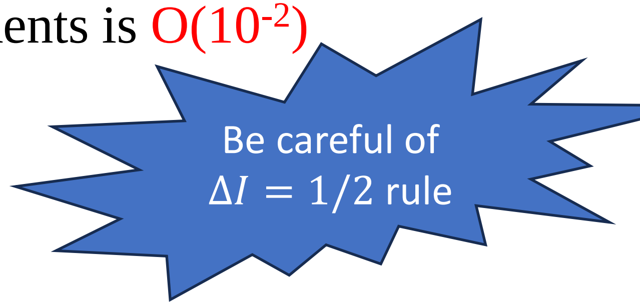
Easiest to measure → **Decay parameter difference** $A = \frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \tan\Delta_s \tan\phi_{CP}$ $\mathbf{-0.5\times10^{-4}}$

Polarization of decayed baryon needs to be measured → **Decay parameter difference** $B = \frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \tan\phi_{CP}$ $\mathbf{3.0\times10^{-3}}$

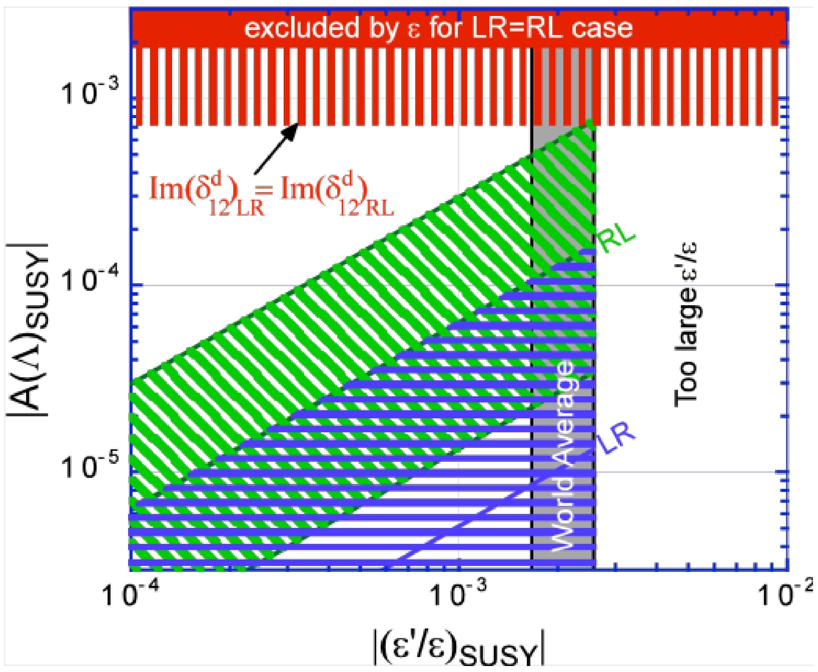
Ξ^-, Ξ^0, Ω^- cascade decay

BSM Theories Allow for Larger Asymmetries

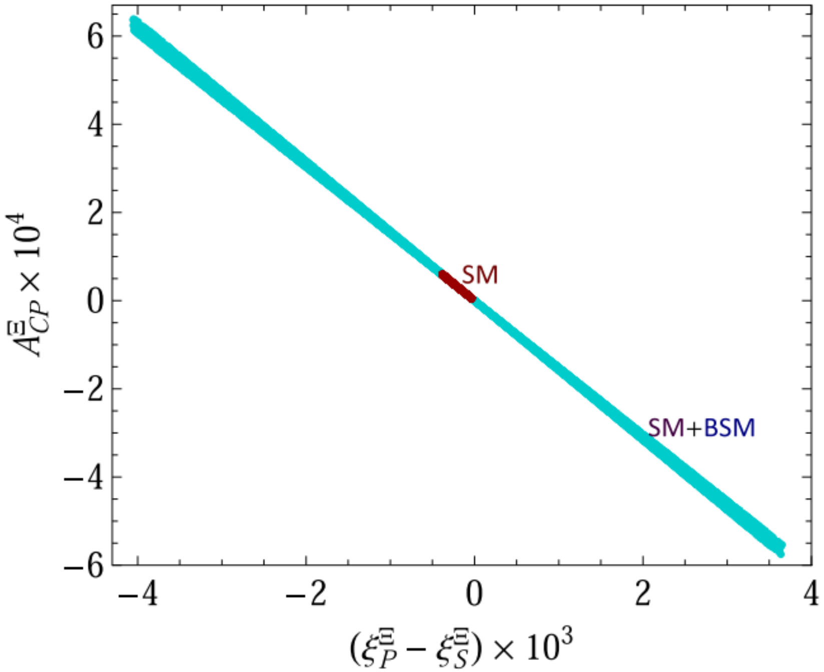
- Tandean (2004) shows that the upper bound on $A_\Xi + A_\Lambda$ from ε'/ε and ε measurements is $O(10^{-2})$
- Some SUSY models which do not generate ε'/ε can lead to A_Λ of $O(10^{-3})$
- The BSM contribution can be higher than SM one by about an order of magnitude

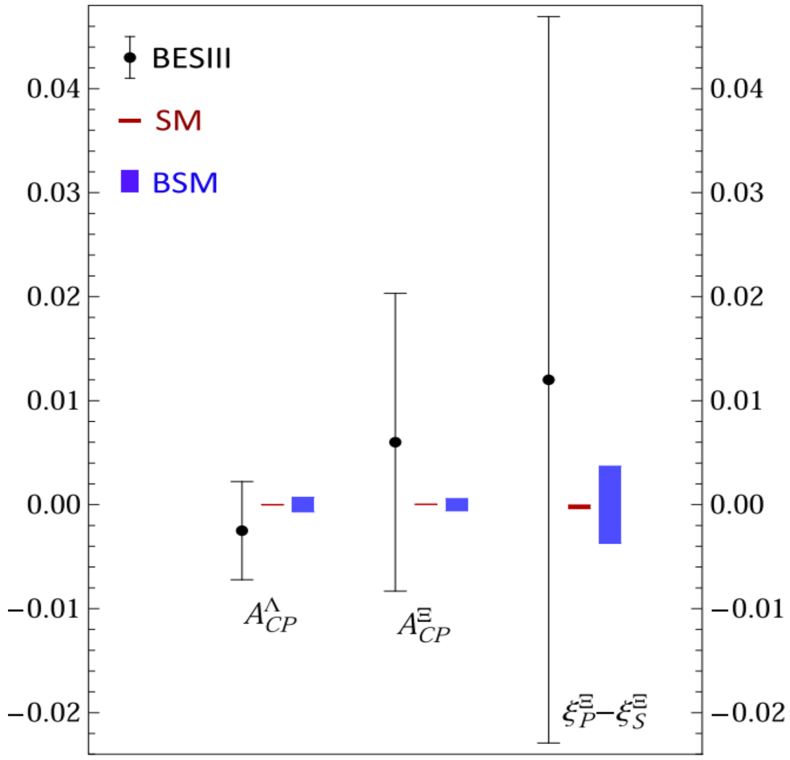


Phys.Rev.D 69 (2004) 076008



Sci.Bull. 67 (2022) 1840-1843 (2022)





Experimental Review

$$A_\Lambda = \frac{\alpha_\Lambda + \bar{\alpha}_\Lambda}{\alpha_\Lambda - \bar{\alpha}_\Lambda} \text{ or } A_\Lambda = \frac{\alpha_\Lambda + \bar{\alpha}_\Lambda}{\alpha_\Lambda - \bar{\alpha}_\Lambda}$$

Experiment	Method	A_Λ	Remark
R608 at ISR (1985)	$pp \to \Lambda X, p\bar{p} \to \bar{\Lambda} X$	-0.02 ± 0.14	Assume $P_\Lambda = P_{\bar{\Lambda}}$
DM2 at Orsay (1988)	$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$	0.01 ± 0.10	1077 events
PS185 at LEAR (1989)	$\bar{p}p \to \bar{\Lambda}\Lambda$	-0.023 ± 0.057	16,000 events
BESII at BEPC (2010)	$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$	$-0.081 \pm 0.055 \pm 0.059$	9000 events

$$A_{\Xi\Lambda} = \frac{\alpha_\Xi \alpha_\Lambda - \bar{\alpha}_\Xi \bar{\alpha}_\Lambda}{\alpha_\Xi \alpha_\Lambda + \bar{\alpha}_\Xi \bar{\alpha}_\Lambda} \approx A_\Lambda + A_\Xi$$

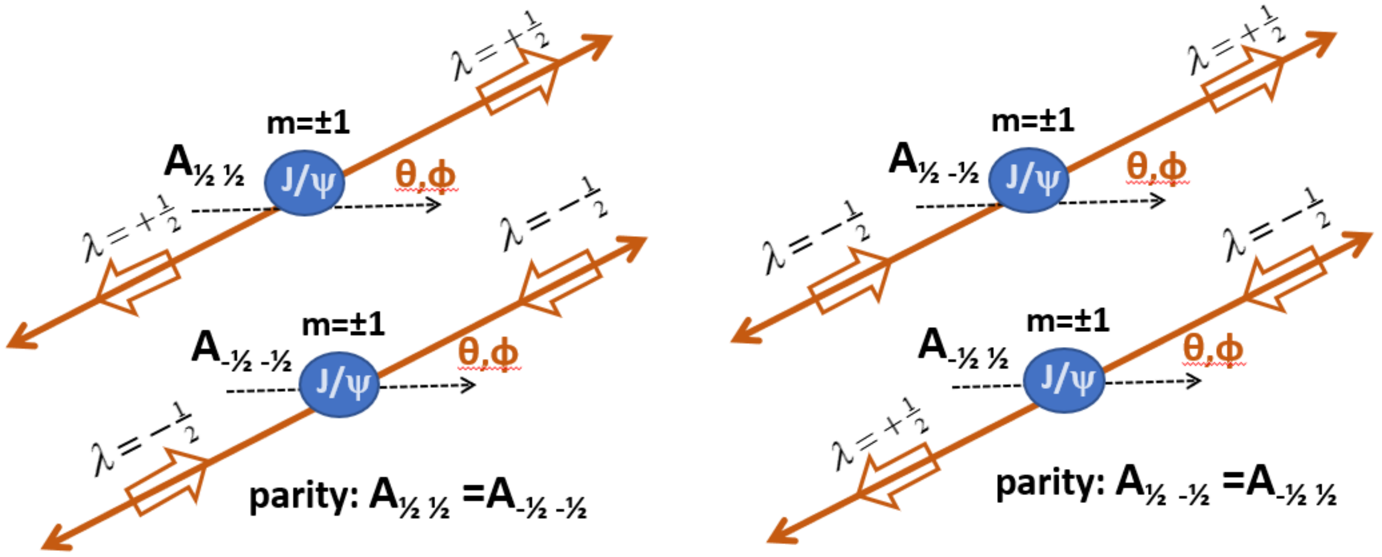
Experiment	Method	$A_{\Xi\Lambda}$	Remark
E756 at Fermilab (2000)	$\Xi \to \Lambda\pi \to p\pi\pi$	0.012 ± 0.014	210k Ξ^- and 70k $\bar{\Xi}^+$
HyperCP at Fermilab (2004)	$\Xi \to \Lambda\pi \to p\pi\pi$	$(0.0 \pm 6.7) \times 10^{-4}$	117M Ξ^- and 41M $\bar{\Xi}^+$
HyperCP at Fermilab (2008, preliminary)	$\Xi \to \Lambda\pi \to p\pi\pi$	$(-6.0 \pm 2.9) \times 10^{-4}$	780M Ξ^- and 270M $\bar{\Xi}^+$

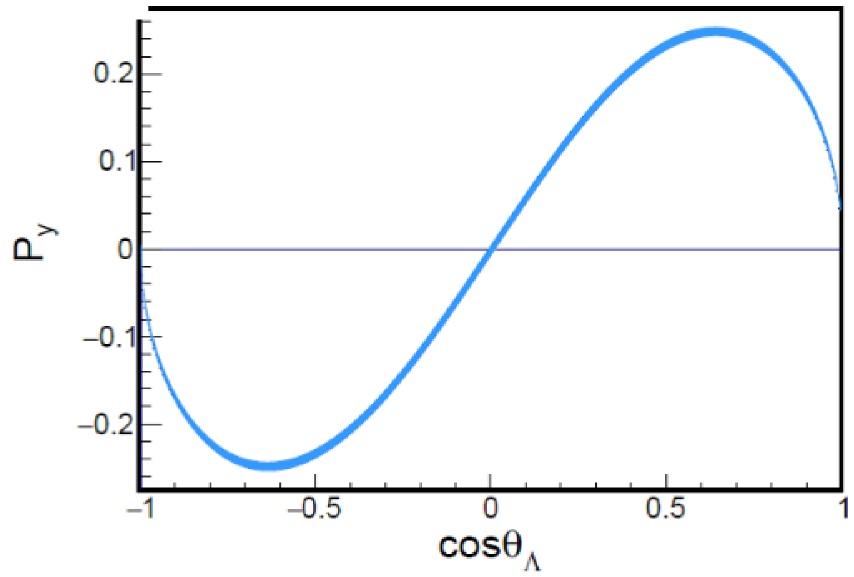
Why Hyperon Physics at BESIII?

10 billion J/ψ events collected

- Large BRs in J/ψ decays ➔ tens millions hyperons
- Transversely polarization due to none zero phase of two helicity amplitudes

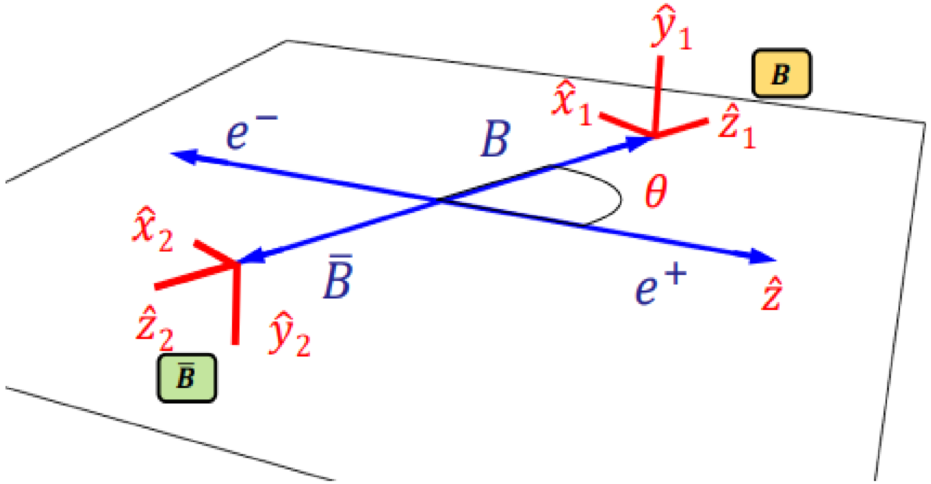
$$P_y = -\frac{\sqrt{1-\alpha^2}\sin\theta\cos\theta}{1+\alpha\cos^2\theta}\sin(\Delta\Phi).$$

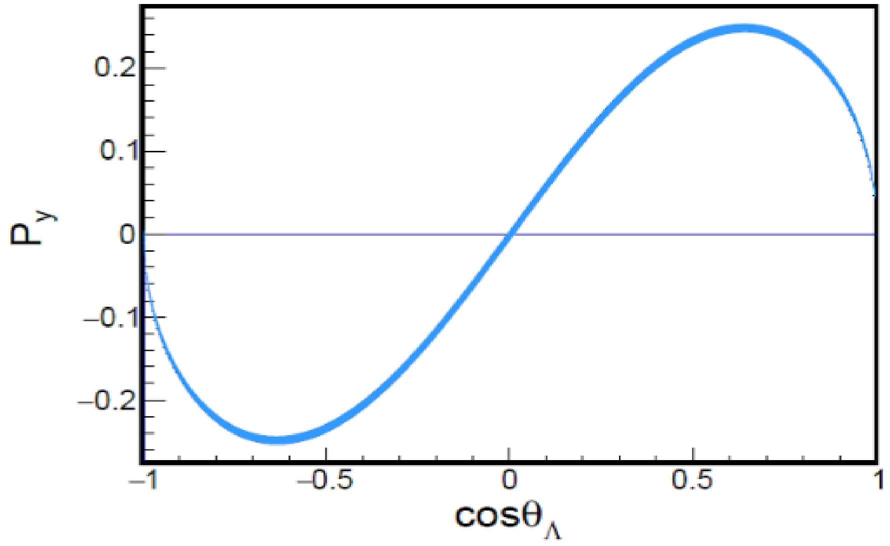




$\Delta\Phi$= complex phase between $A_{\frac{1}{2}\,\frac{1}{2}}$ and $A_{\frac{1}{2}\,-\frac{1}{2}}$

Why Hyperon Physics at BESIII?



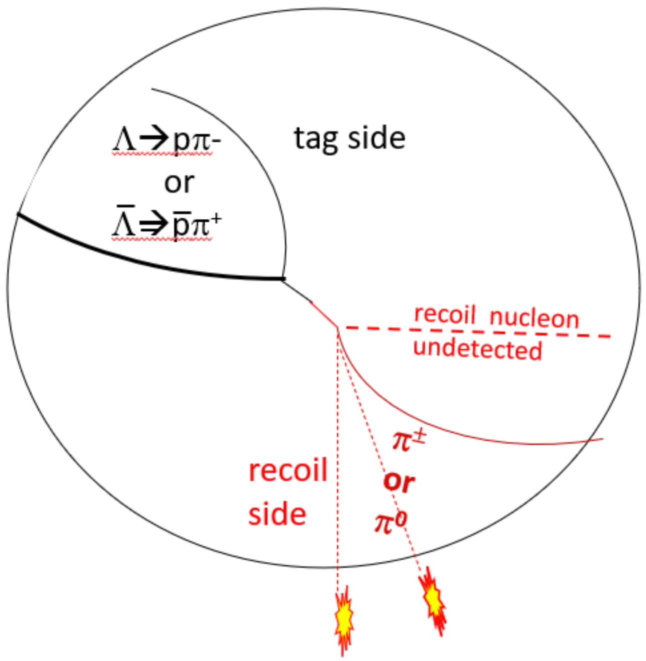


$B\bar{B}$ mode	$\mathcal{B}(\times 10^{-3})$	α_ψ	$\Delta\Phi$	P_y^{max} / $\cos\theta^{max}$
$J/\psi \to \Lambda\bar{\Lambda}$	1.89 ± 0.09	0.475 ± 0.003	0.752 ± 0.008	25% / 0.64
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.07 ± 0.04	-0.508 ± 0.007	-0.27 ± 0.02	16% / 0.82
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.17 ± 0.03	-0.45 ± 0.02	0.09 ± 0.02	5% / 0.80
$J/\psi \to \Sigma^-\bar{\Sigma}^{+*}$	1.51 ± 0.01	-0.37 ± 0.02	0.006 ± 0.005	0.5% / 0.78
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.17 ± 0.04	0.66 ± 0.06	1.16 ± 0.02	27% / 0.61
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.97 ± 0.08	0.59 ± 0.02	1.21 ± 0.05	30% / 0.62

*not yet published results

Advantages at e^+e^- Machine

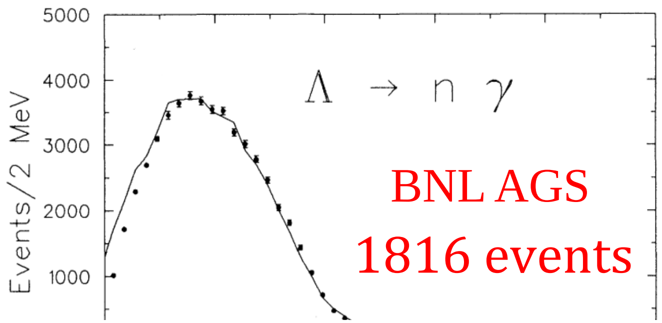
- Known initial 4-momentum
- Strongly boosted: $\beta \approx 0.7$
- Substantial polarization: maximum 30%
- Decay with neutron & π^0: uncertainty limited within 1%
- Decay with invisibles: missing particles

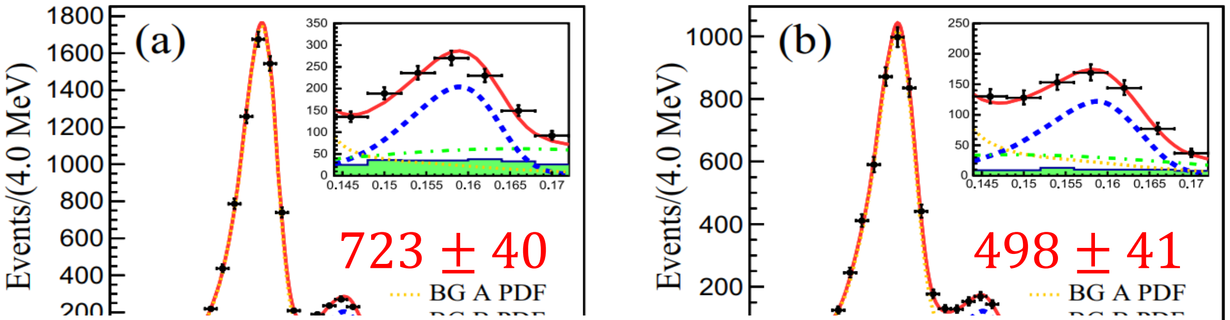


Both hyperons can be reconstructed, and the systematic uncertainties are under control.

Compare of e^+e^- and Fix-target Experiments

Hyperon rare decay ($\mathcal{O}(10^{-3})$)

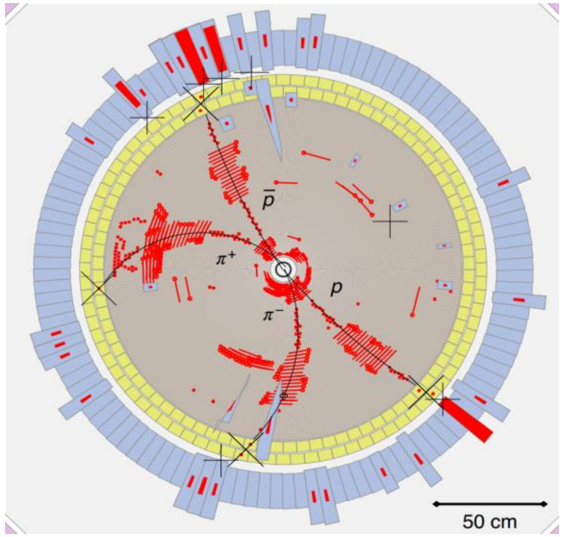




$B_i \to B_f\gamma$	BF ($\times10^{-3}$) BESIII	BF ($\times10^{-3}$) PDG	α_γ BESIII	α_γ PDG
$\Lambda \to n\gamma$	$0.832 \pm 0.038 \pm 0.054$ [5]	1.75 ± 0.15	$-0.16 \pm 0.10 \pm 0.05$ [5]	–
$\Sigma^+ \to p\gamma$	$0.996 \pm 0.021 \pm 0.018$ [6]	1.23 ± 0.05	$-0.652 \pm 0.056 \pm 0.020$ [6]	-0.76 ± 0.08
$\Xi^0 \to \Lambda\gamma$	$1.347 \pm 0.066 \pm 0.062$(this work)	1.17 ± 0.07	$-0.741 \pm 0.066 \pm 0.062$(this work)	-0.70 ± 0.07
$\Xi^0 \to \Sigma^0\gamma$	–	3.33 ± 0.10	–	-0.69 ± 0.06
$\Xi^- \to \Sigma^-\gamma$	–	0.127 ± 0.023	–	–
$\Sigma^0 \to n\gamma$	–	–	–	–

Hyperons at BESIII: less statistics compare with large flux hyperon beam with polarization, but with better precision, charge-conjugate channels

$e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda}, \Lambda(\bar{\Lambda}) \rightarrow p\pi$



- Matrix element of $e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda}$:

$$\mathcal{M} = F_1\gamma_\mu + \frac{F_2}{2m} q_\nu \sigma^{\nu\mu}\gamma_5 + i\epsilon^{\mu\nu\alpha\beta}\frac{\sigma_{\alpha\beta}}{4m} q_\nu F_3 + \frac{1}{2m}\left(q^\mu - \frac{q^2}{2m}\gamma^\mu\right)\gamma_5 F_4$$

- Differential cross section using spin density matrix and decay matrix
- A correlated 5-dim. angular distribution $\xi = (\theta_\Lambda, \theta_p, \phi_p, \theta_{\bar{p}}, \phi_{\bar{p}})$with 4 parameters is constructed

$$\mathcal{W}^{\Lambda\bar{\Lambda}}(\boldsymbol{\xi};\boldsymbol{\omega}) = \sum_{\mu,\nu=0}^{3} C_{\mu\nu} a^{\Lambda}_{\mu 0} a^{\bar{\Lambda}}_{\nu 0}$$

$$\omega(\xi, \Delta\Phi, \alpha_\psi, \alpha_-, \alpha_\gamma) = 1 + \alpha_\psi cos^2\theta_\Lambda$$

Unpolarized part

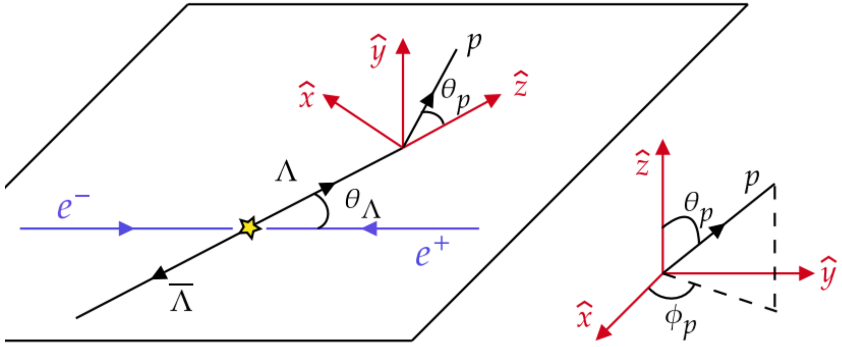
$$+\alpha_-\alpha_\gamma[sin^2\theta_\Lambda(n_{1,x}, n_{2,x} - \alpha_\psi n_{1,y}, n_{2,y}) + (cos^2\theta_\Lambda + \alpha_\psi) n_{1,z}, n_{2,z}]$$

$$+ \alpha_-\alpha_\gamma\sqrt{1-\alpha_\psi{}^2}\, cos(\Delta\Phi)\, sin\theta_\Lambda cos\theta_\Lambda (n_{1,x}, n_{2,z} + n_{1,z}, n_{2,x})$$

Correlated part

$$+\sqrt{1-\alpha_\psi{}^2}\, sin(\Delta\Phi)\, sin\theta_\Lambda cos\theta_\Lambda (\alpha_- n_{1,y} + \alpha_\gamma n_{2,y})$$

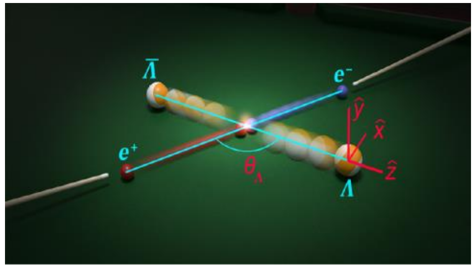
Polarized part



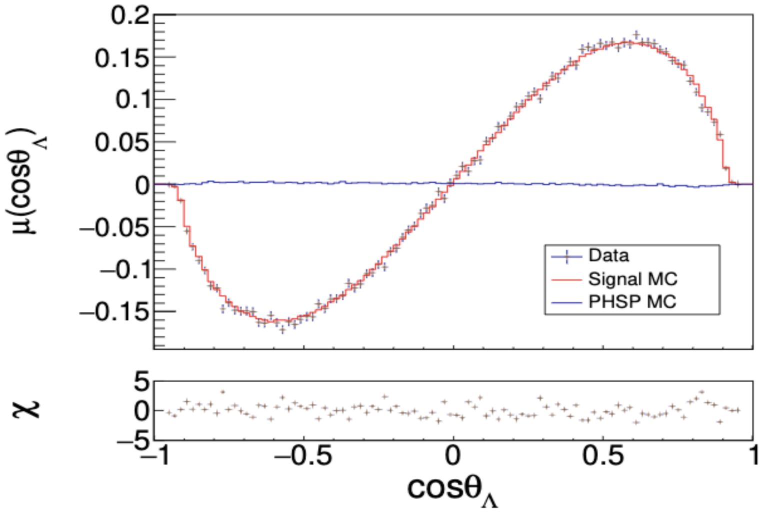
Polarization of Λ hyperons and CPV

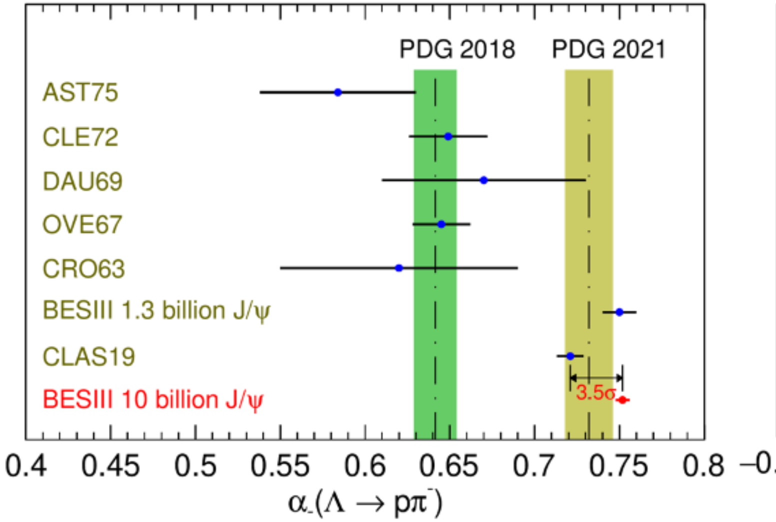
- Updated results based on 10B J/ψ events: ~0.42M signals
- Decay asymmetries with best precisions ever

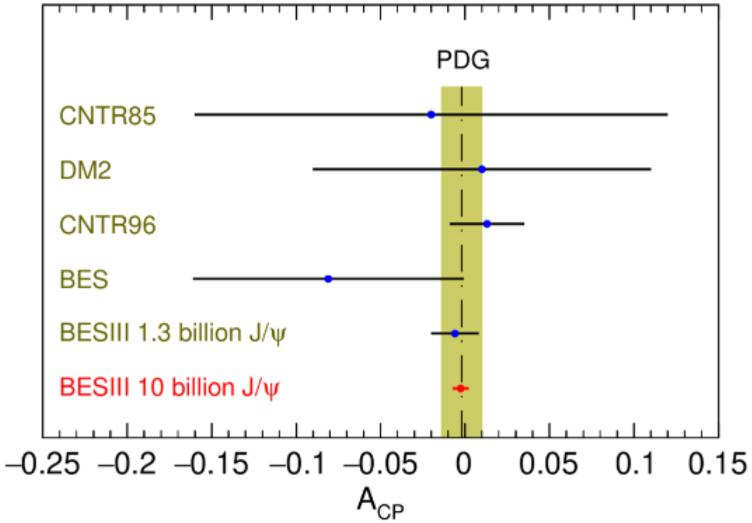
CP test $A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$



NP15(2019)631; PRL129, 131801 (2022)







Par.	This Work*	Previous results **	PDG 2018 ***
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$	-
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013
α_+	$-0.7559 \pm 0.0036 \pm 0.0029$	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0011$	$0.006 \pm 0.012 \pm 0.007$	-
$\alpha_{\pm,avg.}$	$0.7542 \pm 0.0010 \pm 0.0020$	$0.754 \pm 0.003 \pm 0.002$	-

~7σ upward shift from all previous measurements

0.5% level sensitivity for CPV test
SM prediction: 10^{-4}~10^{-5}

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

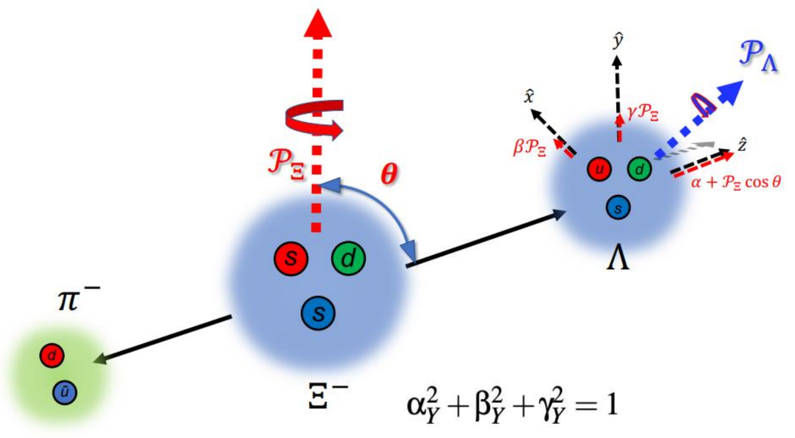
- For the sequential weak decays, the formula of sequential decays is:

$$\mathcal{W}(\boldsymbol{\xi},\boldsymbol{\omega}) = \sum_{\mu,\bar{\nu}=0}^{3} C_{\mu\bar{\nu}} \sum_{\mu',\bar{\nu}'=0}^{3} a^{B_1}_{\mu\mu'} a^{\bar{B}_1}_{\bar{\nu}\bar{\nu}'} a^{B_2}_{\mu'0} a^{\bar{B}_2}_{\bar{\nu}'0}$$

PRD99(2019)056008
PRD100(2019)114005

- Angular distribution $d\Gamma \propto W(\xi,\omega)$
  - ξ: 9 kinematic variables, denoted by 9 helicity angles
  - $\omega = (\alpha_\psi, \Delta\Phi, \alpha_\Xi, \alpha_{\bar{\Xi}}, \phi_\Xi, \phi_{\bar{\Xi}}, \alpha_\Lambda, \alpha_{\bar{\Lambda}})$: 8 free parameters

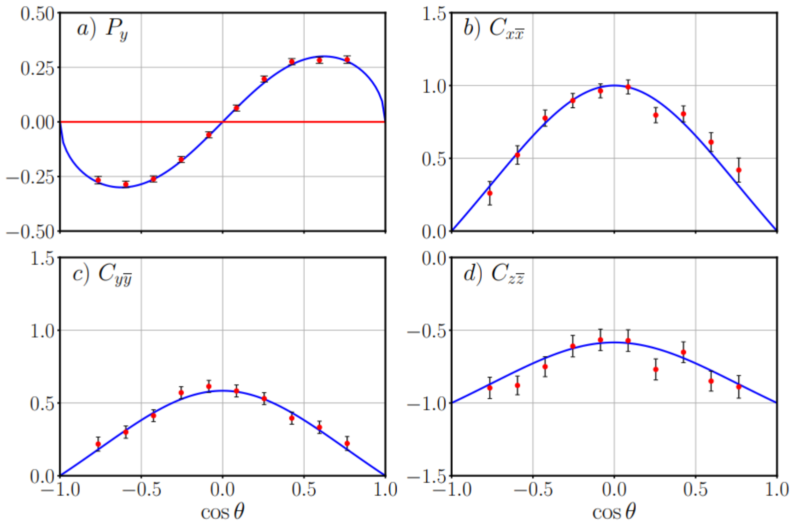
first measurement!



$\alpha_Y^2 + \beta_Y^2 + \gamma_Y^2 = 1$

$\beta_Y = \sqrt{1-\alpha_Y^2}\sin\phi_Y, \quad \gamma_Y = \sqrt{1-\alpha_Y^2}\cos\phi_Y$

More parameters in sequential decay!



- Data sample: 1.3 billion J/ψ events.
- Final dataset: $73.2 \cdot 10^3$ events with 199 backgrounds.

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

Nature 606 (2022) 7912, 64-69

Parameter	This work	Previous result
α_ψ	0.586±0.012±0.010	0.58±0.04±0.08
$\Delta\Phi$	1.213±0.046±0.016 rad	–
α_Ξ	−0.376±0.007±0.003	−0.401±0.010
ϕ_Ξ	0.011±0.019±0.009 rad	−0.037±0.014 rad
$\bar{\alpha}_\Xi$	0.371±0.007±0.002	–
$\bar{\phi}_\Xi$	−0.021±0.019±0.007 rad	–
α_Λ	0.757±0.011±0.008	0.750±0.009±0.004
$\bar{\alpha}_\Lambda$	−0.763±0.011±0.007	−0.758±0.010±0.007
$\xi_P-\xi_S$	$(1.2\pm3.4\pm0.8)\times10^{-2}$ rad	–
$\delta_P-\delta_S$	$(-4.0\pm3.3\pm1.7)\times10^{-2}$ rad	$(10.2\pm3.9)\times10^{-2}$ rad
A_{CP}^{Ξ}	$(6\pm13\pm6)\times10^{-3}$	–
$\Delta\phi_{CP}^{\Xi}$	$(-5\pm14\pm3)\times10^{-3}$ rad	–
A_{CP}^{Λ}	$(-4\pm12\pm9)\times10^{-3}$	$(-6\pm12\pm7)\times10^{-3}$
$\langle\phi_\Xi\rangle$	0.016±0.014±0.007 rad	

First measurement of the Ξ^- polarization in J/ψ decay

First direct and simultaneously measurement of the charged Ξ decay parameters

First measurement of weak phase difference in Ξ decay

Three independent *CP* tests

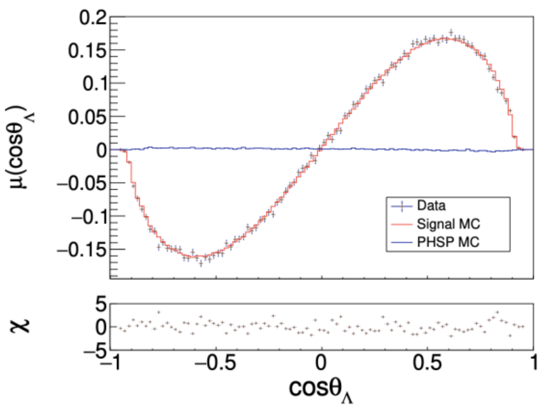
We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

HyperCP: PRL 93(2004) 011802

Polarization behavior in different hyperon pair productions

$J/\psi \to \Lambda\bar{\Lambda}$

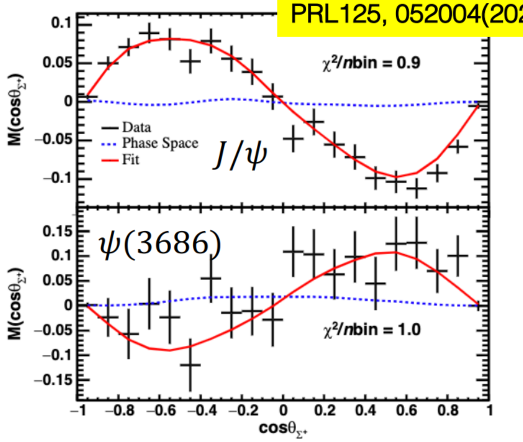
PRL129, 131801(2022)



$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)\,rad$
$A_{CP} = -0.0025 \pm 0.0046 \pm 0.0012$

$\psi \to \Sigma^+\bar{\Sigma}^- \to p\pi^0\bar{p}\pi^0$

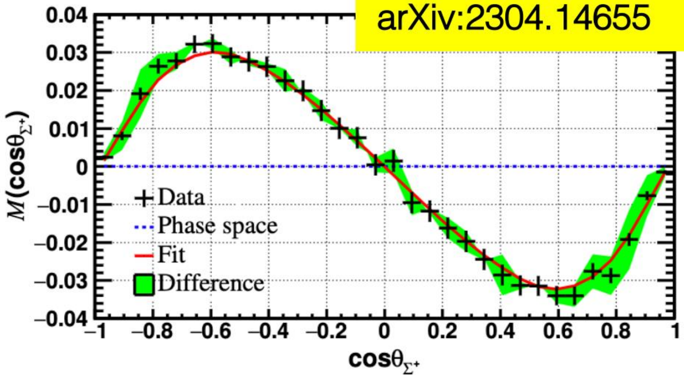
PRL125, 052004(2020)



$\Delta\Phi(J/\psi) = (-15.5 \pm 0.7 \pm 0.5)^\circ$
$\Delta\Phi(\psi(2S)) = (21.7 \pm 4.0 \pm 0.8)^\circ$
$A_{CP} = -0.004 \pm 0.037 \pm 0.010$

$J/\psi \to \Sigma^+\bar{\Sigma}^- \to n\pi^+\bar{p}\pi^0$

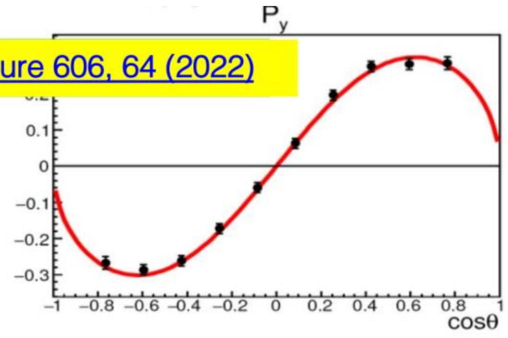
arXiv:2304.14655



$\Delta\Phi = (-0.277 \pm 0.004 \pm 0.004)\,rad$
$A_{CP} = -0.080 \pm 0.052 \pm 0.028$

$J/\psi \to \Xi^-\bar{\Xi}^+$

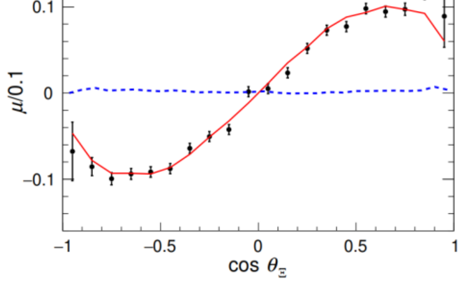
Nature 606, 64 (2022)



$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016)\,rad$
$A_{CP} = -0.006 \pm 0.013 \pm 0.006$

$J/\psi \to \Xi^0\bar{\Xi}^0$

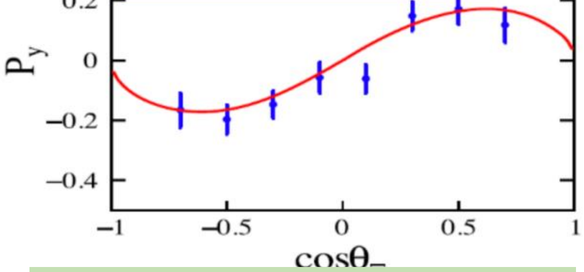
arXiv:2305.09218v1



$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018)\,rad$
$A_{CP} = -0.0054 \pm 0.0065 \pm 0.0031$

$\psi(2S) \to \Xi^-\bar{\Xi}^+$

PRD106, L091101(2022)



$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)\,rad$
$A_{CP} = -0.015 \pm 0.051 \pm 0.010$

BESIII Achievement on Hyperon Decay

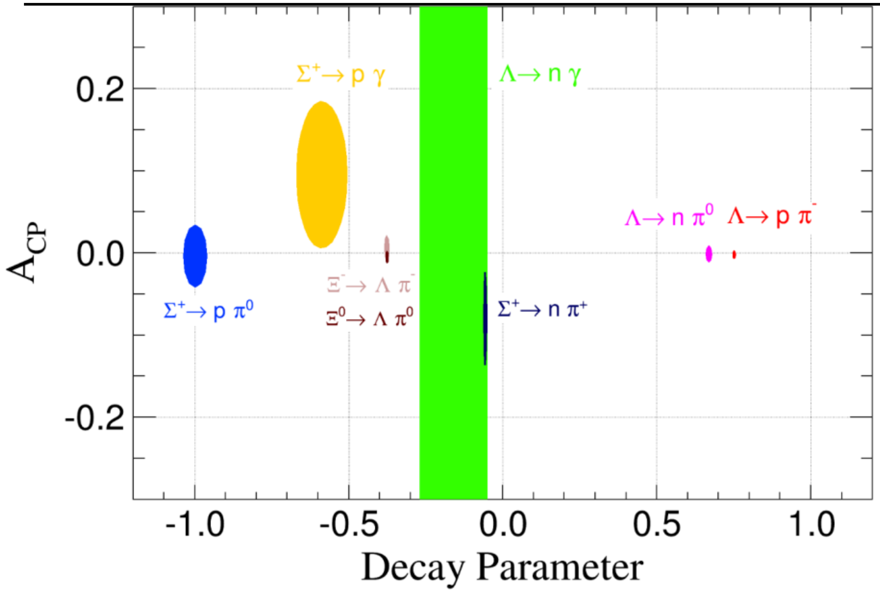
- Polarization of hyperon disentangled
- Most precise decay parameters obtained
- More CPV observable constructed

$$A_{\Lambda} = -0.0025 \pm 0.0046 \pm 0.0011 \text{ (10billion } J/\psi)$$
$$A_{\Sigma} = -0.004 \pm 0.037 \pm 0.010 \text{ (1.3 billion } J/\psi)$$
$$A_{\Xi} = 0.006 \pm 0.013 \pm 0.006 \text{ (1.3 billion } J/\psi)$$
$$\Delta\phi_{\Xi} = -0.005 \pm 0.014 \pm 0.003 \text{ (1.3 billion } J/\psi)$$

- Weak phase determined for the first time

$$\xi^P_\Lambda - \xi^S_\Lambda = (-1.1 \pm 2.1)^\circ \quad \in \{-4.5^\circ, +2.1^\circ\} \quad (90\% \text{ C.L.})$$

$B\bar{B}$ mode	P_y^{max} / $\cos\theta^{max}$
$J/\psi \to \Lambda\bar{\Lambda}$	25% / 0.64
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	16% / 0.82
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	5% / 0.80
$J/\psi \to \Sigma^-\bar{\Sigma}^{+*}$	0.5% / 0.78
$J/\psi \to \Xi^0\bar{\Xi}^0$	27% / 0.61
$J/\psi \to \Xi^-\bar{\Xi}^+$	30% / 0.62

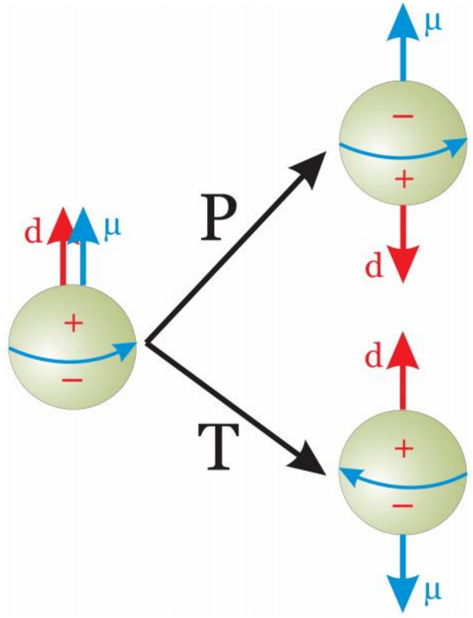


To discovery CPV in hyperon, more new ideas are needed.

Searching for hyperon EDM at BESIII

$$\mathcal{M} = F_1\gamma_\mu + \frac{F_2}{2m} q_\nu \sigma^{\nu\mu}\gamma_5 + i\epsilon^{\mu\nu\alpha\beta}\frac{\sigma_{\alpha\beta}}{4m} q_\nu F_3 + \frac{1}{2m}\left(q^\mu - \frac{q^2}{2m}\gamma^\mu\right)\gamma_5 F_4$$

μ: magnetic dipole moment
d: electric dipole moment



Systematic measurement of the EDMs of the hyperon family!
BESIII is expected to improve the measurement precision of the Λ EDM by a factor of **1000**

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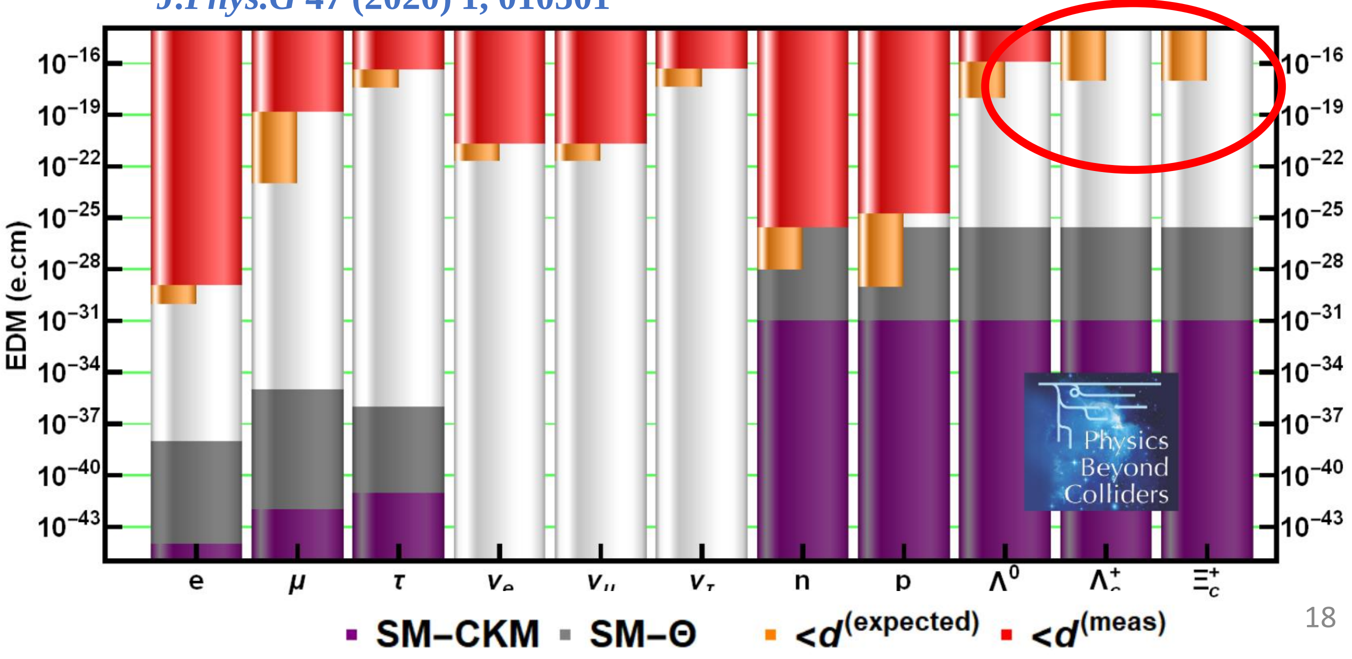
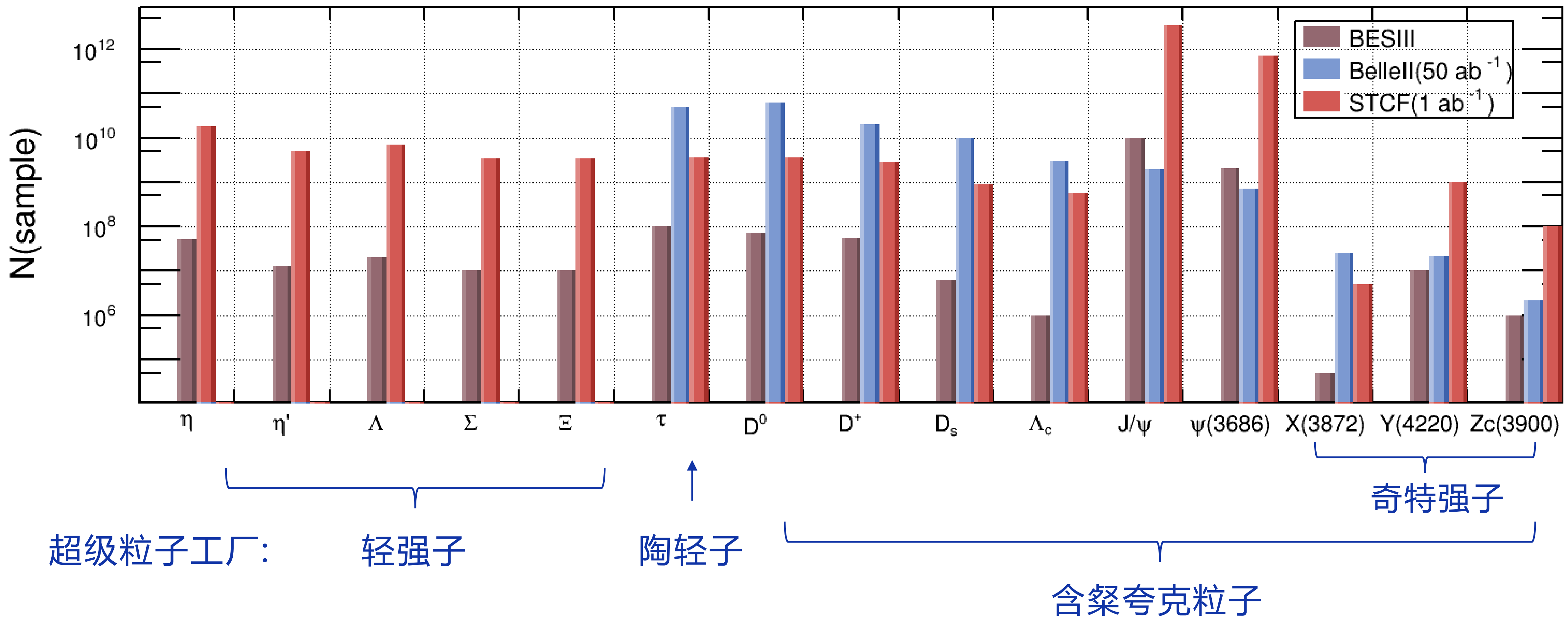


Non-zero EDM will violate P and T symmetry:
T violation ↔ CP violation, if CPT holds.

Expected samples at STCF and hyperon CPV



Probe CP violation at tau-charm factory

Billions hyperon pairs from J/ψ decay, clean topology, background free

Transversely polarized, spin correlation

Sensitivity: $A_{CP}\sim10^{-4}$, $\xi\sim0.05^{\circ}$

CP in hyperon decay

CP in tau decay/production

Peak cross section in $\sqrt{s}$ =4-5 GeV, $\sigma_{\tau\tau}\approx$ 3.5 nb, 10 ab^{-1} data in total

Sensitivity of τ decay with 1ab^{-1} @ 4.26 GeV ~9.7×10^{-4}

CP in charm mixing

Billions $D^0/\bar{D}^0$, threshold production, quantum coherence with $(D^0\bar{D}^0)_{CP=-}$ or $(D^0\bar{D}^0)_{CP=+}$

Sensitivity: $x\sim0.035\%$, y~0.023%, $r_{CP}\sim0.017$, $\alpha_{CP}\sim1.3^{\circ}$

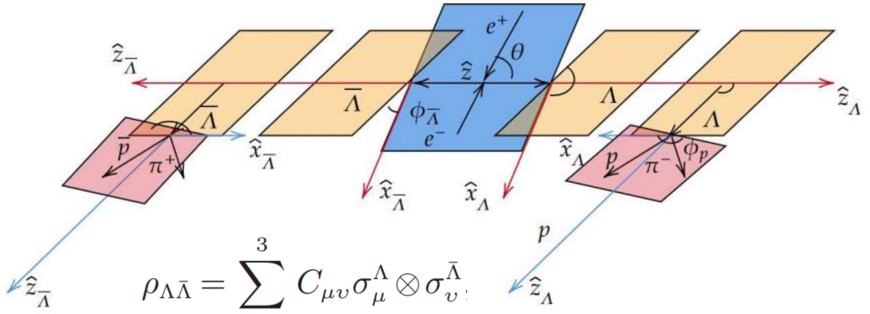
CPT in kaon mixing

CP tagging and flavor tagging of $K^0/\bar{K}^0$ available from J/ψ decay

CP variables determined with time-dependent decay rate

CPT Sensitivity: $\eta_{\pm}\sim10^{-3}$, $\Delta\phi_{\pm}\sim0.05^{\circ}$

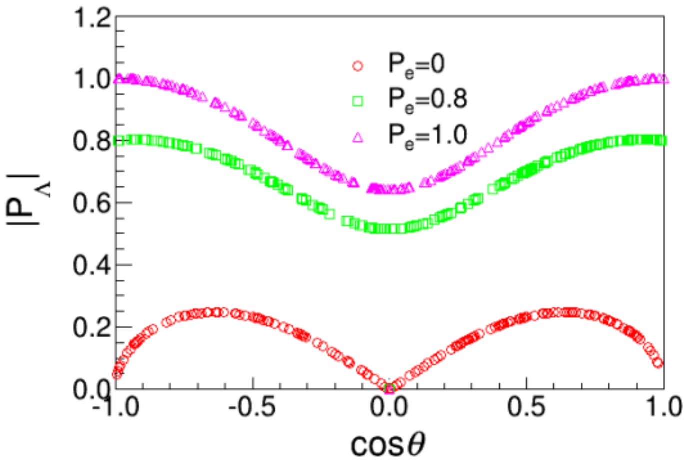
CPV in Λ decay with polarized electron beam

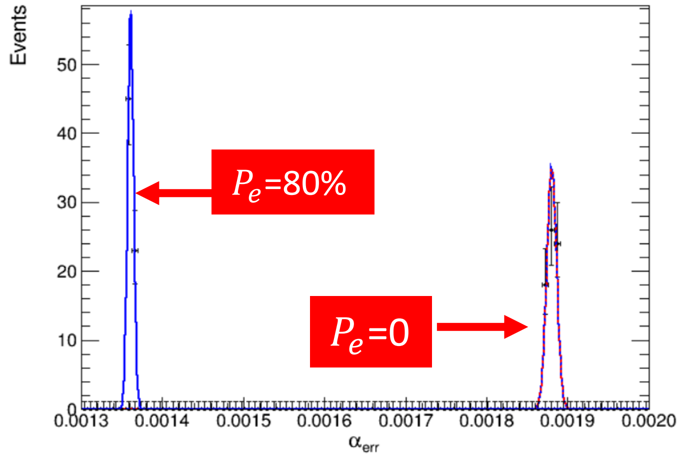


$$\rho_{\Lambda\bar{\Lambda}} = \sum_{\mu\nu=0}^{3} C_{\mu\nu}\sigma_{\mu}^{\Lambda} \otimes \sigma_{\nu}^{\bar{\Lambda}}$$

$$\begin{bmatrix} 1+\alpha_\psi \cos^2\theta & \gamma_\psi P_e \sin\theta & \beta_\psi \sin\theta\cos\theta & (1+\alpha_\psi)P_e\cos\theta \\ \gamma_\psi P_e \sin\theta & \sin^2\theta & 0 & \gamma_\psi \sin\theta\cos\theta \\ -\beta_\psi \sin\theta\cos\theta & 0 & \alpha_\psi \sin^2\theta & -\beta_\psi P_e \sin\theta \\ -(1+\alpha_\psi)P_e\cos\theta & -\gamma_\psi \sin\theta\cos\theta & -\beta_\psi P_e \sin\theta & -\alpha_\psi - \cos^2\theta \end{bmatrix},$$

$$\mathbf{P}_\Lambda = \frac{\gamma_\psi P_e \sin\theta \hat{x}_1 - \beta_\psi \sin\theta\cos\theta \hat{y}_1 - (1+\alpha_\psi)P_e\cos\theta\hat{z}_1}{1+\alpha_\psi\cos^2\theta}.$$



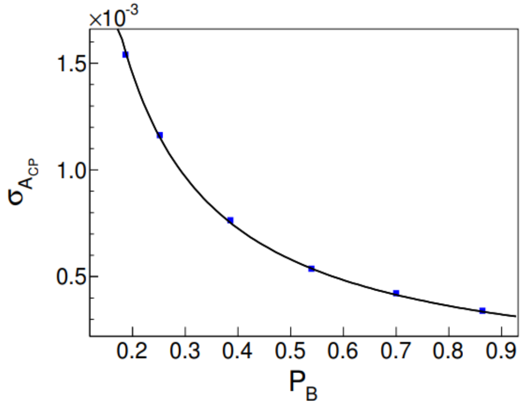


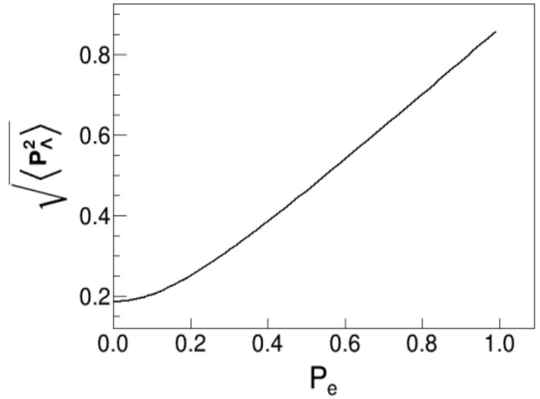
- Large statistics and electron polarization will improve the sensitivity of CPV significantly.
- The sensitivity of CPV follows :

$$\sigma_{A_{CP}} \approx \sqrt{\frac{3}{2}} \frac{1}{\alpha_1 \sqrt{N_{sig}} \sqrt{\langle P_B^2 \rangle}}.$$

$$\xrightarrow{1\times10^9\ \Lambda\bar{\Lambda},\ \ \langle P_B^2\rangle=0.1} \sigma_{A_{CP}} \sim 1.4\times10^{-4}$$

$$\xrightarrow{1\times10^9\ \Lambda\bar{\Lambda},\ \ \langle P_B^2\rangle=0.8} \sigma_{A_{CP}} \sim 0.5\times10^{-5}$$





Summary

- **CPV in hyperon decay at BESIII**
  - Complementary to CPV studies with Kaons
  - BESIII has already rewritten the PDG book for Λ and Ξ decays
  - Results of $\Sigma^{\pm}, \Xi$ with 10 billion J/ψ will be coming soon
- **CPV in hyperon production at BESIII**
  - First measurements of $\Sigma^{+}, \Xi^{-}, \Xi^{0}, \Omega$ hyperons EDM
  - The sensitivity of the hyperon EDM can be reached at the order of 10^{-19}
- **STCF is expected to improve 1-2 orders of magnitudes in precision of hyperon CPV, and more opportunities in *K*, *τ*, *D*.**