CP symmetry tests in hyperon weak decays at BESIII

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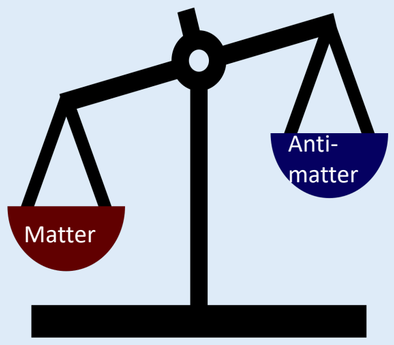
Introduction

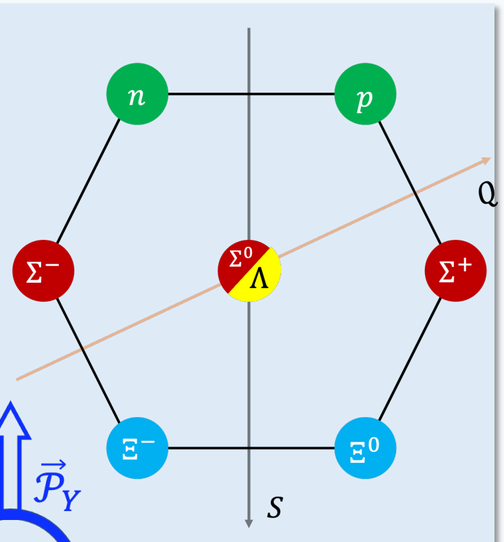
- We live in a Universe made of matter with almost no anti-matter, why?
- We test CP symmetry in hyperon two body weak decays — a new method to probe differences between matter and antimatter with an unprecedent sensitivity.

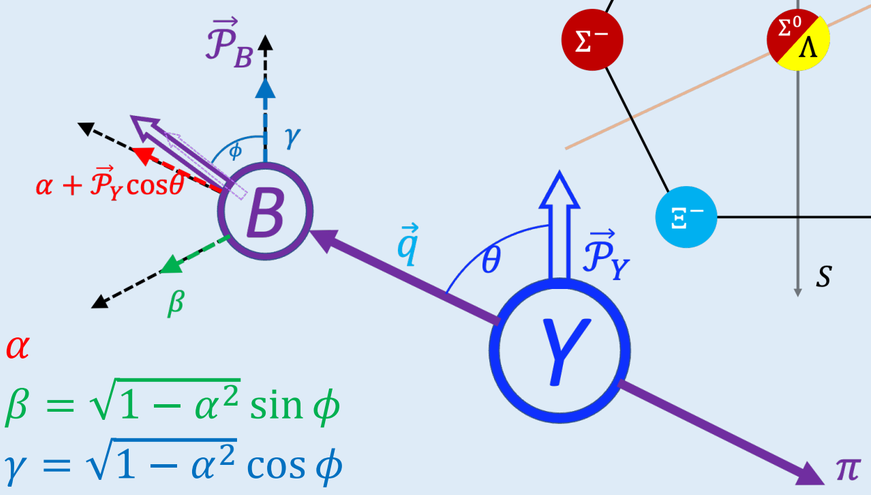


Hyperon Decay

- Decay process

$$\begin{cases} J/\psi \to Y\bar{Y} \\ Y \to B\pi \end{cases} \Rightarrow \begin{cases} 1^{--} \to 1/2^{+}1/2^{-} \\ 1/2^{+} \to 1/2^{+}0^{-} \end{cases}$$





α

$\beta = \sqrt{1-\alpha^2}\sin\phi$

$\gamma = \sqrt{1-\alpha^2}\cos\phi$

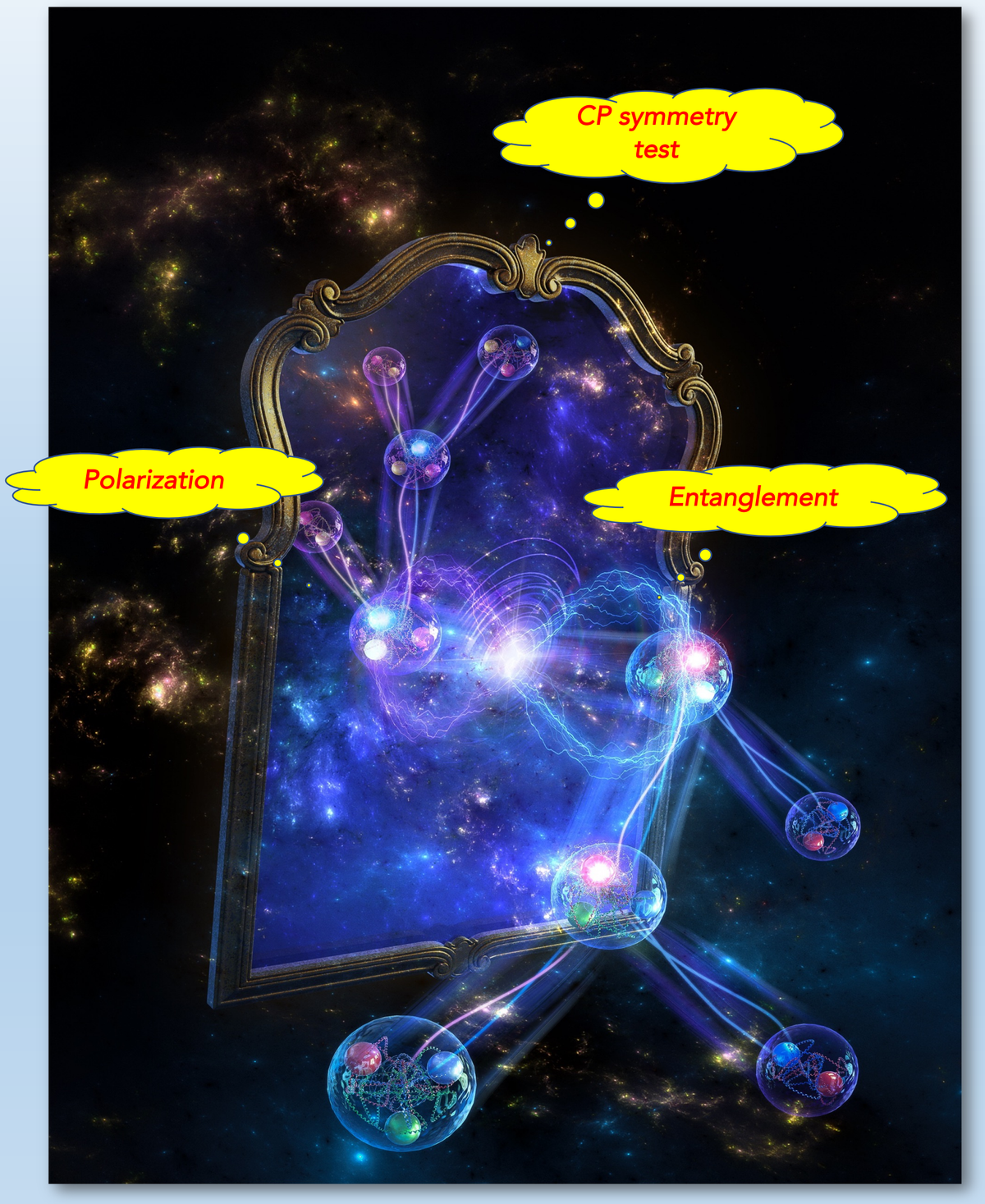
- CP observables require interference between S-wave and P-wave

$$S = |S|e^{i\delta_S}e^{i\xi_S} \qquad P = |P|e^{i\delta_P}e^{i\xi_P}$$

δ strong phase of final state interaction, ξ weak CP-odd phase

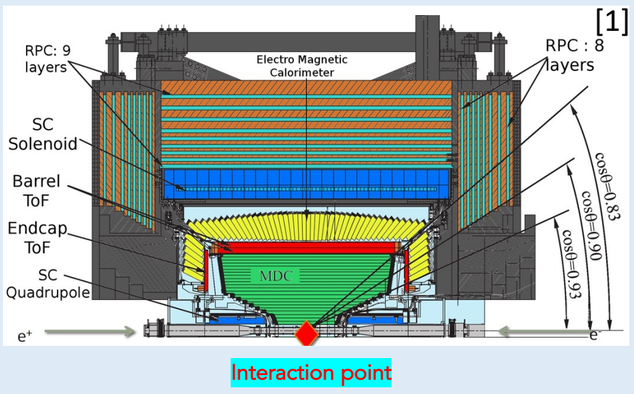
$$A_{CP} = \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} = -\sin\phi\frac{\sqrt{1-\alpha^2}}{\alpha}\tan(\xi_P-\xi_S)$$

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



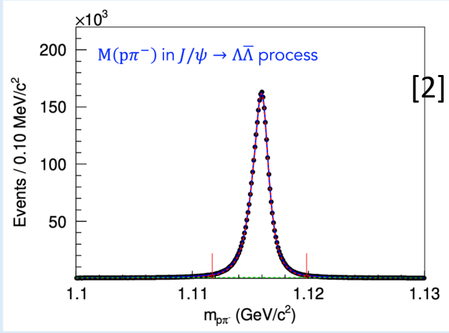
Entanglement in pair-production of hyperons enhances the statistical sensitivity by a factor of ~2.5

Experiment



- Symmetric particle – anti-particle conditions
- Very low background level

- Multipurpose detector with 4π angular coverage
- World's largest J/ψ data set collected at 2009, 2012, 2018 and 2019



High purity of 99.9%

Method

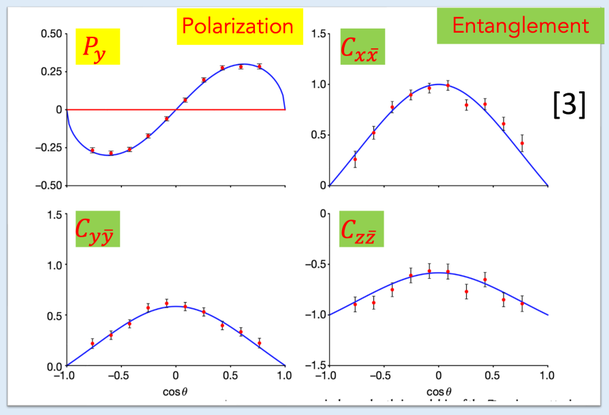
- Maximum log likelihood Fit
- Decay chain

$J/\psi \to Y\bar{Y}$, $Y \to B\pi$, $\bar{Y} \to \bar{B}\pi$, $Y' \to B\pi$, $\bar{Y}' \to \bar{B}\pi$

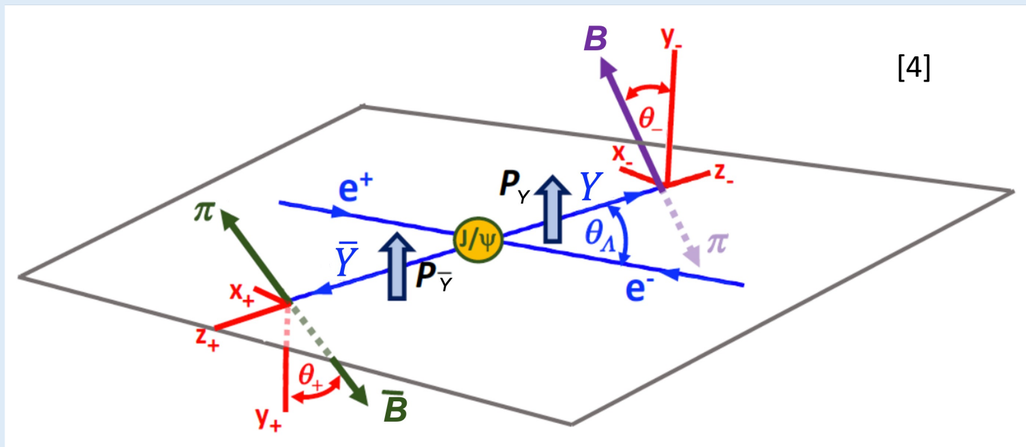
- Angular Amplitude

$$\mathcal{W}(\xi;\Omega) \propto C_{\mu\nu}a^{Y}_{\mu\mu'}a^{\bar{Y}}_{\nu\nu'}a^{Y'}_{\mu'0}a^{\bar{Y}'}_{\nu'0}$$

C: spin density matrix; a: decay matrix



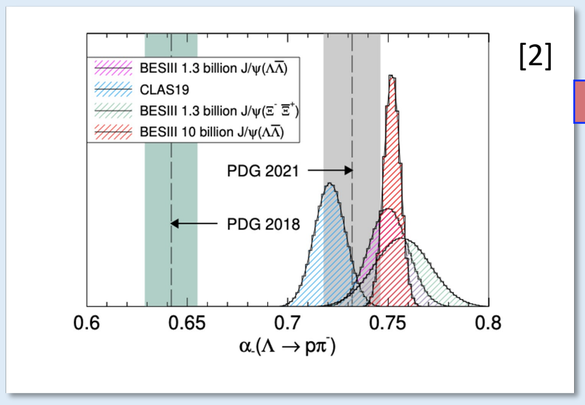
- Angular variables Ω: $\theta_\psi, \theta_Y, \phi_Y, \theta_{\bar{Y}}, \phi_{\bar{Y}}, \theta_{Y'}, \phi_{Y'}, \theta_{\bar{Y}'}, \phi_{\bar{Y}'}$
- Parameters ξ: $\alpha_\psi, \Delta\Phi_\psi, \alpha_Y, \phi_Y, \alpha_{\bar{Y}}, \phi_{\bar{Y}}, \alpha_{Y'}, \alpha_{\bar{Y}'}$

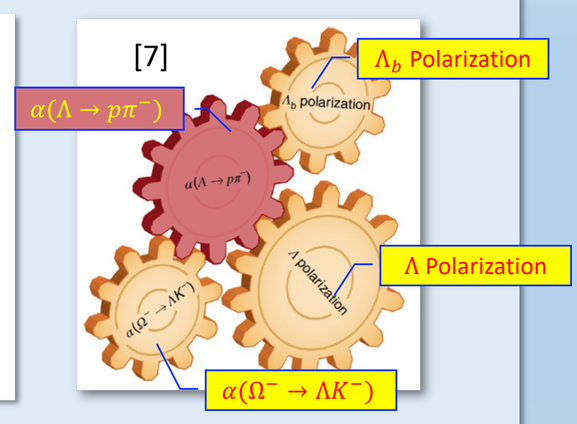


Results

Parameter	$1.3\times10^9 J/\psi$	$1.0\times10^{10} J/\psi$
$\Lambda \to p\pi^-, c.c.$ [2,5]		
$\langle\alpha_\Lambda^-\rangle$	$0.754 \pm 0.003 \pm 0.002$	$0.7542 \pm 0.0010 \pm 0.0020$
A_{CP}^{Λ}	$0.006 \pm 0.012 \pm 0.007$	$-0.0025 \pm 0.0046 \pm 0.0011$
$\Sigma^+ \to p\pi^0, c.c.$ [6]		
$\langle\alpha_\Sigma\rangle$	$-0.994 \pm 0.004 \pm 0.002$	on-going
A_{CP}^{Σ}	$-0.004 \pm 0.037 \pm 0.010$	
$\Xi^- \to \Lambda(\to p\pi^-)\pi^-, c.c.$ [3]		
$\langle\phi_\Xi\rangle$ (rad)	$0.016 \pm 0.014 \pm 0.007$	on-going
$\langle\alpha_\Xi\rangle$	$-0.373 \pm 0.005 \pm 0.002$	
$\langle\alpha_\Lambda\rangle^1$	$0.760 \pm 0.006 \pm 0.003$	
$\xi_P - \xi_S$ (rad)	$(1.2 \pm 3.4 \pm 0.8)\times10^{-2}$	
$\delta_P - \delta_S$ (rad)	$(-4.0 \pm 3.3 \pm 1.7)\times10^{-2}$	
A_{CP}^{Ξ}	$(6 \pm 13 \pm 6)\times10^{-3}$	
$\Delta\phi_{CP}^{\Xi}$ (rad)	$(-5 \pm 14 \pm 3)\times10^{-3}$	
A_{CP}^{Λ}	$(-4 \pm 12 \pm 9)\times10^{-3}$	

[1] has been independently confirmed.





New determination of α_Λ will affect many other physics process

Outlook

- More results of hyperon studies with 10 billion J/ψ events will come soon
  - $\Lambda, \Sigma, \Xi^0, \Xi^-$ Charged and neutral decays

Reference

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2. *arXiv:2204.11058*
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4. *arXiv:2102.13290*
5. *Nature Phys. 15 (2019) 631-634*
6. *Phys. Rev. Lett. 125, 052004*
7. *News & view Nat. Phys.* ***15,*** *624–625 (2019)*