Recent results on hyperon decays at BESIII

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Institute of High Energy Physics
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National Centre for Nuclear Research
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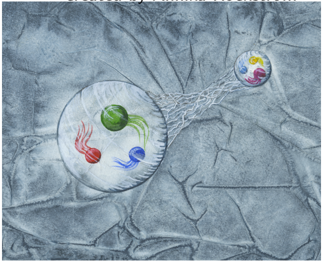
Introduction

- More than 50 years of the knowledge about CP violation (CPV)
  - Confirmed only in meson decays

created by Annika Rockström



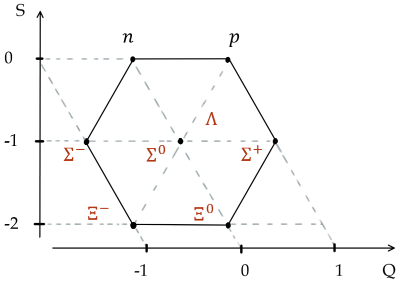
- SM CPV is not sufficient to explain observed matter-antimatter asymmetry
- Baryogenesis requires C and CP violation in the processes

  [PismaZh.Eksp.Teor.Fiz.5(1967)32]

- Systematical mapping with different hadronic systems and complementary methods are needed for understanding CPV in flavour sector

Ground-state strange baryons

- Spin-$\frac{1}{2}$ baryon octet
- Weak $\Delta S = 1$ transitions



$+\ \Omega^-$ spin-$\frac{3}{2}$

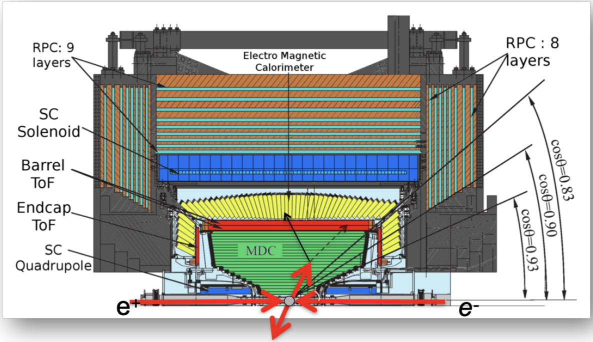
Hyperon	Mass [GeV/c^2]	Decay ($\mathcal{B}$)
$\Lambda(uds)$	1.116	$p\pi^-(64.1\%)$ $n\pi^0(35.9\%)$
$\Sigma^-(dds)$	1.197	$n\pi^-(99.8\%)$
$\Sigma^+(uus)$	1.189	$p\pi^0(51.6\%)$ $n\pi^+(48.3\%)$
$\Xi^0(uss)$	1.315	$\Lambda\pi^0(99.5\%)$
$\Xi^-(dss)$	1.322	$\Lambda\pi^-(99.9\%)$
$\Omega^-(sss)$	1.672	$\Lambda K^-(67.8\%)$ $\Xi^0\pi^-(23.6\%)$ $\Xi^-\pi^0(8.6\%)$

Experimental facility:
BEPCII and BESIII

BESIII @ BEPCII

[Nucl.Instrum.Meth.A598(2009)7]

- Beijing Electron-Positron Collider (BEPCII)
  - e^+e^- collider with 2.0 GeV$< E_{\text{CMS}} < 4.95$ GeV
  - $\mathcal{L}_{\text{peak}} = 10^{33}\text{cm}^{-2}\text{s}^{-1}$
  - Data taking since 2009



- Beijing Spectrometer (BESIII)
  - Optimized for flavour physics
  - Covers 93% of 4π solid angle
  - 1.0 T super-condacting solenoid
  - Momentum resolution: $\sigma(p)/p = 0.5\%$ at 1 GeV/c
  - Time resolution: 68 (65) ps in the barrel (end cap)

BESIII data sample

- World's largest charmonia sample:
  - $N_{J/\psi} \sim 10^{10}$
  - $N_{\psi(2S)} \sim 3 \cdot 10^{9}$
- Full baryon-antibaryon octet kinematically accessible

Resonance	Pair	$\epsilon(\%)$	$\mathcal{B}(\cdot 10^{-4})$	Reference
J/ψ	$\Lambda\bar{\Lambda}$	42.37 ± 0.14	19.43 ± 0.03	[PRD95(2017)052003]
	$\Sigma^0\bar{\Sigma}^0$	17.83 ± 0.06	11.64 ± 0.04	
	$\Sigma^+\bar{\Sigma}^-$	24.1 ± 0.7	10.61 ± 0.04	[JHEP11(2021)226]
	$^*\Xi^-\bar{\Xi}^+$	18.40 ± 0.04	10.40 ± 0.06	[PRD93(2016)072003]
	$\Xi^0\bar{\Xi}^0$	14.05 ± 0.04	11.65 ± 0.04	[PLB770(2017)217]
$\psi(2S)$	$\Lambda\bar{\Lambda}$	42.83 ± 0.34	3.97 ± 0.02	[PRD95(2017)052003]
	$\Sigma^0\bar{\Sigma}^0$	14.79 ± 0.12	2.44 ± 0.03	
	$\Sigma^+\bar{\Sigma}^-$	18.6 ± 0.5	2.52 ± 0.04	[JHEP11(2021)226]
	$^*\Xi^-\bar{\Xi}^+$	18.04 ± 0.04	2.78 ± 0.05	[PRD93(2016)072003]
	$\Xi^0\bar{\Xi}^0$	14.10 ± 0.04	2.73 ± 0.03	[PLB770(2017)217]
	$\Omega^-\bar{\Omega}^+$	$17.1/18.9$	0.59 ± 0.03	[PRL126(2021)092002]

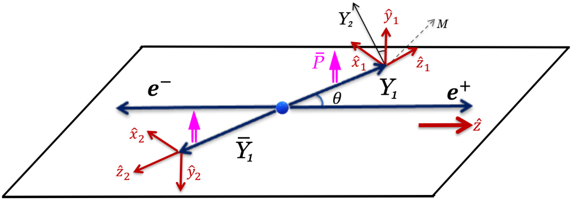
numbers for $1.31 \cdot 10^9\, J/\psi$ and $0.45 \cdot 10^9\, \psi(2S)$

*numbers for $0.22 \cdot 10^9\, J/\psi$ and $0.11 \cdot 10^9\, \psi(2S)$

Modular method to study full process:
$e^+e^- \to (c\bar{c}) \to Y\bar{Y} \to (BM)(\bar{B}\bar{M})$

Production process

[PRD99(2019)056008]

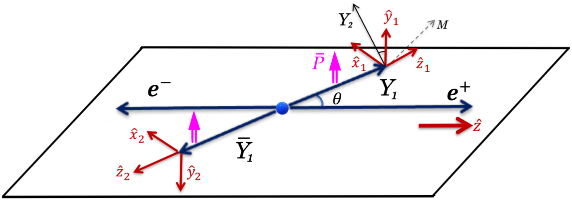


- Spin $\frac{1}{2}+\frac{\bar{1}}{2}$ baryon-antibaryon density matrix:

$$\rho_{1/2,\overline{1/2}} = \frac{1}{4}\sum_{\mu\bar{\nu}} C_{\mu\bar{\nu}}\sigma_{\mu}^{Y_1}\otimes\sigma_{\bar{\nu}}^{\bar{Y}_1}$$

Production process

[PRD99(2019)056008]



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- Spin $\frac{1}{2} + \frac{\bar{1}}{2}$ baryon-antibaryon density matrix:

Y_1 transverse polarization

$$C_{\mu\bar{\nu}} = \begin{pmatrix} 1+\alpha_\psi \cos^2\theta & 0 & \beta_\psi \sin\theta\cos\theta & 0 \\ 0 & \sin^2\theta & 0 & \gamma_\psi \sin\theta\cos\theta \\ -\beta_\psi \sin\theta\cos\theta & 0 & \alpha_\psi \sin^2\theta & 0 \\ 0 & -\gamma_\psi \sin\theta\cos\theta & 0 & -\alpha_\psi - \cos^2\theta \end{pmatrix}$$

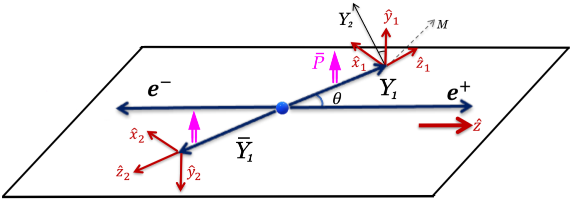
$\bar{Y}_1$ transverse polarization

spin-correlation terms

$$\beta_\psi = \sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi), \quad \gamma_\psi = \sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)$$

Production process

[PRD99(2019)056008]



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$\bar{Y}_1$ transverse polarization

spin-correlation terms

$$\beta_\psi = \sqrt{1-\alpha_\psi{}^2}\,\sin(\Delta\Phi), \quad \gamma_\psi = \sqrt{1-\alpha_\psi{}^2}\,\cos(\Delta\Phi)$$

- Unpolarised e^+e^- beams $\Longrightarrow$ transverse polarisation (if $\Delta\Phi \neq 0$):

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

Decay amplitudes in hyperon decays

- S- and P-wave amplitudes:
  $Y \to BM$ like $\Lambda \to p\pi^-$
  $Y_1 \to Y_2(\to BM)M$ like $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$

$$\mathcal{A} = S + P\vec{\sigma}\cdot\hat{\mathbf{n}}$$

weak CP-odd phases

$$S = |S| exp(\xi_S) exp(i\delta_S)$$
$$P = |P| exp(\xi_P) exp(i\delta_P)$$

strong phases

- $|\Delta I| = 1/2$
- Contribution of $|\Delta I| = 3/2$ is $\sim 10\%$

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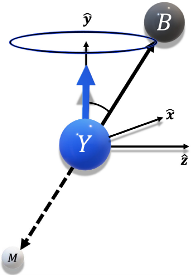
strong phases

- $|\Delta I| = 1/2$
- Contribution of $|\Delta I| = 3/2$ is $\sim 10\%$
  - Two measurable parameters

$$\boldsymbol{\alpha} = \frac{2\mathrm{Re}(S*P)}{|S|^2+|P|^2}, \qquad \beta = \frac{2\mathrm{Im}(S*P)}{|S|^2+|P|^2} = \sqrt{1-\alpha^2}\sin\boldsymbol{\phi}$$

Measured hyperon decay parameters

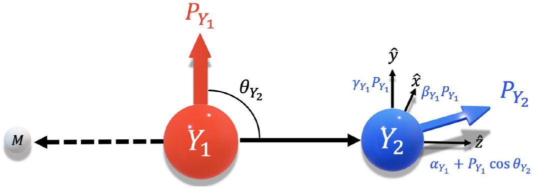
- Polarisation of hyperons is experimentally accessible in weak parity-violating decays



- Example:
  angular distribution of $Y \to BM$

$$I(\cos\theta_B) \propto 1 + \alpha_B P_y \cos\theta_B$$

- Angle ϕ is accessible when polarisation of daughter baryon is measured
  - Example: $Y_1 \to Y_2(\to BM)M$ like $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$



CP tests in hyperon decays

- If CP conserved: $\bar{\alpha} = -\alpha$, $\bar{\beta} = -\beta$, $\bar{\phi} = -\phi$
- Possible CP tests:

weak P-S phase difference

$$A_{CP} = \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} = -\sin\phi\tan(\xi_P - \xi_S)\frac{\sqrt{1-\alpha^2}}{\alpha}$$
$$\Phi_{CP} = \frac{\phi+\bar{\phi}}{2} = \cos\phi\tan(\xi_P - \xi_S)\frac{\alpha}{\sqrt{1-\alpha^2}}$$

- SM predictions [PRD105(2022)116022]

$$-3\cdot 10^{-5} \leq A_{\Lambda} \leq 3\cdot 10^{-5}$$
$$0.5\cdot 10^{-5} \leq A_{\Xi} \leq 6\cdot 10^{-5}$$

Decay mode	$\xi_P - \xi_S$ $[10^{-4}\text{rad}]$
$\Lambda \to p\pi^-$	-0.2 ± 2.2
$\Xi^- \to \Lambda\pi^-$	-2.1 ± 1.7

- HyperCP: $A^{\Lambda}_{\text{CP}} + A^{\Xi}_{\text{CP}} = (0.0 \pm 5.1_{\text{stat}} \pm 4.4_{\text{syst}})\cdot 10^{-4}$ [PRL93(2004)262001]
- HyperCP[preliminary]: $A^{\Lambda}_{\text{CP}} + A^{\Xi}_{\text{CP}} = (-6.0 \pm 2.1_{\text{stat}} \pm 2.0_{\text{syst}})\cdot 10^{-4}$ [BEACH2008]

  signal statistics increased by factor 6-7

Joint angular amplitude

[PRD99(2019)056008] [PRD100(2019)114005]

- Production matrix:

$$\rho_{1/2,\overline{1/2}} = \frac{1}{4}\sum_{\mu\bar{\nu}} C_{\mu\bar{\nu}}\sigma_{\mu}^{Y_1} \otimes \sigma_{\bar{\nu}}^{\bar{Y}_1}$$

- Decay matrix:

$$\sigma_{\mu}^{Y_1} \to \sum_{\mu'=0}^{3} a_{\mu\mu'}^{Y_1}(\alpha_{Y_1}, \phi_{Y_1}; \theta_{Y_2}, \varphi_{Y_2})\sigma_{\mu'}^{Y_2}$$

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[PRD99(2019)056008] [PRD100(2019)114005]

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- Joint angular amplitude of full decay chain takes into account polarisation, entanglement and sequential decays

$$\mathcal{W}(\boldsymbol{\xi},\boldsymbol{\omega}) = \sum_{\mu,\bar{\nu}=0}^{3} C_{\mu\bar{\nu}} \sum_{\mu',\bar{\nu}'=0}^{3} a_{\mu\mu'}^{Y_1} a_{\bar{\nu}\bar{\nu}'}^{\bar{Y}_1} a_{\mu'0}^{Y_2} a_{\bar{\nu}'0}^{\bar{Y}_2}$$

$\boldsymbol{\xi} = (\theta_{Y_1},\theta_{Y_2},\varphi_{Y_2},\bar{\theta}_{Y_2},\bar{\varphi}_{Y_2},\theta_B,\varphi_B,\bar{\theta}_B,\bar{\varphi}_B)$ - set of helicity angles

$\boldsymbol{\omega} = (\alpha_{\psi},\Delta\Phi,\alpha_{Y_1},\phi_{Y_1},\bar{\alpha}_{Y_1},\bar{\phi}_{Y_1},\alpha_{Y_2},\bar{\alpha}_{Y_2})$ - set of measured parameters

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- $e^+e^- \to (c\bar{c}) \to Y\bar{Y} \to (BM)(\bar{B}\bar{M})$
  - $\boldsymbol{\xi}$ = 5 angles, $\boldsymbol{\omega}$ = 4 parameters

Joint angular amplitude

[PRD99(2019)056008] [PRD100(2019)114005]

- Production matrix:

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$\boldsymbol{\xi} = (\theta_{Y_1}, \theta_{Y_2}, \varphi_{Y_2}, \bar{\theta}_{Y_2}, \bar{\varphi}_{Y_2}, \theta_B, \varphi_B, \bar{\theta}_B, \bar{\varphi}_B)$ - set of helicity angles

$\boldsymbol{\omega} = (\alpha_{\psi}, \Delta\Phi, \alpha_{Y_1}, \phi_{Y_1}, \bar{\alpha}_{Y_1}, \bar{\phi}_{Y_1}, \alpha_{Y_2}, \bar{\alpha}_{Y_2})$ - set of measured parameters

- $e^+e^- \to (c\bar{c}) \to Y\bar{Y} \to (BM)(\bar{B}\bar{M})$
  - $\boldsymbol{\xi}$ = 5 angles, $\boldsymbol{\omega}$ = 4 parameters
- $e^+e^- \to (c\bar{c}) \to Y_1\bar{Y}_1 \to (Y_2M_1)(\bar{Y}_2\bar{M}_1) \to (BM_2M_1)(\bar{B}\bar{M}_2\bar{M}_1)$
  - $\boldsymbol{\xi}$ = 9 angles, $\boldsymbol{\omega}$ = 8 parameters

Experimental results:
$e^+e^- \to Y\bar{Y} \to (BM)(\bar{B}\bar{M})$

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda},\ \Lambda \to p\pi^-$+c.c. (1)

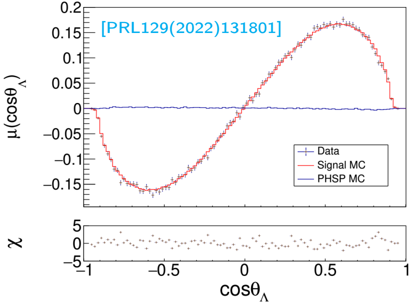
- Increasing data statistics have allowed for the significant result improvement ($\sim 3\sigma$):

  [1] [Nature Phys.15(2019)631] $\Longrightarrow$ [2] [PRL129(2022)131801]

	This work[2]	Previous work[1]
$N_{J/\psi}$	10^{10}	$1.31 \cdot 10^9$
$N_{\rm sig}$	$3.2 \cdot 10^6$	$421 \cdot 10^3$
$N_{\rm bkg}$	3801 ± 63	399 ± 20

- Angular dependence of the moment for the acceptance-corrected data:

$$\mu(\cos\theta_\Lambda) = \frac{\alpha_\Lambda - \bar{\alpha}_\Lambda}{2}\frac{1+\alpha_\psi\cos^2\theta_\Lambda}{3+\alpha_\psi}P_y(\cos\theta_\Lambda)$$



Parameters	This work[2]	Previous results[1]
α_ψ	$\mathbf{0.4748 \pm 0.0022 \pm 0.0024}$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$ [rad]	$\mathbf{0.7521 \pm 0.0042 \pm 0.0080}$	$0.740 \pm 0.010 \pm 0.009$
α_Λ	$\mathbf{0.7519 \pm 0.0036 \pm 0.0019}$	$0.750 \pm 0.009 \pm 0.004$
$\bar{\alpha}_\Lambda$	$\mathbf{-0.7559 \pm 0.0036 \pm 0.0029}$	$-0.758 \pm 0.010 \pm 0.007$

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda},\ \Lambda \to p\pi^-$+c.c. (2)

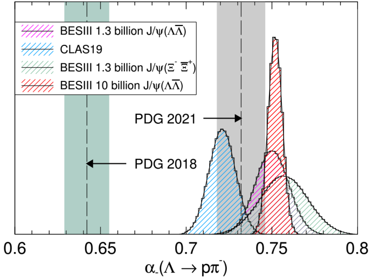
[PRL129(2022)131801]

$$A_{CP}^{\Lambda} = \frac{\alpha_\Lambda + \bar{\alpha}_\Lambda}{\alpha_\Lambda - \bar{\alpha}_\Lambda} = -0.0025 \pm 0.0046_{\rm stat} \pm 0.0011_{\rm syst}$$

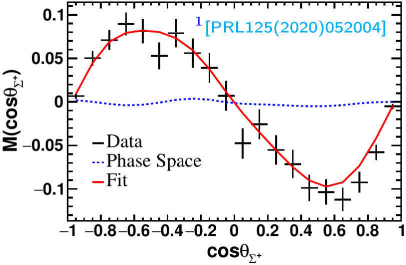
- BESIII: $A_{CP}^{\Lambda} = -0.006 \pm 0.012_{\rm stat} \pm 0.007_{\rm syst}$ [Nature Phys.15(2019)631]
- PS185: $A_{CP}^{\Lambda} = 0.013 \pm 0.021_{\rm tot}$ [PRC54(1996)1877]

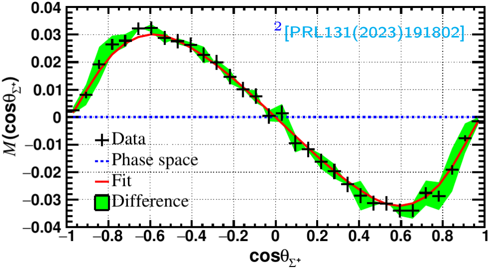
$$\langle \alpha_\Lambda \rangle = \frac{\alpha_\Lambda - \bar{\alpha}_\Lambda}{2} = 0.7542 \pm 0.0010_{\rm stat} \pm 0.0020_{\rm syst}$$

- BESIII: $\langle \alpha_\Lambda \rangle = 0.754 \pm 0.003_{\rm stat} \pm 0.002_{\rm syst}$ [Nature Phys.15(2019)631]
- CLAS: $\alpha_\Lambda = 0.721 \pm 0.006_{\rm stat} \pm 0.005_{\rm syst}$ [PRL123(2019)182301]



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





First result

Parameters	$(p\pi^0)(\bar{p}\pi^0)$ [1]	$(p\pi^0)(\bar{n}\pi^-)$ + c.c. [2]
N$_{J/\psi}$ N$_{\text{sig}}$	$1.31 \cdot 10^9$ $87 \cdot 10^3$ with 5% bkg	10^{10} $(3.1 + 7.5) \cdot 10^5$ with 2% bkg
$\alpha_{J/\psi}$ $\Delta\Phi_{J/\psi}$ [rad]	$-0.508 \pm 0.006 \pm 0.004$ $-0.270 \pm 0.012 \pm 0.009$	$\mathbf{-0.5156 \pm 0.0030 \pm 0.0061}$ $\mathbf{-0.2772 \pm 0.0044 \pm 0.0041}$
$\langle\alpha_0\rangle$ $\langle\alpha_+\rangle$	$-0.994 \pm 0.004 \pm 0.002$	 $0.0506 \pm 0.0026 \pm 0.0019$

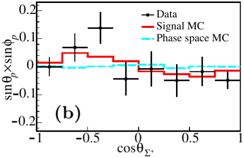
[3] [PRD67(2003)056001]

First result

A^0_{CP}	$\mathbf{-0.004 \pm 0.037 \pm 0.010}$	$3.6 \cdot 10^{-6}$ (SM[3])
A^+_{CP}	$3.9 \cdot 10^{-4}$ (SM[3])	$\mathbf{-0.080 \pm 0.052 \pm 0.028}$

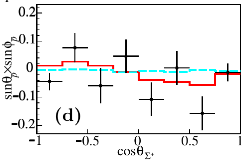
$e^+e^- \to J/\psi \to \Sigma^+\bar{\Sigma}^- \to (p\gamma)(\bar{p}\pi^0)$+c.c.

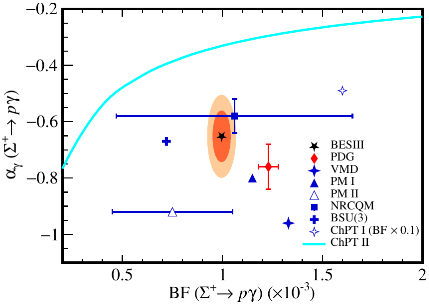
[PRL130(2023)211901]



$\longleftarrow \bar{\Sigma}^- \to \bar{p}\gamma$

$\Sigma^+ \to p\gamma \longrightarrow$





- Data sample: 10^{10} J/ψ
- 1189 ± 38 and 1306 ± 39 events for $(p\gamma)(\bar{p}\pi^0)$ and $(p\pi^0)(\bar{p}\gamma)$, respectively

$$\mathcal{B} = (0.996 \pm 0.021 \pm 0.018) \cdot 10^{-3}$$
$$\langle \alpha_\gamma \rangle = -0.651 \pm 0.056 \pm 0.020$$

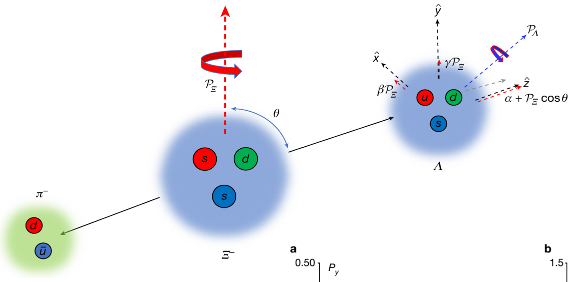
$$\Delta_{CP} = \frac{\mathcal{B} - \bar{\mathcal{B}}}{\mathcal{B} + \bar{\mathcal{B}}} = 0.006 \pm 0.011 \pm 0.004$$
$$A_{CP} = \frac{\bar{\alpha}_\gamma + \alpha_\gamma}{\bar{\alpha}_\gamma - \alpha_\gamma} = 0.095 \pm 0.087 \pm 0.018$$

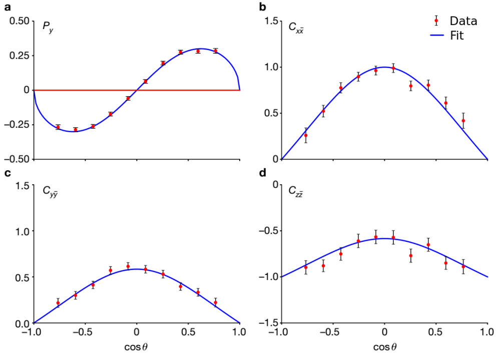
Experimental results:

$$e^+e^- \to Y_1\bar{Y}_1 \to (Y_2M_1)(\bar{Y}_2\bar{M}_1) \to (BM_2M_1)(\bar{B}\bar{M}_2\bar{M}_1)$$

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+$, $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$+c.c. (1)

[Nature 606(2022)64]





- Data sample: $1.3 \cdot 10^9\, J/\psi$
- $73.2 \cdot 10^3$ events with $N_{\text{bkg}} = 199 \pm 17$

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+$, $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$+c.c. (2)

[Nature 606(2022)64]

Parameter	This work	Previous result	
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	[1]
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	[2]
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad	-0.037 ± 0.014 rad	[2]
$\overline{\alpha}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	–	
$\overline{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007$ rad	–	
α_Λ	$0.757 \pm 0.011 \pm 0.008$	$0.7519 \pm 0.0036 \pm 0.0019$	[3]
$\overline{\alpha}_\Lambda$	$-0.763 \pm 0.011 \pm 0.007$	$-0.7559 \pm 0.0036 \pm 0.0029$	[3]
$\xi_P - \xi_S$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad	–	
$\delta_P - \delta_S$	$(-4.0 \pm 3.3 \pm 1.7) \times 10^{-2}$ rad	$(10.2 \pm 3.9) \times 10^{-2}$ rad	[4]
A_{CP}^{Ξ}	$(6.0 \pm 13.4 \pm 5.6) \times 10^{-3}$	–	
$\Delta\phi_{CP}^{\Xi}$	$(-4.8 \pm 13.7 \pm 2.9) \times 10^{-3}$ rad	–	
A_{CP}^{Λ}	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-2.5 \pm 4.6 \pm 1.1) \times 10^{-3}$	[3]
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad		

[1] [PRD93(2016)072003] [2] [PTEP2020(2020)083C01] [3] [PRL129(2022)131801] [4] [PRL93(2004)011802]

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+$, $\Xi^- \to \Lambda(\to p\pi^-)\pi^-$+c.c. (2)

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- First measurement of Ξ^- polarisation at e^+e^- collider
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  - Excellent agreement with previous BESIII results

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- Two independent CP tests
- First measurement of weak phase difference

$(\xi_P-\xi_S)_{\rm SM} = (-2.1\pm1.7)\cdot10^{-4}$ rad [PRD105(2022)116022]

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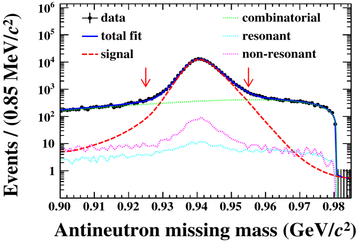
$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+ \to (\Lambda(p\pi^-)\pi^-)(\bar{\Lambda}(\bar{n}\pi^0)\pi^+)$+c.c. (1)

[PRL132(2024)101801]

- Data sample: $10^{10} J/\psi$
- $144 \cdot 10^3$ and $123 \cdot 10^3$ events for $(p2\pi^-)(\bar{n}\pi^0\pi^+)$ and $(n\pi^0\pi^-)(\bar{p}2\pi^+)$, respectively
- Result is consistent with $\Xi^-\bar{\Xi}^+ \to (p2\pi^-)(\bar{p}2\pi^+)$

  [Nature 606(2022)64]



Parameters	This work	Previous result
α_0/α_-	$0.877 \pm 0.015^{+0.014}_{-0.010}$	1.01 ± 0.07 [1]
$\bar{\alpha}_0/\alpha_+$	$0.863 \pm 0.014^{+0.012}_{-0.008}$	$0.913 \pm 0.028 \pm 0.012$ [2]

[1] [PTEP2022(2022)083C01] [2] [Nature Phys.15(2019)631] [3] [PRL129(2022)131801]

$$A_{CP}^{-} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = -0.007 \pm 0.008^{+0.002}_{-0.003}$$ *[3]

$$A_{CP}^{0} = \frac{\alpha_0 + \bar{\alpha}_0}{\alpha_0 - \bar{\alpha}_0} = 0.001 \pm 0.009^{+0.005}_{-0.007}$$

$$A_{CP}^{\Lambda} = (2A_{CP}^{-} + A_{CP}^{0})/3 = -0.004 \pm 0.007^{+0.003}_{-0.004}$$

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+ \to (\Lambda(p\pi^-)\pi^-)(\bar{\Lambda}(\bar{n}\pi^0)\pi^+)$+c.c. (2)

[PRL132(2024)101801]

- If CP is conserved, $\alpha_-\alpha_\Xi = \alpha_+\bar{\alpha}_\Xi$ and $R(\cos\theta_i, \cos\theta_{\bar{i}}) = \frac{1+\alpha_-\alpha_\Xi\cos\theta_i}{1+\alpha_+\alpha_{\bar{\Xi}}\cos\theta_{\bar{i}}}$ with $i = \{p, n\}$ are flat and equal to unity
- If no $\Delta I = 3/2$ transition in Λ decay, $\alpha_- = \alpha_0$ and $R(\cos\theta_{\overset{(-)}{n}}, \cos\theta_{\overset{(-)}{p}}) = \frac{1+\overset{(-)}{\alpha}_0\overset{(-)}{\alpha}_\Xi\cos\theta_{\overset{(-)}{n}}}{1+\overset{(-)}{\alpha}_-\overset{(-)}{\alpha}_\Xi\cos\theta_{\overset{(-)}{p}}}$ are flat and equal to unity

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  $i = \{p, n\}$ are flat and equal to unity

- Consistent with CP symmetry test
  $R_1 = \frac{1+\alpha_\Lambda\alpha_\Xi \cos\theta}{1+\bar{\alpha}_\Lambda\bar{\alpha}_\Xi \cos\theta}$ with $\alpha_\Lambda = (2\alpha_- + \alpha_0)/3$

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  are flat and equal to unity

- Indication of $\Delta I = 3/2$ contribution
  in Λ decay
  $R_2 = \frac{1+\langle\alpha_0\rangle\langle\alpha_\Xi\rangle \cos\theta}{1+\langle\alpha_-\rangle\langle\alpha_\Xi\rangle \cos\theta}$

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+ \to (\Lambda(p\pi^-)\pi^-)(\bar{\Lambda}(\bar{n}\pi^0)\pi^+)$+c.c. (2)

[PRL132(2024)101801]

- If CP is conserved,
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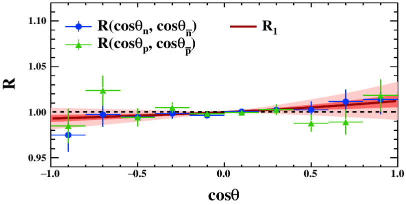

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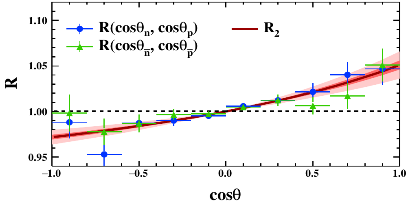

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$(\Delta I = 3/2)/(\Delta I = 1/2)$
in S wave: $0.0349 \pm 0.0017^{+0.0012}_{-0.0013} \pm 0.0047$
in P wave: $-0.0752 \pm 0.0078^{+0.0067}_{-0.0062} \pm 0.0044$

constraint for lQCD [PRD102(2020)054509] and dual QCD [EPJC74(2014)2871] approach

$e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0$, $\Xi^0 \to \Lambda(\to p\pi^-)\pi^0$+c.c.

[PRD108(2023)L031106]

- Data sample: $10^{10} J/\psi$
- $3.3 \cdot 10^5$ events with 2% bkg
- First measurement of Ξ^0 polarisation
- Improved measurement:
  - All $\Xi^0\bar{\Xi}^0$ decay parameters
  - Weak phase difference
  - Two independent CP tests

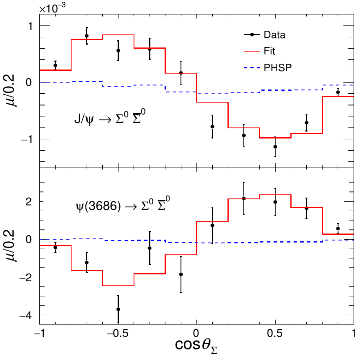
Parameter	This work	Previous result	
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$	0.66 ± 0.06	[1]
$\Delta\Phi(\text{rad})$	$1.168 \pm 0.019 \pm 0.018$	-	
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$	-0.358 ± 0.044	[2]
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$	0.363 ± 0.043	[2]
$\phi_\Xi(\text{rad})$	$0.0051 \pm 0.0096 \pm 0.0018$	0.03 ± 0.12	[2]
$\bar{\phi}_\Xi(\text{rad})$	$-0.0053 \pm 0.0097 \pm 0.0019$	-0.19 ± 0.13	[2]
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$	0.7519 ± 0.0043	[3]
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$	-0.7559 ± 0.0047	[3]
$\xi_P - \xi_S(\text{rad})$	$(0.0 \pm 1.7 \pm 0.2) \times 10^{-2}$	-	
$\delta_P - \delta_S(\text{rad})$	$(-1.3 \pm 1.7 \pm 0.4) \times 10^{-2}$	-	
A^{Ξ}_{CP}	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$	$(-0.7 \pm 8.5) \times 10^{-2}$	[2]
$\Delta\phi^{\Xi}_{CP}(\text{rad})$	$(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$	$(-7.9 \pm 8.3) \times 10^{-2}$	[2]
A^{Λ}_{CP}	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$	$(-2.5 \pm 4.8) \times 10^{-3}$	[3]
$\langle\alpha_\Xi\rangle$	$-0.3770 \pm 0.0024 \pm 0.0014$	-	
$\langle\phi_\Xi\rangle(\text{rad})$	$0.0052 \pm 0.0069 \pm 0.0016$	-	
$\langle\alpha_\Lambda\rangle$	$0.7499 \pm 0.0029 \pm 0.0013$	0.7542 ± 0.0026	[3]

[1] [PLB770(2017)217] [3] [PRL129(2022)131801]

[2] [PRD108(2023)L011101] $\psi(2S) \to \Xi^0\bar{\Xi}^0$, $0.45 \cdot 10^9 \psi(2S)$, $N_{sig} \sim 2 \cdot 10^3$ with 1.2% bkg

$e^+e^- \to J/\psi, \psi(2S) \to \Sigma^0\bar{\Sigma}^0 \to (\Lambda\gamma)(\bar{\Lambda}\gamma)$

[arXiv:2406.06118]



- Data sample:
  - $10^{10} J/\psi$ with $N_{sig} \sim 1.1 \cdot 10^6$
  - $2.7 \cdot 10^9 \psi(2S)$ with $N_{sig} \sim 52 \cdot 10^3$

Parameters	This work	Previous result[1]
$\alpha_{J/\psi}$	$-0.4133 \pm 0.0035 \pm 0.0077$	-0.449 ± 0.022
$\Delta\Phi_{J/\psi}$ [rad]	$-0.0828 \pm 0.0068 \pm 0.0033$	–
$\alpha_{\psi(2S)}$	$0.814 \pm 0.028 \pm 0.028$	0.71 ± 0.12
$\Delta\Phi_{\psi(2S)}$ [rad]	$0.512 \pm 0.085 \pm 0.034$	–
α_{Σ^0}	$-0.0017 \pm 0.0021 \pm 0.0018$	–
$\bar{\alpha}_{\Sigma^0}$	$0.0021 \pm 0.0020 \pm 0.0022$	–

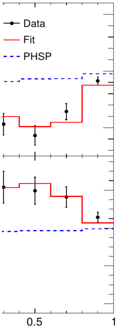
First result (first four rows)

First result (last two rows)

[1] [PRD95(2017)052003]

$e^+e^- \to J$

2406.06118]



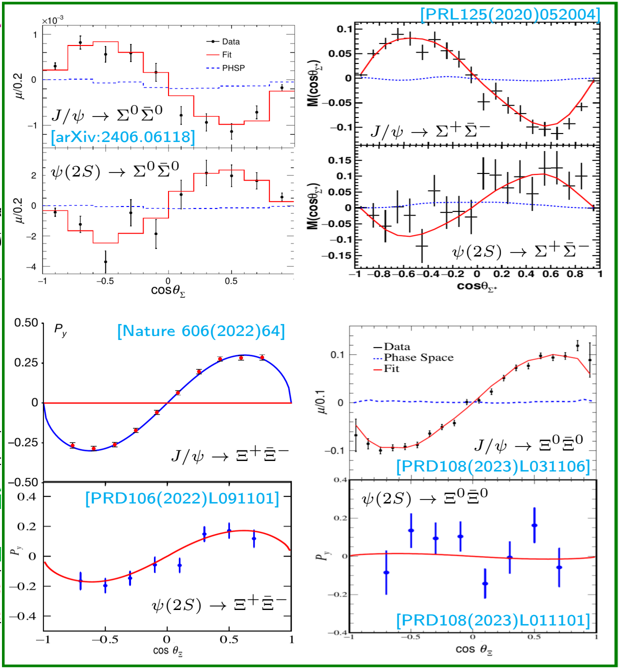
- Data sample
  - 10^{10} J
  - $2.7 \cdot 1$

Par	lt[1]
α_J	022
$\Delta\Phi$	
α_ψ	2
$\Delta\Phi$	
α_Σ	
$\bar{\alpha}_\Sigma$	

First result

First result

52003]



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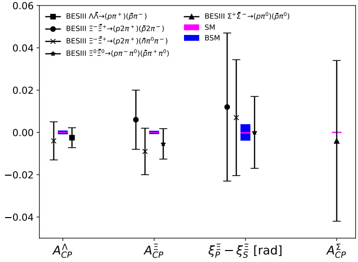
  - CP tests comparing hyperon and antihyperon
    - Separation of strong and weak decay phases $\Longrightarrow$ more sensitive CP tests



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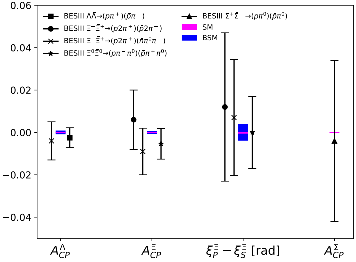

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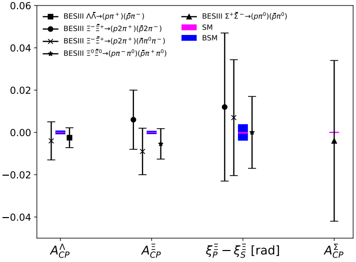

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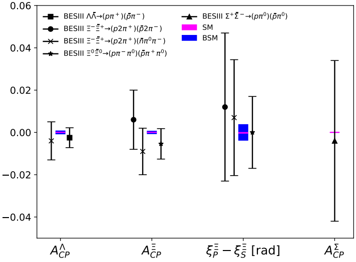

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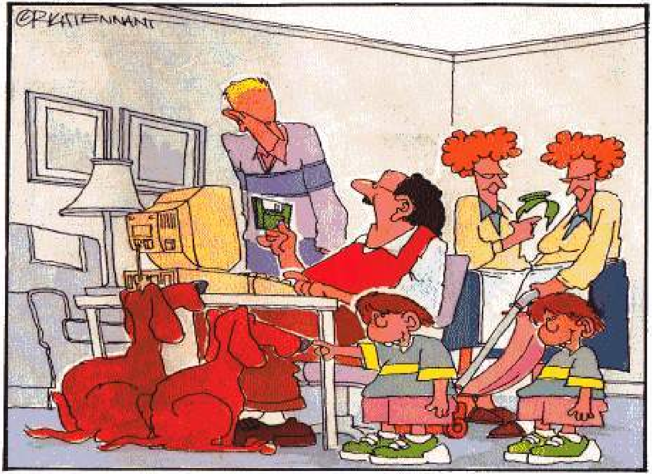
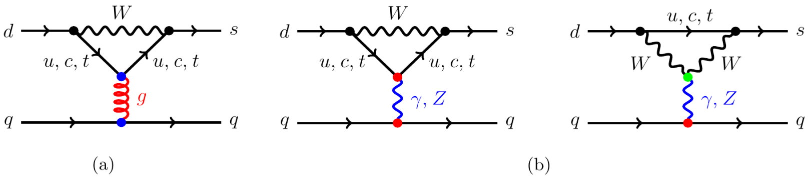
Stay tuned!

Backups



" I ALWAYS BACK UP EVERYTHING."

Complementarity of hyperon and kaon decays



$$(\xi_P - \xi_S)_{\mathrm{BSM}} = \frac{C'_B}{B_G}\left(\frac{\epsilon'}{\epsilon}\right)_{\mathrm{BSM}} + \frac{C_B}{\kappa}\epsilon_{\mathrm{BSM}}$$

[PRD69(2004)076008]

- BSM predictions [PRD105(2022)116022]

$$|A_\Lambda + A_\Xi| \leq 11 \cdot 10^{-4}$$

Decay mode	$\lvert\xi_P - \xi_S\rvert$ [rad]	C_B	C'_B
$\Lambda \to p\pi^-$	$\leq 5.3 \cdot 10^{-3}$	0.9 ± 1.8	0.4 ± 0.9
$\Xi^- \to \Lambda\pi^-$	$\leq 3.7 \cdot 10^{-3}$	-0.5 ± 1.0	0.4 ± 0.7

with $0.5 < B_G < 2$ and $0.2 < |\kappa| < 1$ [PRD61(2000)071701]
$|\epsilon'/\epsilon|_{\mathrm{BSM}} \leq 1 \cdot 10^{-3}$ and $|\epsilon|_{\mathrm{BSM}} \leq 2 \cdot 10^{-4}$ [JHEP12(2020)097]