HADRON 2021

19th International Conference on Hadron Spectroscopy and Structure in memoriam Simon Eidelman

Light Hyperon Physics at BESIII

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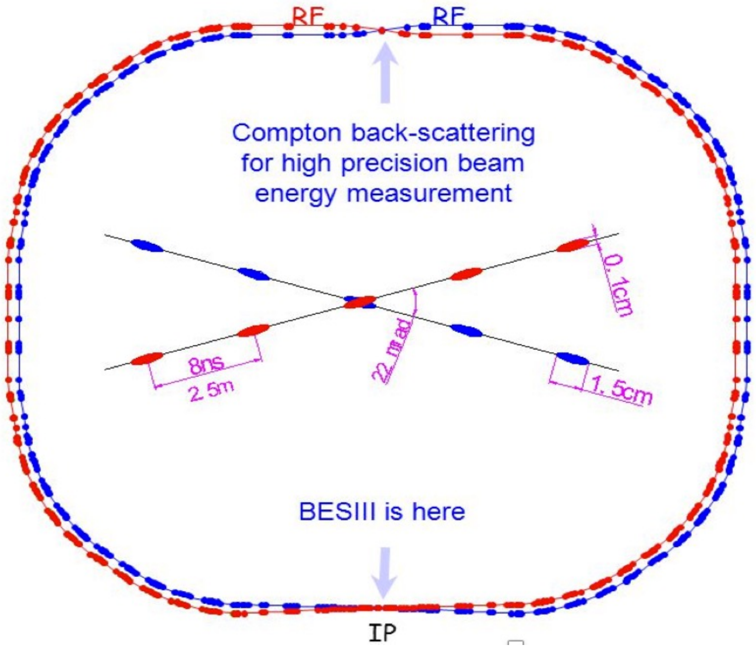
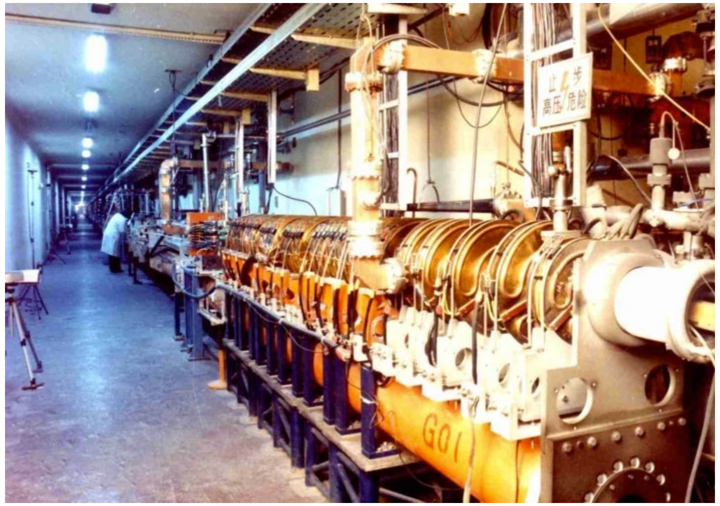
(On behalf of BESIII Collaboration)

Mexico City, 27th July 2021

(online)

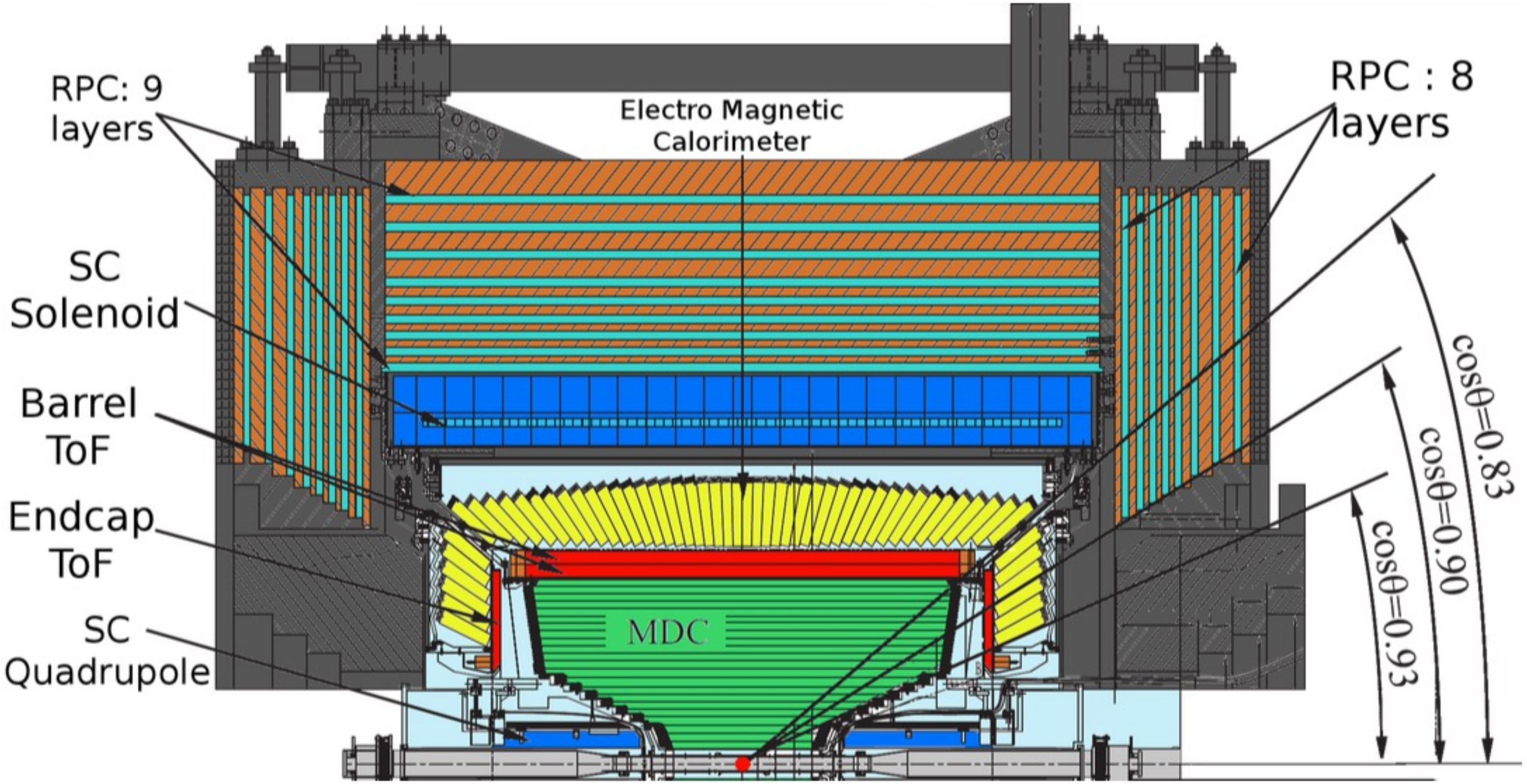
BEPCII storage rings: a τ-charm factory



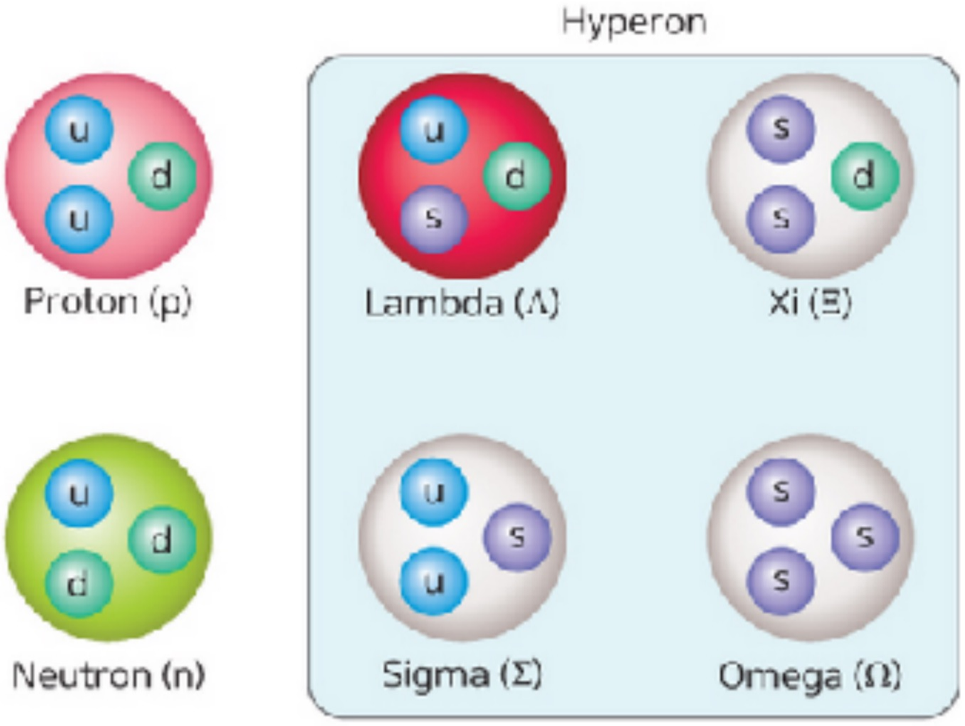


Update of BEPC (started 2004, first collisions July 2008)	
Beam energy	1 - 2.47 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	11mrad
Design luminosity	1×10^{33} cm^{-2} s^{-1}
Achieved	1×10^{33} cm^{-2} s^{-1}

BESIII detectors



- Main Drift Chamber (MDC)
  - $\sigma(p)/p = 0.5\%$
  - $\sigma_{dE/dX} = 5.0\%$
- Time-of-flight (TOF)
  - $\sigma(t) = 68ps$ (barrel)
  - $\sigma(t) = 65ps$ (endcap)
- Electro Magnetic Calorimeter (EMC)
  - $\sigma(E)/E = 2.5\%$
  - $\sigma_{z,\phi}(E) = 0.5 – 0.7$ cm
- RPC MUON Detector
  - $\sigma(xy) < 2$ cm



Hyperons are a laboratory for strong interaction and baryon structure

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

Polarization related work:

- Λ (BESIII Collaboration), Nat. Phys. 15, 631 (2019).
- Σ^+ (BESIII Collaboration), Phys. Rev. Lett. 125, 052004 (2020).
- Ξ^- (BESIII Collaboration), arXiv: 2105.11155.
- Ω (BESIII Collaboration), Phys. Rev Lett. 126, 092002 (2021).

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

Nature Phys. 15 (2019) 631

- Polarization
  - Studies of two-body hyperon weak decays plays an important role in the study of the fundamental symmetries P and CP.
  - The polarization of spin ½ hyperon can be determined in two-body weak decays by $(1 + \alpha_0 \mathbf{P}_{\Sigma^+} \hat{\mathbf{p}}/4\pi)$

Parity violation S state
Parity conservation P state

$$\alpha = \frac{2\,\mathrm{Re}(S^* P)}{|S|^2 + |P|^2}, \quad \beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2}, \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

α, β, γ could be determined experimentally.

T. D. Lee and C. N. Yang, Phys. Rev. 108,1645 (1957)

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

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If the relative phase between hadronic form factor is not zero(Polarized), the decay parameters α_0 and $\bar{\alpha}_0$ could be simultaneous and direct measured, then test CP symmetry.

T. D. Lee and C. N. Yang, Phys. Rev. 108,1645 (1957)

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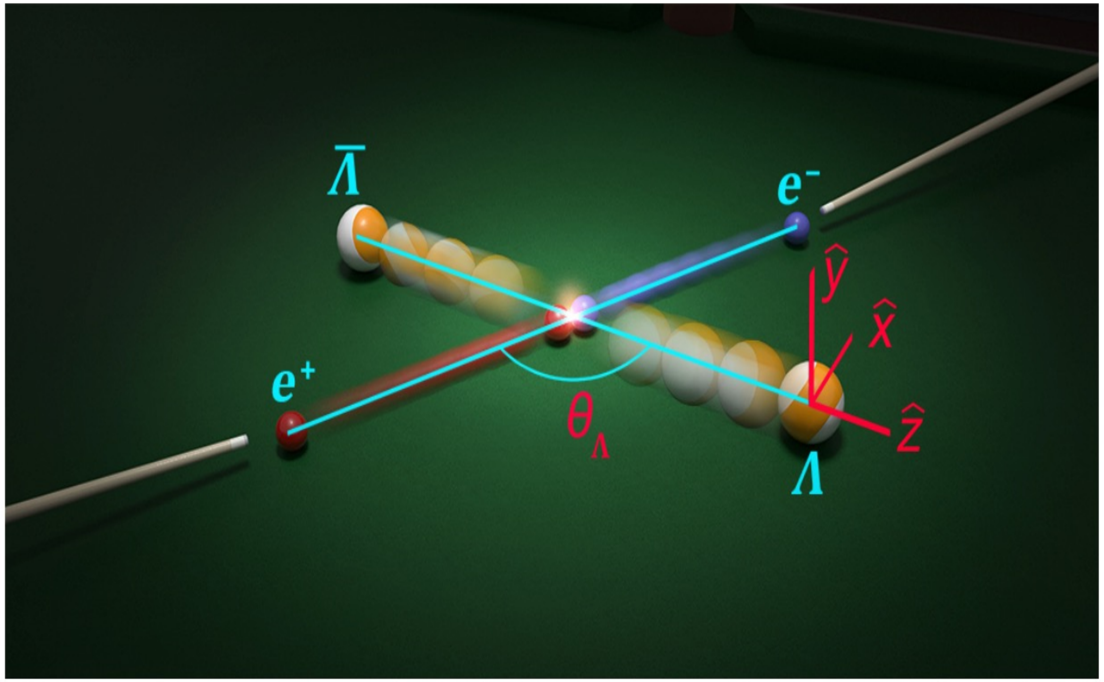


Unpolarized e^+ e^- beams -> Transverse polarization:

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

Formulas

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

Phys. Lett. B 772, 16 (2017)

$$\begin{aligned}\mathcal{W}(\boldsymbol{\xi}) =& \mathcal{T}_0(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_5(\boldsymbol{\xi}) \\ & -\alpha_0\bar{\alpha}_0 \left(\mathcal{T}_1(\boldsymbol{\xi}) + \sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_6(\boldsymbol{\xi})\right) \\ & +\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\left(\alpha_0\mathcal{T}_3(\boldsymbol{\xi}) - \bar{\alpha}_0\mathcal{T}_4(\boldsymbol{\xi})\right)\end{aligned}$$

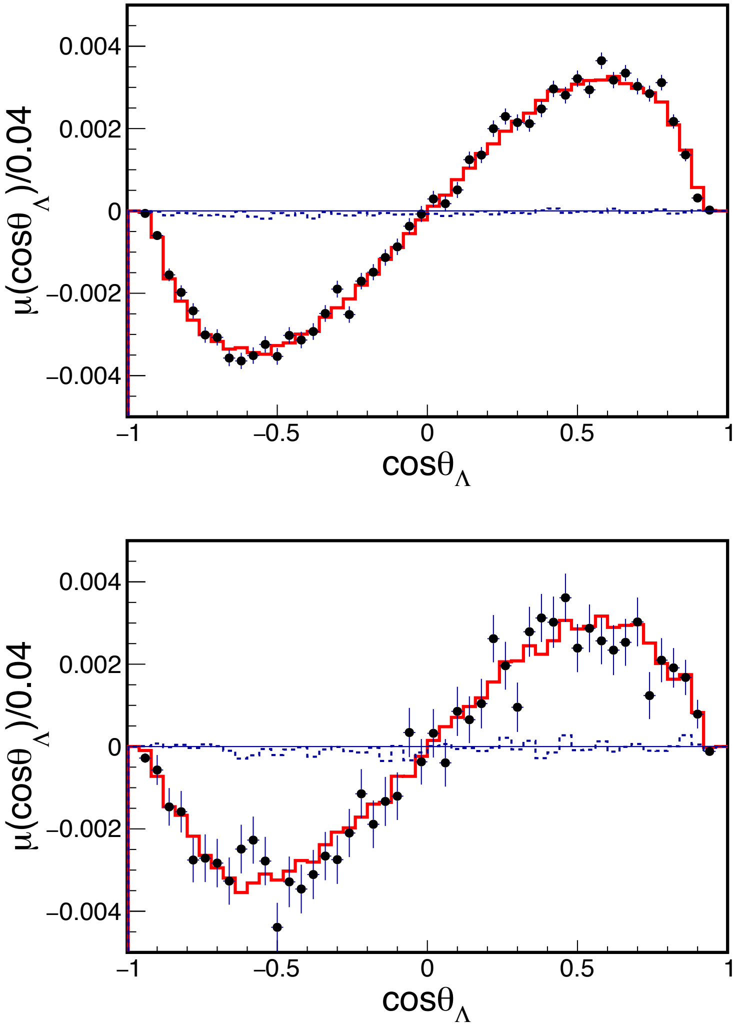
SPIN CORRELATIONS

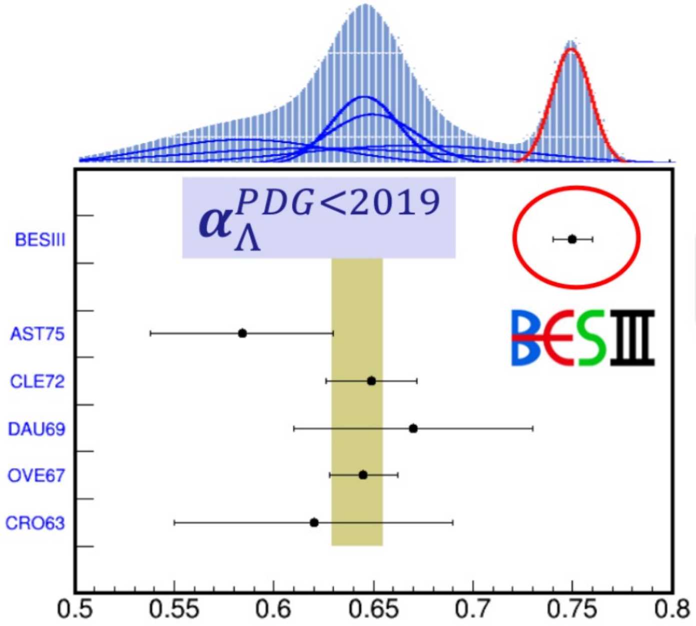
POLARIZATIONS

$$\begin{aligned}\mathcal{T}_0(\boldsymbol{\xi}) =& 1 \\ \mathcal{T}_1(\boldsymbol{\xi}) =& \sin^2\theta \sin\theta_p \sin\theta_{\bar{p}} \cos\phi_p \cos\phi_{\bar{p}} + \cos^2\theta \cos\theta_p \cos\theta_{\bar{p}} \\ \mathcal{T}_2(\boldsymbol{\xi}) =& \sin\theta\cos\theta\left(\sin\theta_p\cos\theta_{\bar{p}}\cos\phi_p + \cos\theta_p\sin\theta_{\bar{p}}\cos\phi_{\bar{p}}\right) \\ \mathcal{T}_3(\boldsymbol{\xi}) =& \sin\theta\cos\theta\sin\theta_p\sin\phi_p \\ \mathcal{T}_4(\boldsymbol{\xi}) =& \sin\theta\cos\theta\sin\theta_{\bar{p}}\sin\phi_{\bar{p}} \\ \mathcal{T}_5(\boldsymbol{\xi}) =& \cos^2\theta \\ \mathcal{T}_6(\boldsymbol{\xi}) =& \cos\theta_p\cos\theta_{\bar{p}} - \sin^2\theta\sin\theta_p\sin\theta_{\bar{p}}\sin\phi_p\sin\phi_{\bar{p}}.\end{aligned}$$

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

Nature Phys. 15 (2019) 631





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

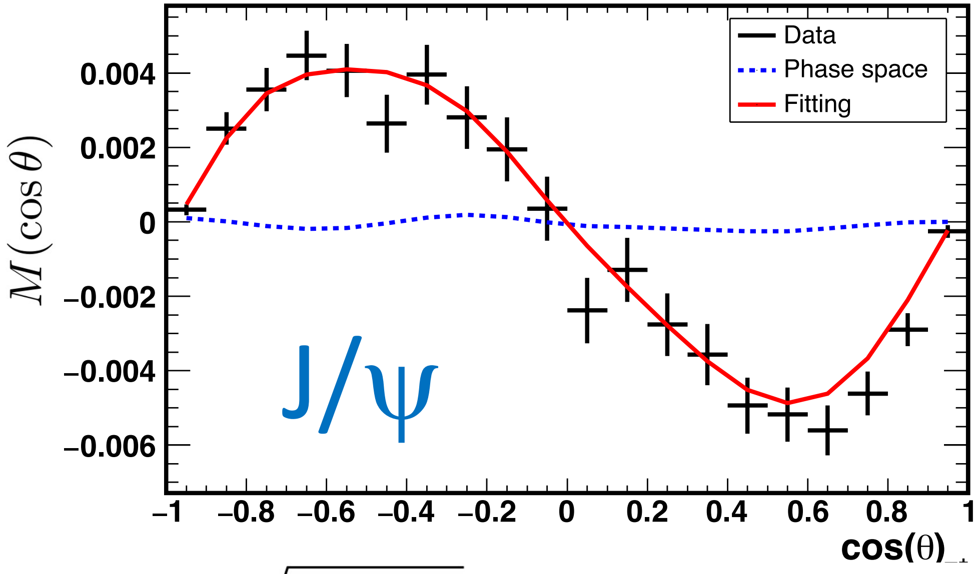
CLAS: $\alpha_\Lambda = 0.721 \pm 0.006 \pm 0.005$

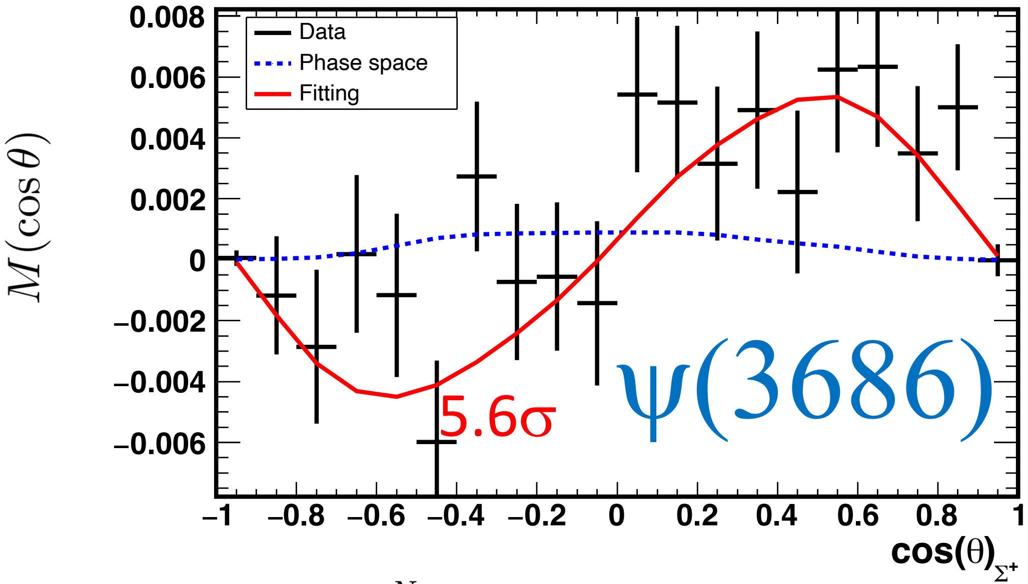
PRL 123 (2019) 182301

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 ψ(3686) ->$\Sigma^+ \bar{\Sigma}^-$

Phys. Rev. Lett. 125, 052004 (2020)





$$\frac{dM}{d\cos\theta} \sim \sqrt{1-\alpha_\psi^2}\alpha_0 \sin\Delta\Phi \cos\theta \sin\theta$$

$$M(\cos\theta) = (m/N)\sum_i^{N_k}(\sin\theta_p^i \cos\phi_p^i - \sin\theta_{\bar{p}}^i \cos\phi_{\bar{p}}^i)$$

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.

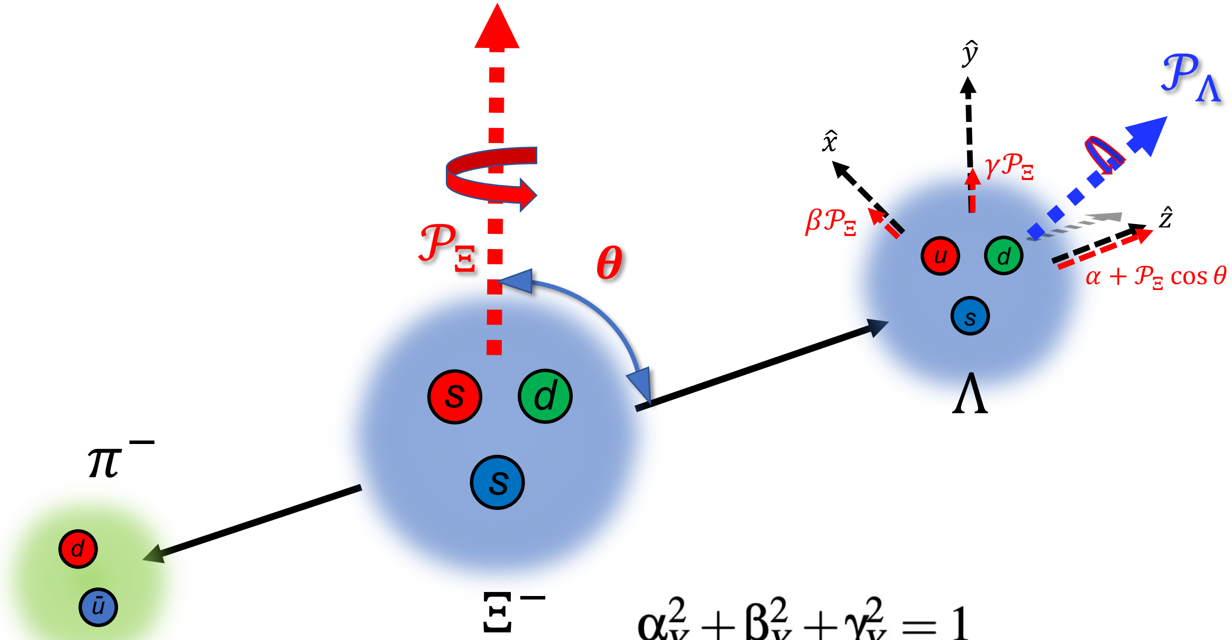
Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

CP asymmetry $-0.004 \pm 0.037 \pm 0.010$

average decay asymmetry $-0.994 \pm 0.004 \pm 0.002$

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

arXiv:2105.11155



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

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

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

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

8 parameters:

Production

$$\omega = (\alpha_\Psi, \Delta\Phi, \alpha_\Xi, \phi_\Xi, \alpha_\Lambda, \bar{\alpha}_\Xi, \bar{\phi}_\Xi, \bar{\alpha}_\Lambda)$$

Decay

There are 73k events (190 background), the 8 parameters are estimated with unbinned MLL fit!

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

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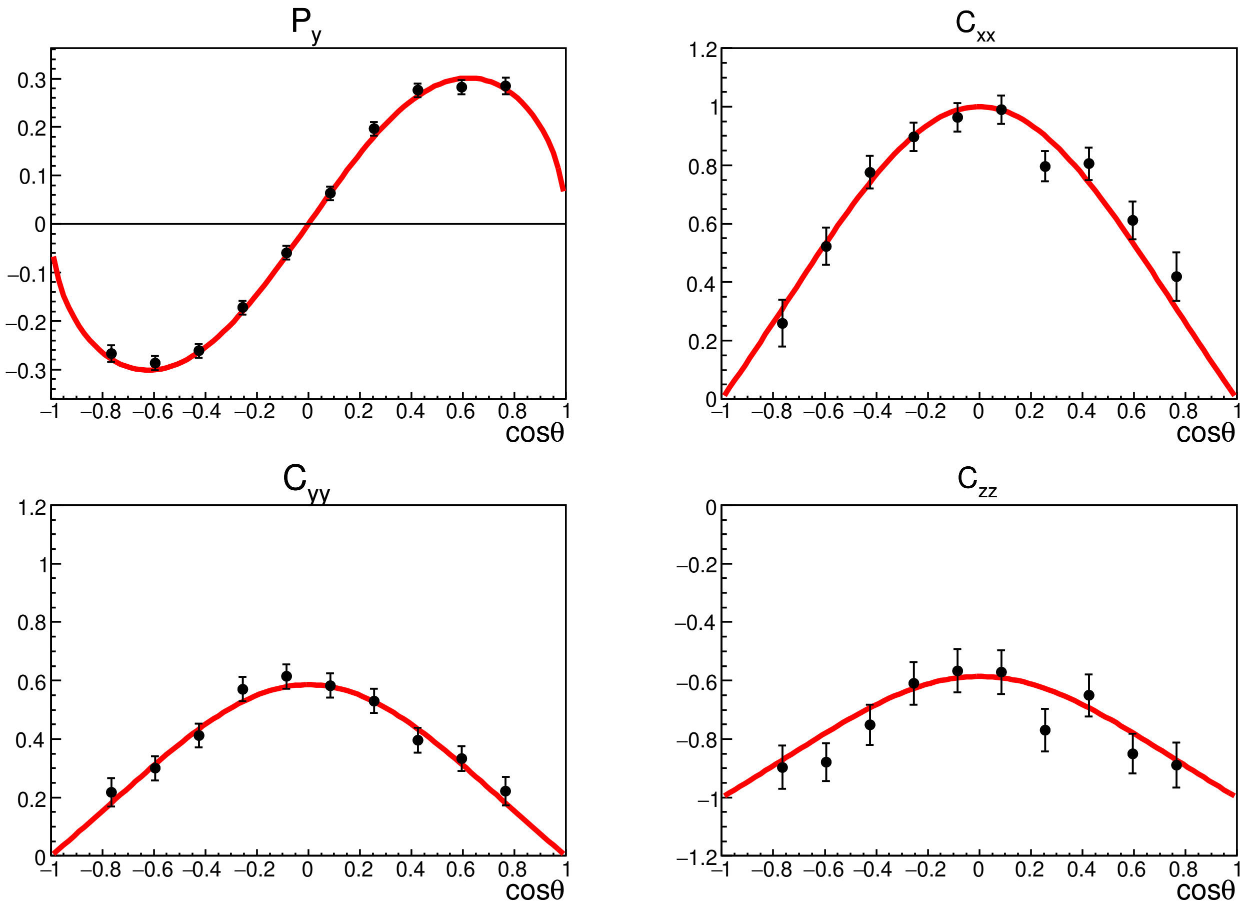


Polarization and spin correlations in the $J/\psi \to \Xi^- \bar{\Xi}^+$

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

arXiv:2105.11155

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_{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}	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$	[14]
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad		

Independent measurement of α_Λ

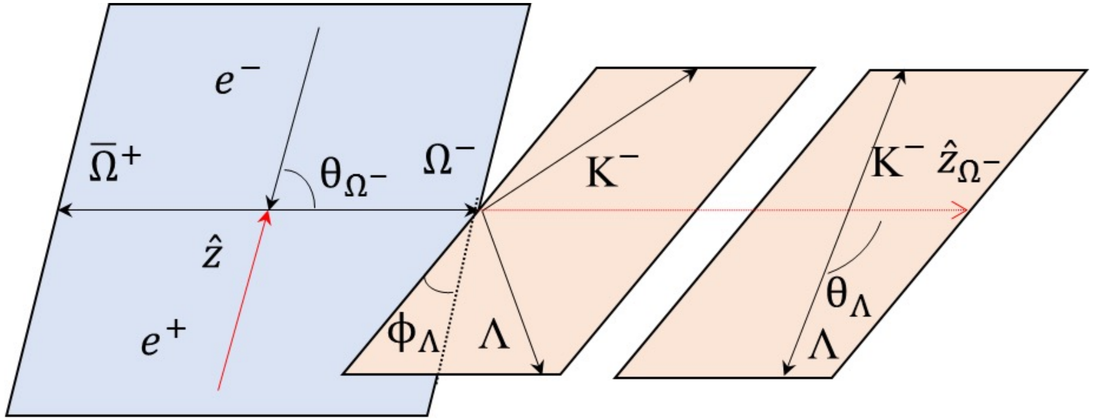
First measurement of weak phase difference!

3 CP test

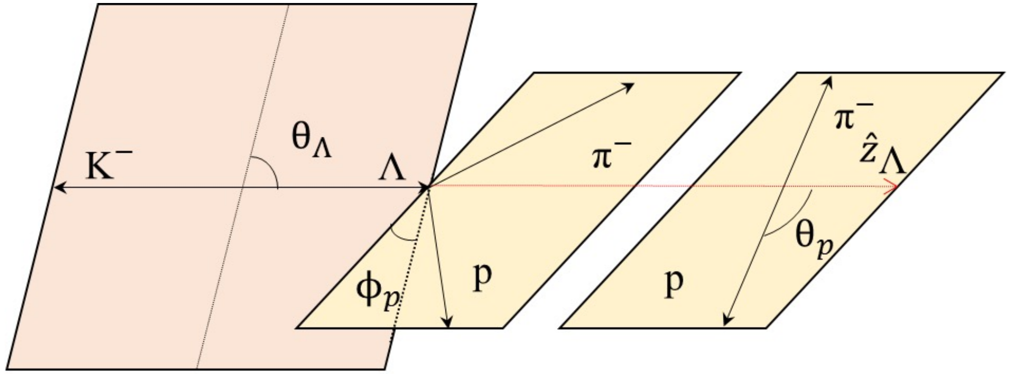
$\psi(3686)$->$\Omega^- \ \Omega^+$

Phys. Rev. Lett. 126, 092002 (2021)

- The spin of Ω^- J= 3/2 has never 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.



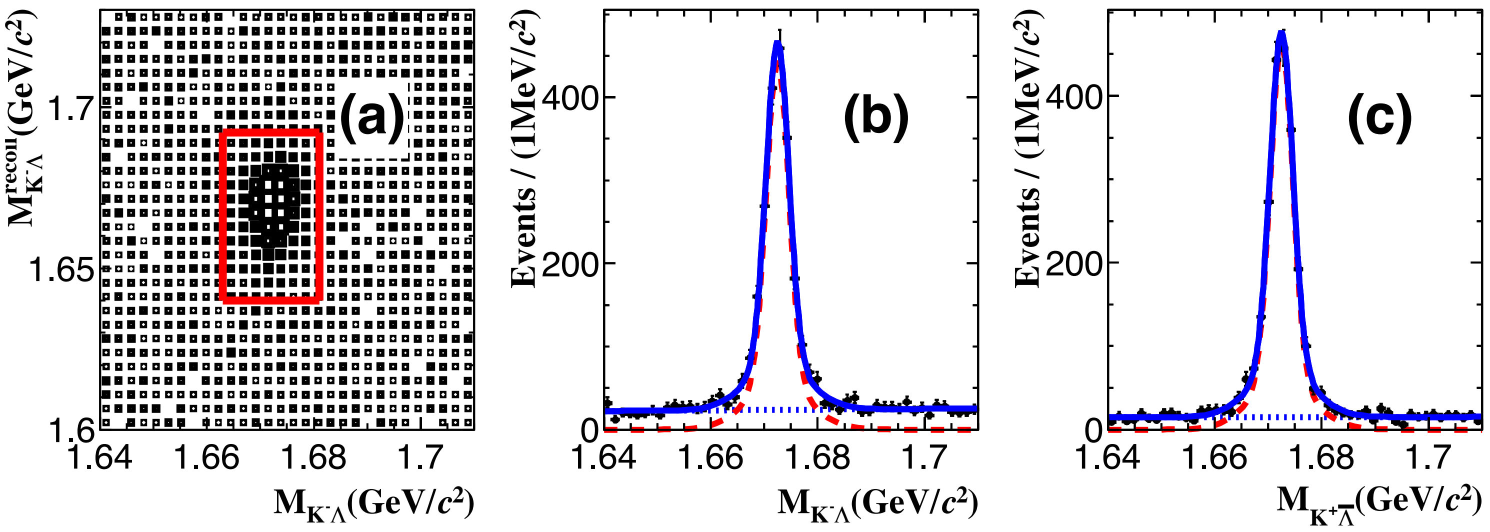
e^+e^- c.m. system Ω^- rest frame

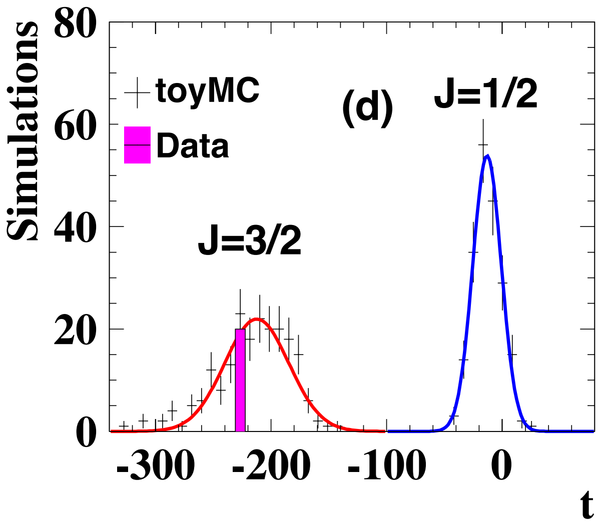


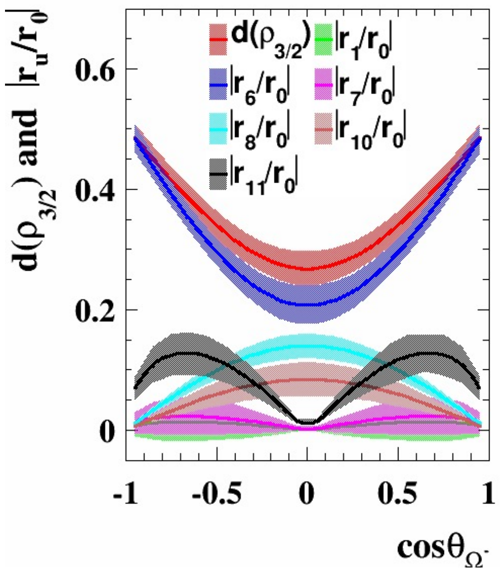
Ω^- rest frame Λ rest frame

$\psi(3686)$->$\Omega^- \Omega^+$

Phys. Rev. Lett. 126, 092002 (2021)







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

Summary

- Hyperons are important probe to study QCD and fundamental symmetries.
- 10 Billion J/ψ data and 3 Billion $\psi(3686)$ data collected in future will bring more exciting results.
- More hyperons study results come soon.

THANK YOU