Light Hyperon Physics at BESIII

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Abstract

The BESIII experiment at the electron positron collider BECPII in Beijing is successfully operating since 2008 and has collected large data samples in the tau-mass region, including the world's largest data samples: 10 Billion J/ψ and 3 Billion ψ(3686).

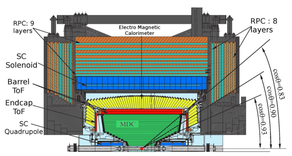
The recent observation of hyperon polarizations at BESIII opens a new window for testing CP conservation, as it allows for simultaneous production and detection of hyperon and anti-hyperon pair two body weak decays. The CP-symmetry tests can be performed in processes of Λ, Σ, Ξ pair production.

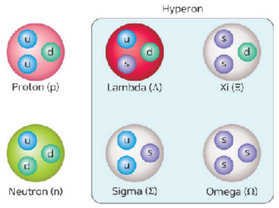
For the Ξ decay, it is possible to perform three independent CP tests and determine the strong phase and weak phase difference.

Introduction

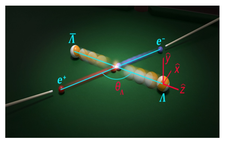
Update of BEPC (started 2004, first collisions July 2008)

Beam energy	1 - 2.47 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	11mrad
Design luminosity	1×10^{33} cm^{-2} s^{-1}
Achieved	1×10^{33} cm^{-2} s^{-1}





Hyperons are a laboratory for strong interaction and baryon structure.



Hyperon pair production could be used to study the polarization, decay parameter and CP test.

Decay	$\mathcal{B}$ (10^{-5})	Events at BESIII
$J/\psi \to \Lambda\bar{\Lambda}$	189 ± 9	18.9×10^6
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	150 ± 24	15.0×10^6
$J/\psi \to \Xi\bar{\Xi}$	97 ± 8	9.7×10^6
$\psi(2S) \to \Sigma\bar{\Sigma}$	23.2 ± 1.2	116×10^3
$\psi(2S) \to \Omega\bar{\Omega}$	5.66 ± 0.30	28×10^3

Methodology

Unpolarized e^+e^- beams → Transverse polarization: [1]

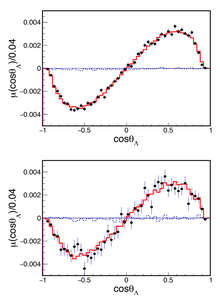
$$P_y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

$$d\sigma \propto \mathcal{W}(\boldsymbol{\xi})d\boldsymbol{\xi} \qquad \boldsymbol{\xi} = (\theta, \theta_p, \phi_p, \theta_{\bar{p}}, \phi_{\bar{p}})$$

$$\mathcal{W}(\boldsymbol{\xi}) = \mathcal{T}_0(\boldsymbol{\xi}) + \alpha_\psi\mathcal{T}_5(\boldsymbol{\xi}) \quad \text{SPIN CORRELATIONS}$$
$$-\alpha_0\bar{\alpha}_0\left(\mathcal{T}_1(\boldsymbol{\xi}) + \sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi}) + \alpha_\psi\mathcal{T}_6(\boldsymbol{\xi})\right)$$
$$+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\left(\alpha_0\mathcal{T}_3(\boldsymbol{\xi}) - \bar{\alpha}_0\mathcal{T}_4(\boldsymbol{\xi})\right). \quad \text{POLARIZATIONS}$$

Results

$J/\psi \to \Lambda\bar{\Lambda}$ [2]



$<\alpha>=\frac{\alpha-\bar{\alpha}}{2} = 0.754 \pm 0.003 \pm 0.002$

CLAS: $\alpha_\Lambda = 0.721 \pm 0.006 \pm 0.005$
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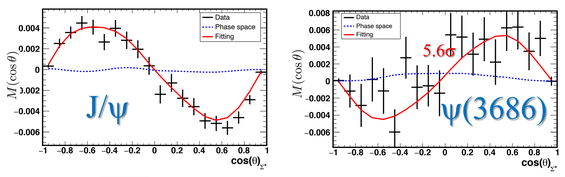
Parameters	This work	Previous results
α_ψ	$\mathbf{0.461 \pm 0.006 \pm 0.007}$	0.469 ± 0.027 BESIII
$\Delta\Phi$ (rad)	$\mathbf{0.740 \pm 0.010 \pm 0.008}$	–
α_Λ	$\mathbf{0.750 \pm 0.009 \pm 0.004}$	0.642 ± 0.013 PDG
$\bar{\alpha}_\Lambda$	$\mathbf{-0.758 \pm 0.010 \pm 0.007}$	-0.71 ± 0.08 PDG

J/ψ and $\psi(3686) \to \Sigma^+\bar{\Sigma}^-$ [3]



$$\frac{dM}{d\cos\theta} \sim \sqrt{1-\alpha_\psi^2}\alpha_0\sin\Delta\Phi\cos\theta\sin\theta \qquad M(\cos\theta) = (m/N)\sum_i^{N_k}(\sin\theta_p^i\cos\phi_p^i - \sin\theta_{\bar{p}}^i\cos\phi_{\bar{p}}^i)$$

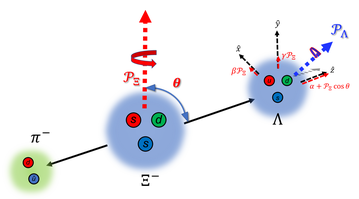
Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
δ_0	$0.990 \pm 0.037 \pm 0.011$

The points with error bars are the data, and the solid-line histogram is the global fit result. The dotted histogram is phase space model.

CP asymmetry $-0.004 \pm 0.037 \pm 0.010$
average decay asymmetry $-0.994 \pm 0.004 \pm 0.002$

Results

$J/\psi \to \Xi^-\bar{\Xi}^+$ [4]

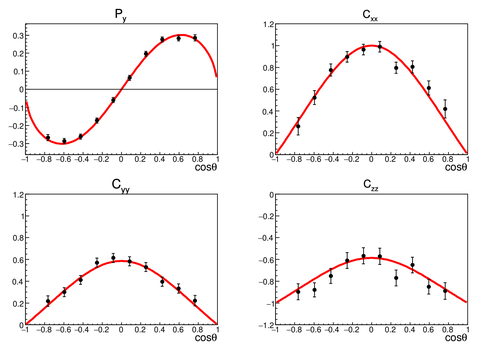


$$W = \sum_{\mu,\bar{\nu}=0}^{3} C_{\mu\bar{\nu}} \sum_{\mu',\bar{\nu}'=0}^{3} a^{\Xi}_{\mu,\mu'} a^{\bar{\Xi}}_{\bar{\nu},\bar{\nu}'} a^{\Lambda}_{\mu',0} a^{\bar{\Lambda}}_{\bar{\nu}',0}$$

$d\Gamma \propto W(\xi,\omega)$, ξ: 9 kin. variables
8 parameters:

$$\omega = (\underbrace{\alpha_\psi, \Delta\Phi}_{\text{Production}}, \underbrace{\alpha_\Xi, \phi_\Xi, \alpha_\Lambda, \bar{\alpha}_\Xi, \bar{\phi}_\Xi, \bar{\alpha}_\Lambda}_{\text{Decay}})$$

With the quantum entangled system, if there is polarization, the decay parameters of the hyperon pair are correlated, which allows a controlled and precise test of CP-symmetry.



Polarization and spin correlations in the $J/\psi \to \Xi^-\bar{\Xi}^+$

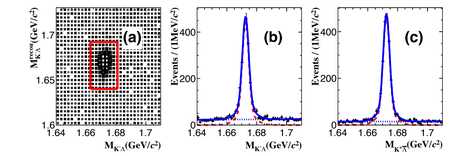
Parameter	This work	Previous result	
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	[39]
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	[21]
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad	-0.037 ± 0.014 rad	[21]
$\bar{\alpha}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	–	
$\bar{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007$ rad	–	
α_Λ	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$	[14]
$\bar{\alpha}_\Lambda$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$	[14]
$\xi_P - \xi_S$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ 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	[17]
A^{Ξ}_{CP}	$(6.0 \pm 13.4 \pm 5.6) \times 10^{-3}$	–	
$\Delta\Phi^{\Xi}_{CP}$	$(-4.8 \pm 13.7 \pm 2.9) \times 10^{-3}$ rad	–	
A^{Λ}_{CP}	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$	[14]
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad		

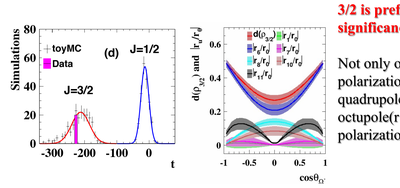
Independent measurement of α_Λ
First measurement of weak phase difference!
3 CP test

Results

$\psi(3686) \to \Omega^-\bar{\Omega}^+$ [5]

- The spin of Ω^- J = 3/2 has never been unambiguously confirmed by experiments directly.
- Polarization of the Ω^- can be studied with the Ω^- weak decay chains, and decay parameters could be measured.
- Helicity amplitude method is used.





3/2 is preferred over 1/2 with significance more than 14σ

Not only observe vector polarization(r1), but also quadrupole (r6, r7, r8) and octupole(r10, r11) polarizations

$Br(\psi(3686) \to \Omega^+\Omega^-) = (5.85 \pm 0.12 \pm 0.25) \times 10^{-5}$
$\alpha = 0.24 \pm 0.10$

Conclusion

Hyperons are an important probe to study QCD and fundamental symmetries.

10 Billion J/ψ data and 3 Billion ψ(3686) data will bring more exciting results in the future.

More results of hyperons studies will come soon.

Reference

[1]. Fäldt, G. and Kupsc, A, Phys. Lett. B 772, 16 (2017)
[2]. Ablikim Medina et al. BESIII Collaboration, Nature Phys. 15 (2019) 631
[3]. Ablikim Medina et al. BESIII Collaboration, Phys. Rev. Lett. 125, 052004 (2020)
[4]. Ablikim Medina et al. BESIII Collaboration, arXiv:2105.11155
[5]. Ablikim Medina et al. BESIII Collaboration, Phys. Rev. Lett. 126, 092002 (2021)