中国科学院大学
UNIVERSITY OF CHINESE ACADEMY OF SCIENCES

Highlight on precise hyperon physics at BESIII

---- Ceremony of the 500 publications of BESIII collaboration

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University of Chinese Academy of Sciences, Beijing, China

Outline

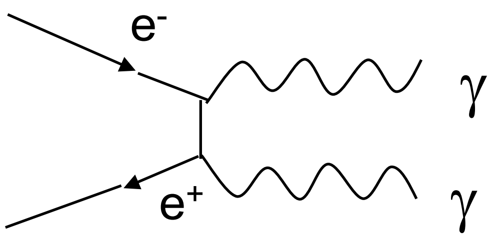
- CP tests in hyperon decays
- Recent results from BESIII
- Hyperon physics in future plans
- Summary and outlooks

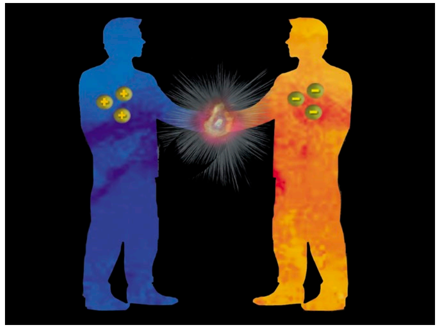
CP tests in hyperon decays

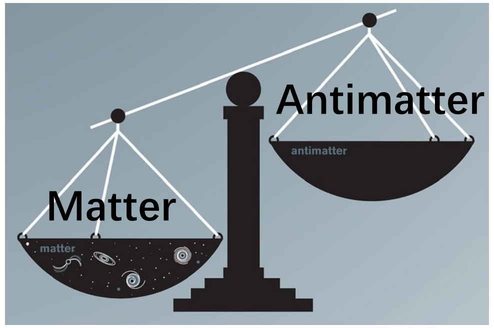
Matter-antimatter asymmetry in the universe

The Big Bang model predicts:

- Matter and antimatter are produced in equal amounts
- Matter and antimatter annihilated into energy







However the very fact that we exist in a matter-dominated universe.

Sakharov three conditions require C and CP violation processes exist.

Andrei Sakharov
(1921-1989)

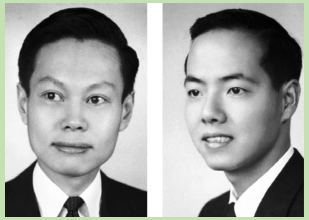
Sakharov three conditions:

1. Baryon number B violation
2. C and CP symmetry violation
3. Interactions out of thermal equilibrium

Pisma Zh. Eksp. Teor. Fiz., 1967, 5: 32-35.

A brief history of Parity and CP violation

Nobel Prize 1957

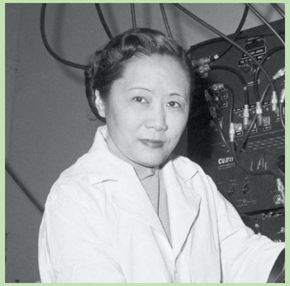


C. N. Yang T. D. Lee

$\theta - \tau$ puzzle [1]

First proposed Parity violation in weak interaction

Confirmed by



Chien-Shiung Wu

1957

No CPV founded in baryon sector!

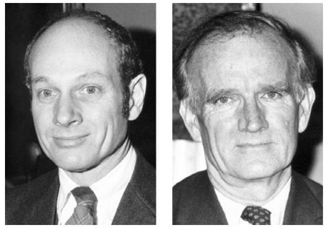
K meson CP violation[2]

B meson CP violation [3,4]

D meson CP violation [5]

1964

James Watson Cronin



Val Logsdon Fitch

Nobel Prize 1980

2001

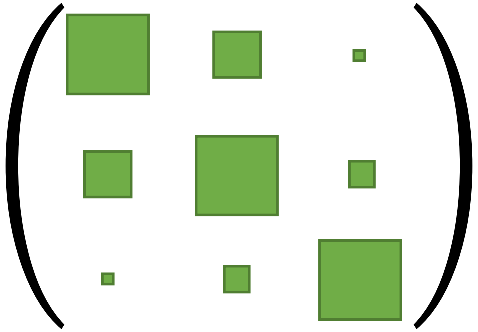
2019

[1] Phys. Rev. 104 (1956) 254-258
[2] Phys. Rev. Lett., 1964, 13: 138-140
[3] Phys. Rev. Lett., 2001, 87: 091801
[4] Phys. Rev. Lett., 2001, 87: 091802
[5] Phys. Rev. Lett., 2019, 122(21): 211803

CPV in Standard Model: CKM matrix

CPV from phase δ

$$V_{\rm CKM} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$



Dirac Medal 2010

Nobel Price 2008

δ_s strong phase ϕ_w weak phase

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

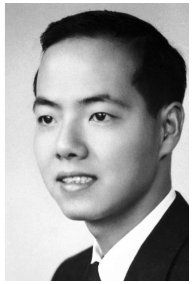
Make $r = A_2/A_1$, $\delta = \delta_s^2 - \delta_s^1$, $\phi = \phi_w^2 - \phi_w^1$

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 $\phi \neq 0$

- Strong and weak phase difference $\neq 0$
- At least two amplitudes, CPV arised from interference between amplitudes.

CPV in hyperon decay

General Partial Wave Analysis of the Decay of a Hyperon of Spin $\frac{1}{2}$

T. D. LEE* AND C. N. YANG

Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)

Phys. Rev. 108, 1645 (1957)

The amplitude of spin ½ baryon B_i decay to a spin ½ baryon B_f and π:

$$\boldsymbol{\mathcal{A}} \sim S\sigma_0 + P\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

The decay parameters are defined as:

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

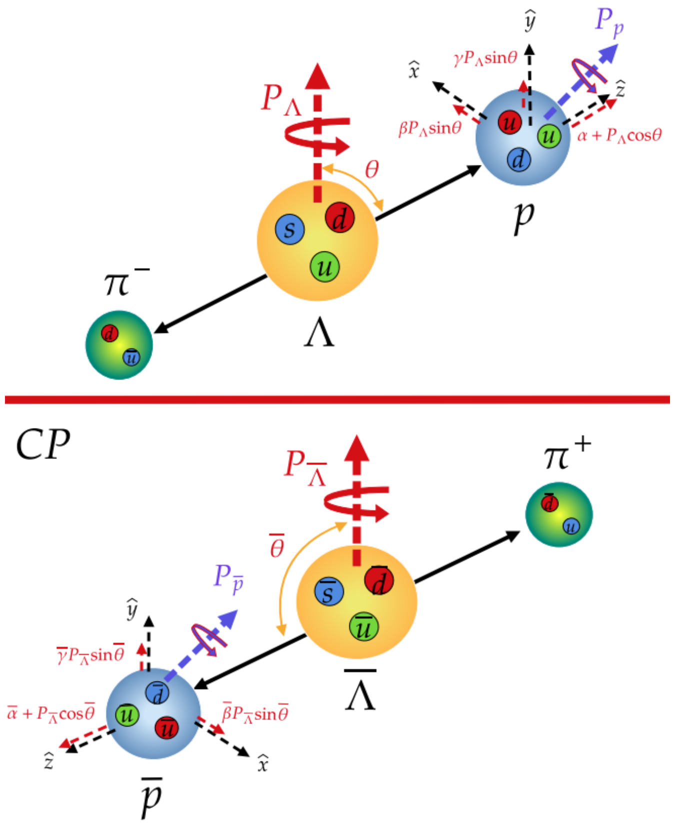
Two complex amplitudes: **ϕ weak phase, δ strong phase**

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

Under CP transformation:

$$\bar{S} = -\Sigma^i S_i e^{i(-\phi_i^S+\delta_i^S)},\qquad \bar{P} = \Sigma^i P_i e^{i(-\phi_i^P+\delta_i^P)}$$

If CP conserved: $S \xrightarrow{CP} -S$, $P \xrightarrow{CP} P$ ⇒ $\alpha \xrightarrow{CP} \bar{\alpha} = -\alpha$, $\beta \xrightarrow{CP} \bar{\beta} = -\beta$



CPV observables:

$$\Delta = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}}$$

$$A = \frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} + \Delta$$

$$B = \frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\beta-\bar{\Gamma}\bar{\beta}} \approx \frac{\beta+\bar{\beta}}{\beta-\bar{\beta}} + \Delta$$

CP observable in hyperon decay



John F. Donoghue　Xiao-Gang He　Sandip Pakvasa

PHYSICAL REVIEW D　VOLUME 34, NUMBER 3　1 AUGUST 1986

Hyperon decays and CP nonconservation

John F. Donoghue
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

Xiao-Gang He and Sandip Pakvasa
Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822

(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.

PRD 34,833 1986

SM Prediction of Λ decay

Not sensitive to *CPV* → **Decay width difference** $\Delta = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}} \approx \sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}}\sin\Delta_s \sin\phi_{CP}$　-5.4×10^{-7}

Easiest to measure → **Decay parameter difference** $A = \frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \tan\Delta_s \tan\phi_{CP}$　-0.5×10^{-4}

Polarization of decayed baryon needs to be measured → **Decay parameter difference** $B = \frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}} \approx \tan\phi_{CP}$　3.0×10^{-3}

Ξ^-, Ξ^0, Ω^- cascade decay

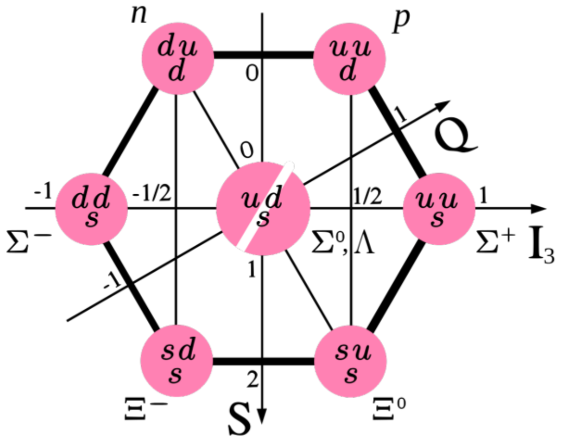
BESIII: a hyperon factory

10 billion J/ψ events collected:
- **Large Br. in J/ψ decay**
- **Quantum entangled pair productions**
- **High efficiency, background free**

Front. Phys. 12(5), 121301 (2017)
Phys. Rev. D 100, 114005 (2019)

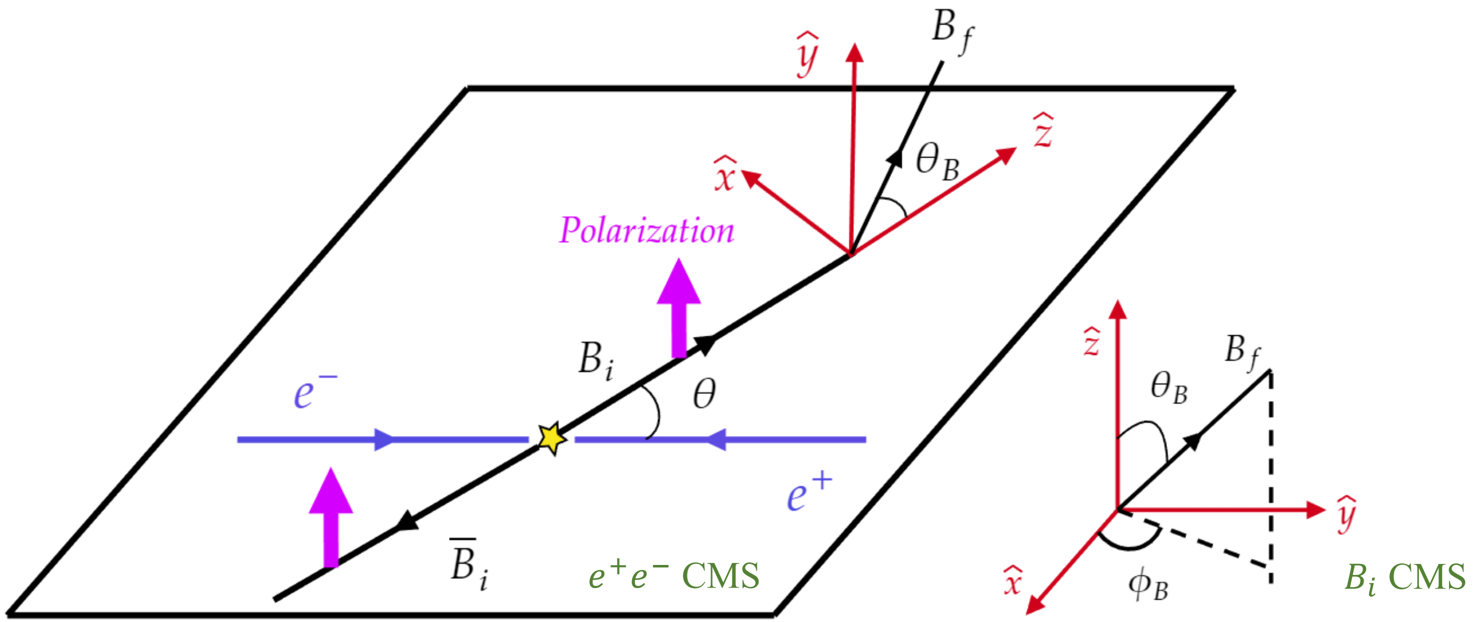
CPV in SM is small:			# events	Experiments
B meson:	$O(1)$	discovered(2001)	10^3	B factory
K meson:	$O(10^{-3})$	discovered(1964)	10^6	Fix targets
D meson:	$O(10^{-4})$	discovered(2019)	10^8	LHCb
Hyperon:	$O(10^{-4})$	no evidence (10^{-2})	$O(10^8)$	Fix targets → **BESIII?**

Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_B\ (\times 10^6)$	Detection Efficiency	Number of reconstructed
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5	40%	4500 X 10^3
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9	25%	600 X 10^3
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4	24%	640 X 10^3
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	0.31 ± 0.05	3.1 ± 0.5		
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.10 ± 0.12	11.0 ± 1.2		
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.20 ± 0.24	12.0 ± 2.4	14%	670 X 10^3
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0	19%	810 X 10^3
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.2 ± 1.4		
$J/\psi \to \Xi(1530)^-\bar{\Xi}^+$	0.59 ± 0.15	5.9 ± 1.5		
$\psi(2S) \to \Omega^-\bar{\Omega}^+$	0.05 ± 0.01	0.15 ± 0.03		



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

Polarized hyperon pairs produced in e^+e^- collisions



Two form factors are used to describe the production of hyperon pair: G_E, G_M

$$\alpha_\psi = \frac{s^2|G_M|^2 - 4m^2|G_E|^2}{s^2|G_M|^2 + 4m^2|G_E|^2}, \quad \frac{G_M}{G_E} = \left|\frac{G_M}{G_E}\right| e^{-i\Delta\Phi}$$

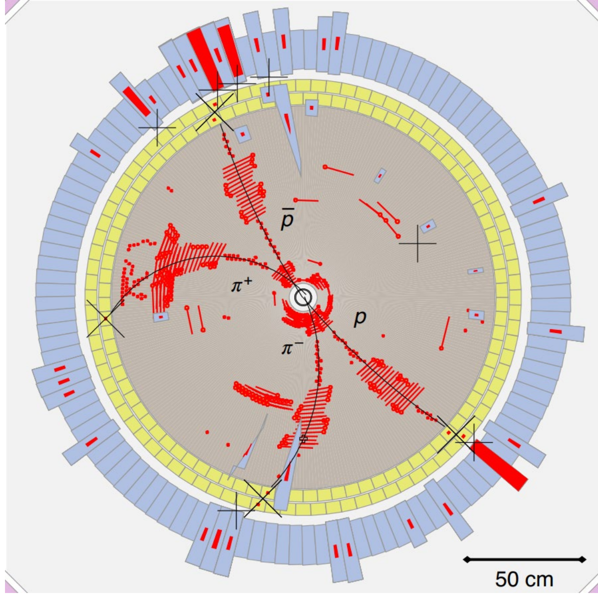
Polarization:

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

- Angular distribution of $\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_\psi \cos^2\theta, \ \alpha_\psi \in [-1.0, 1.0]$
- Unpolarized e^+e^- beams $\Rightarrow$ transverse polarized hyperon (if $\Delta\Phi \neq 0$):

Recent results from BESIII

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



- Joint amplitude:

$$M = \frac{ie^2}{q^2} j_\mu \bar{u}(p_1)\left(F_1\gamma_\mu + \frac{F_2}{2m} p_\nu \sigma^{\nu\mu}\gamma_5\right) v(p_2)$$

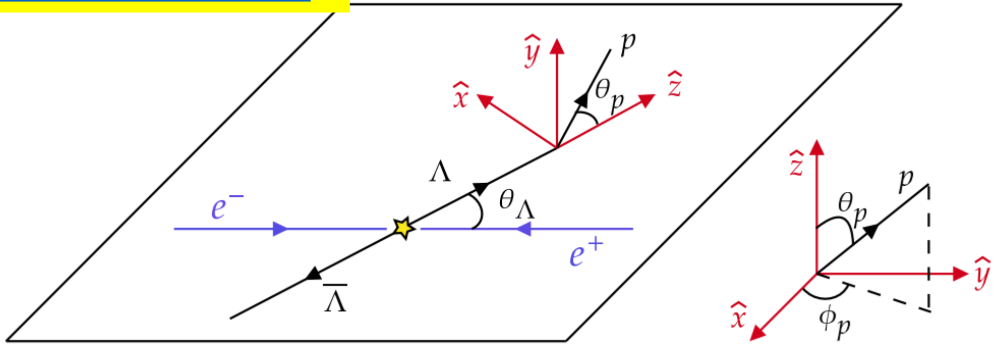
- Differential cross section:

$$d\sigma \sim 1 + \alpha_\psi \cos^2\theta_\Lambda + (\alpha_\psi + \cos^2\theta_\Lambda) s^z_\Lambda s^z_{\bar{\Lambda}} + \sin^2\theta_\Lambda s^x_\Lambda s^x_{\bar{\Lambda}} - \alpha_\psi \sin^2\theta_\Lambda s^y_\Lambda s^y_{\bar{\Lambda}} + \sqrt{1-\alpha_\psi^2}\cos\Delta\Phi \sin\theta_\Lambda \cos\theta_\Lambda (s^x_\Lambda s^z_{\bar{\Lambda}} + s^z_\Lambda s^x_{\bar{\Lambda}}) + \sqrt{1-\alpha_\psi^2}\sin\Delta\Phi \sin\theta_\Lambda \cos\theta_\Lambda (s^y_\Lambda + s^y_{\bar{\Lambda}})$$

SPIN CORRELATIONS

POLARIZATIONS

- The spin vector of Λ is denoted by $\boldsymbol{s}_\Lambda$
- Only $< s^y >$ could be non-zero, if $\sin\Delta\Phi \neq 0$



Nuovo Cim. A 109, 241 (1996)
Phys. Rev.185 D 75, 074026 (2007)
Nucl. Phys. A190 771, 169 (2006)
Phys. Lett. B 772, 16(2017)

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

BESIII has publish 2 works based on 1.3 billion and 10 billion J/ψ data sample:

[1] 1.3 billion: Nature Phys.15(2019)631

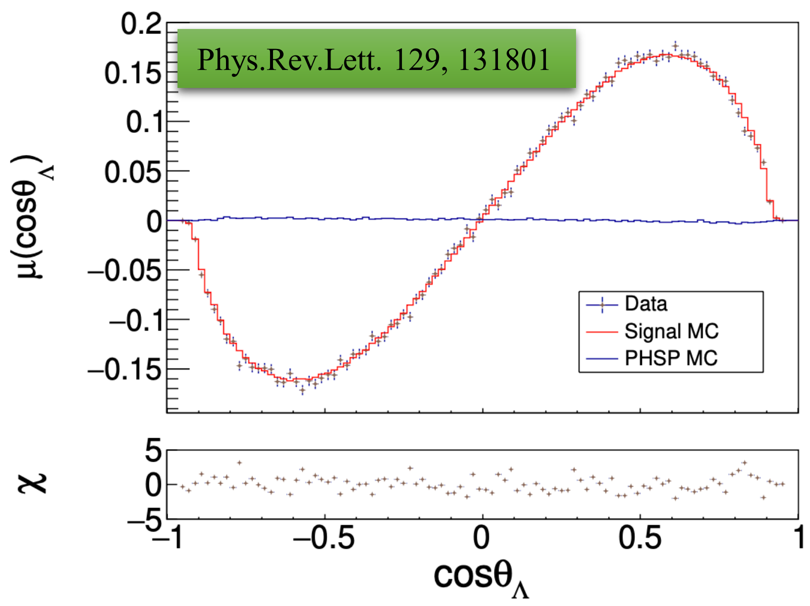
[2] 10 billion: Phys.Rev.Lett. 129 (2022) 13, 131801

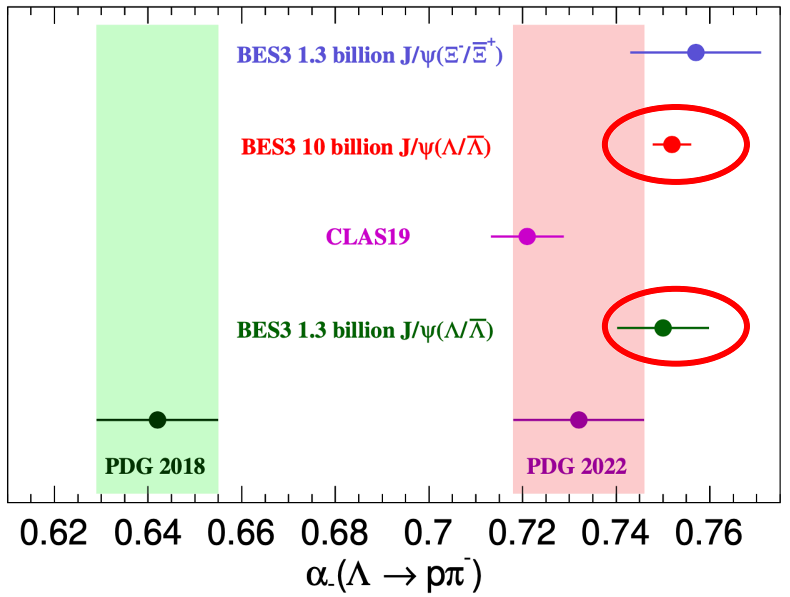
- Most precise values for Λ decay parameter
- One of the most precise CP test in the hyperon sector:

$$A_{CP} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} = -0.0025 \pm 0.0046 \pm 0.0011$$

Standard mode prediction : $A_{CP} \sim 10^{-4}$ (PRD 34, 833 (1986))

Par.	BESIII 10 billion [2]	BESIII 1.3 billion [1]
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0031$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0066$	$0.740 \pm 0.010 \pm 0.009$
α_-	$0.7519 \pm 0.0036 \pm 0.0024$	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.7559 \pm 0.0036 \pm 0.0030$	$-0.758 \pm 0.010 \pm 0.007$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0012$	$0.006 \pm 0.012 \pm 0.007$
$\alpha_{\rm avg}$	$0.7542 \pm 0.0010 \pm 0.0024$	-





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

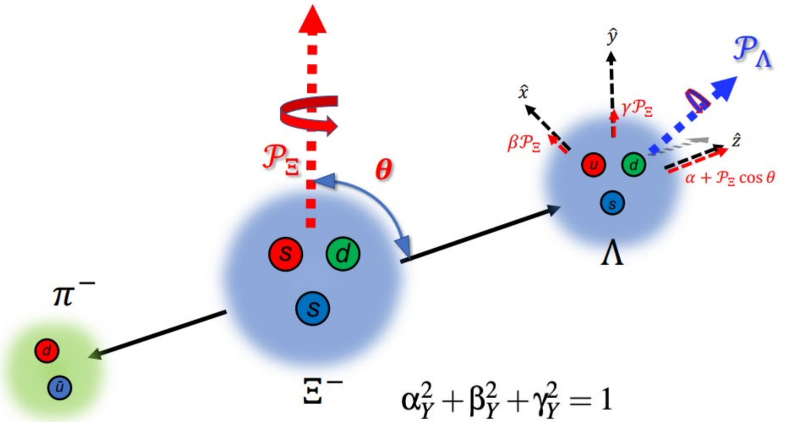
- For the sequential weak decays, the formula of sequential decays is:

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

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

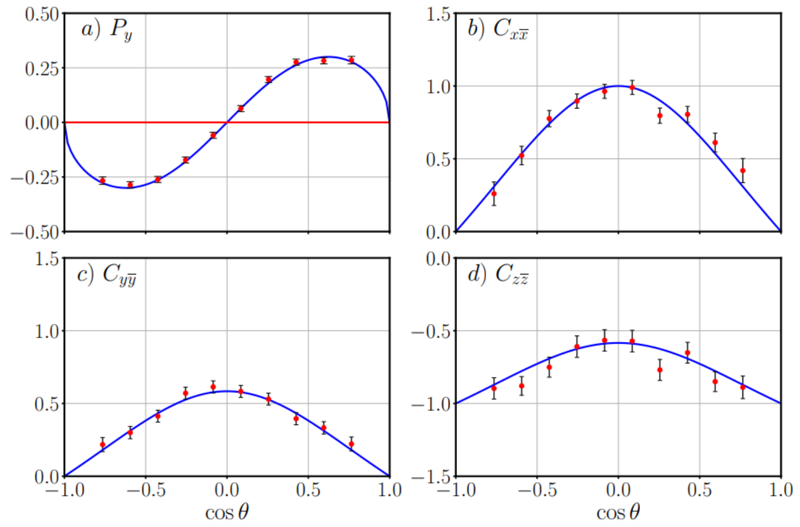
first measurement



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

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

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^Ξ_{CP}	$(6\pm13\pm6)\times10^{-3}$	–
$\Delta\phi^\Xi_{CP}$	$(-5\pm14\pm3)\times10^{-3}$ rad	–
A^Λ_{CP}	$(-4\pm12\pm9)\times10^{-3}$	$(-6\pm12\pm7)\times10^{-3}$
$\langle\phi_\Xi\rangle$	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

HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$

BESIII: $\langle\phi_\Xi\rangle = 0.016\pm0.014\pm0.007$

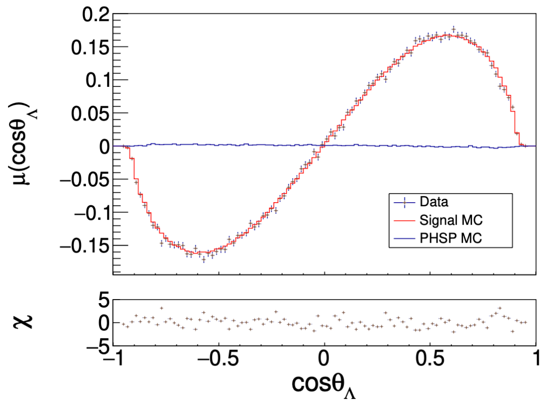
We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

HyperCP: PRL 93(2004) 011802

Polarization behavior in different hyperon pair productions

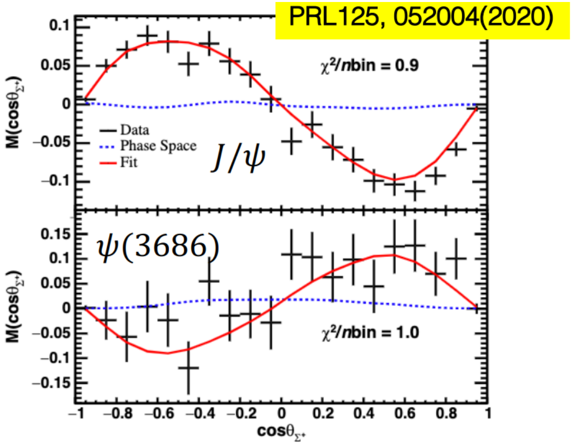
$J/\psi \to \Lambda\bar{\Lambda}$

PRL129, 131801(2022)



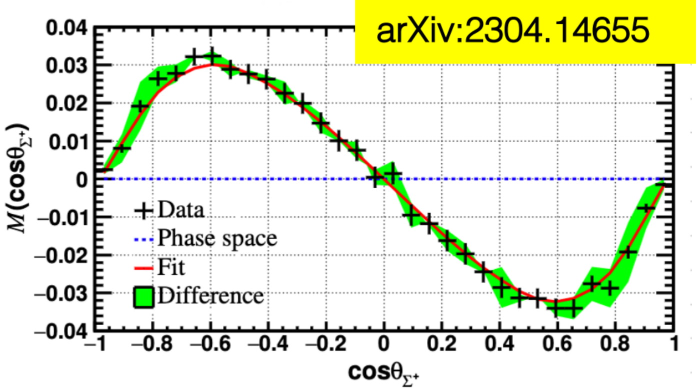
$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)\,rad$
$A_{CP} = -0.0025 \pm 0.0046 \pm 0.0012$

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



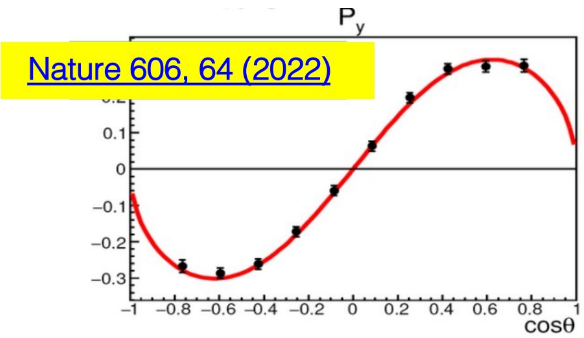
$\Delta\Phi(J/\psi) = (-15.5 \pm 0.7\ \pm 0.5)^\circ$
$\Delta\Phi(\psi(2S)) = (21.7 \pm 4.0\ \pm 0.8)^\circ$
$A_{CP} = -0.004 \pm 0.037\ \pm 0.010$

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



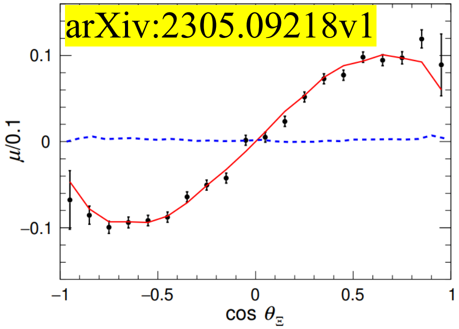
$\Delta\Phi = (-0.277 \pm 0.004 \pm 0.004)\,rad$
$A_{CP} = -0.080 \pm 0.052\ \pm 0.028$

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



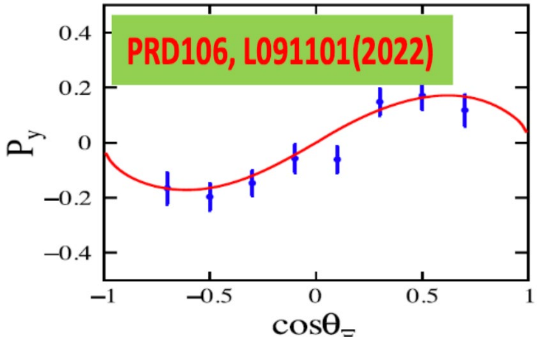
$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016)\,rad$
$A_{CP} = -0.006 \pm 0.013\ \pm 0.006$

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



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

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

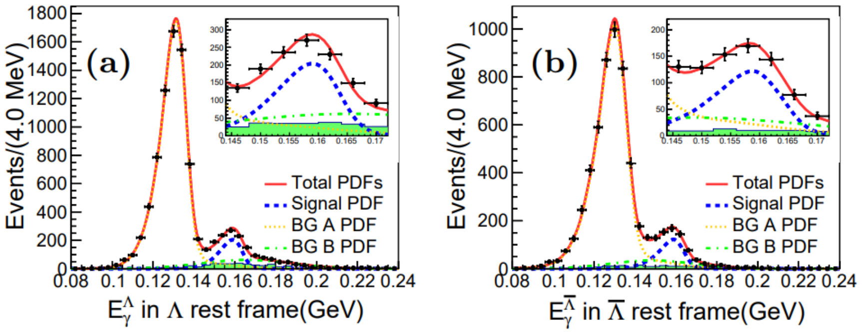


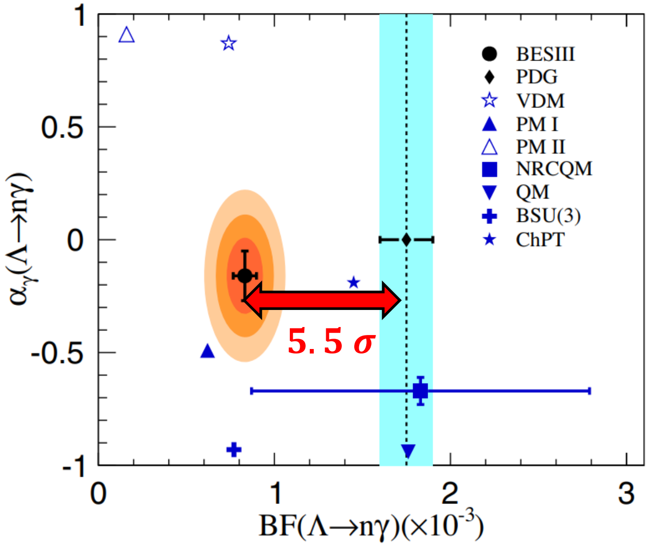
$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)\,rad$
$A_{CP} = -0.015 \pm 0.051\ \pm 0.010$

Study on hyperon rare decays

$\Lambda \to n\gamma$ via $J/\psi \to (\Lambda \to p\pi)(\bar{\Lambda} \to \bar{n}\gamma) + \mathrm{c.c.}$

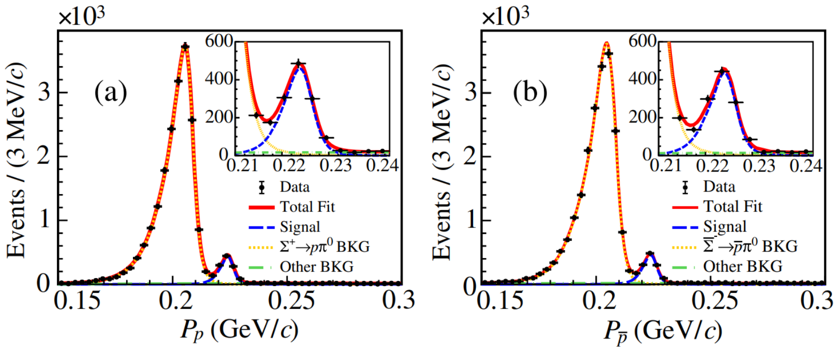
PRL129, 212002 (2022)

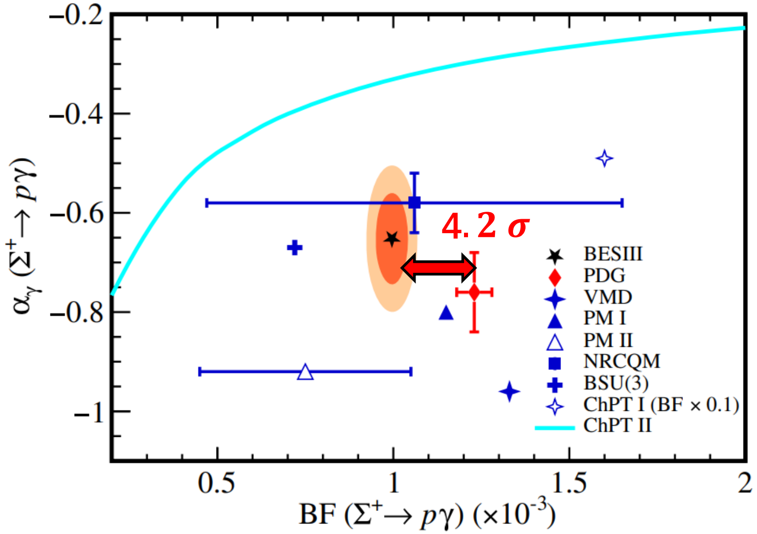




$\Sigma^+ \to p\gamma$ via $J/\psi \to (\Sigma^+ \to p\pi^0)(\bar{\Sigma}^- \to \bar{p}\gamma) + \mathrm{c.c.}$

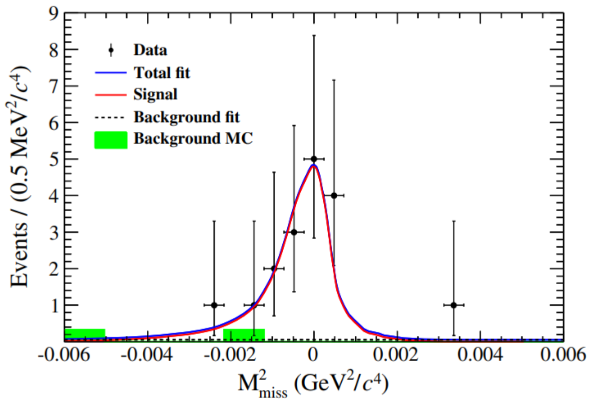
PRL130, 211901(2023)

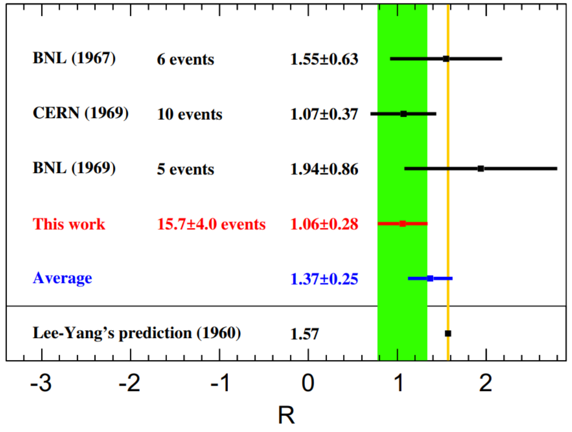




$\Sigma^+ \to \Lambda e^+\nu_e$ via $J/\psi \to \Sigma^+\bar{\Sigma}^-$

Phys.Rev.D 107 (2023) 7, 072010

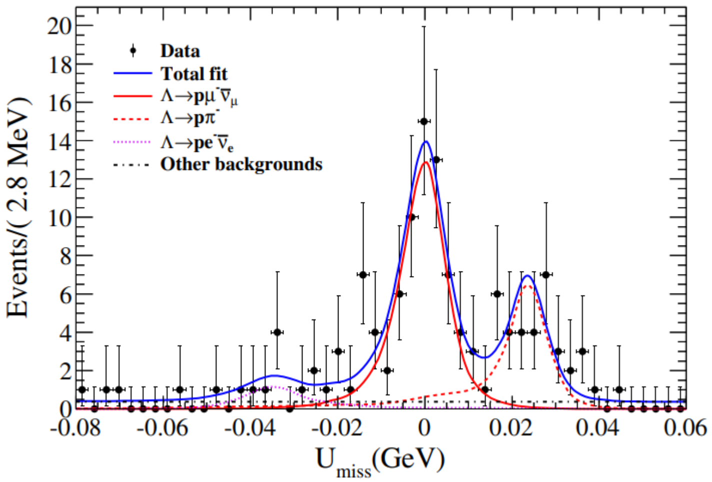




Study on hyperon rare decays

First measurement of the absolute branching fraction of $\Lambda \to p\mu^-\bar{\nu}_\mu$

PRL 127, 121802 (2021)



$$B(\Lambda \to p\mu^-\bar{\nu}_\mu) = (1.48 \pm 0.21 \pm 0.08) \times 10^{-4}$$

$$R^{\mu e} \equiv \frac{\Gamma(\Lambda \to p\mu^-\bar{\nu}_\mu)}{\Gamma(\Lambda \to pe^-\bar{\nu}_e)} = 0.178 \pm 0.028$$

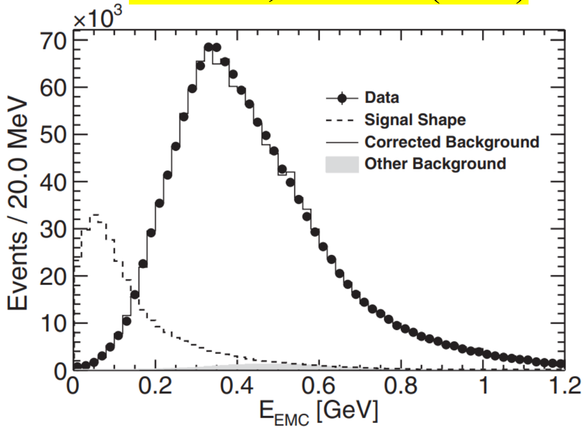
consistent with SM prediction: 0.153 ± 0.008

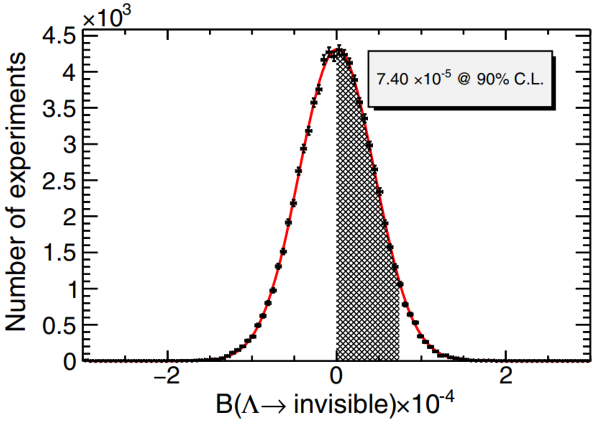
$$A_{CP} \equiv \frac{B(\Lambda \to p\mu^-\bar{\nu}_\mu) - B(\bar{\Lambda} \to \bar{p}\mu^+\nu_\mu)}{B(\Lambda \to p\mu^-\bar{\nu}_\mu) - B(\bar{\Lambda} \to \bar{p}\mu^+\nu_\mu)} = 0.02 \pm 0.14 \pm 0.02$$

Invisible decays: $\Lambda \to invisible$

$B(\Lambda \to invisible) < 7.4 \times 10^{-5}$ (90% CL)

PRD 105, L071101 (2022)

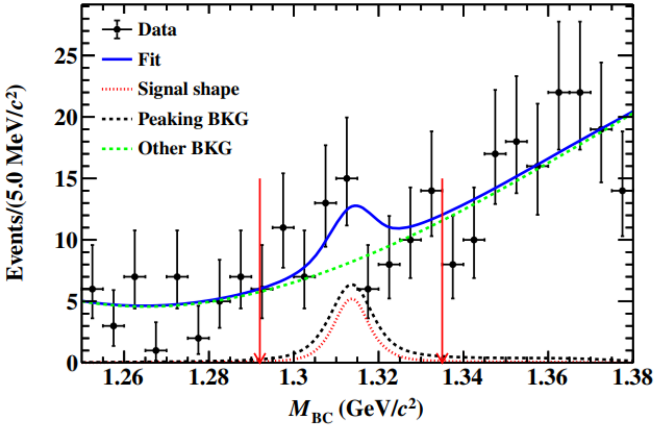


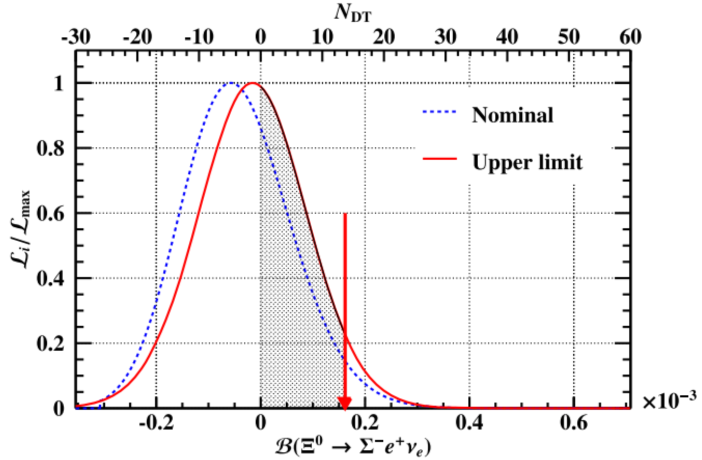


$\Delta S = \Delta Q$ violating process $\Xi^0 \to \Sigma^- e^+ \nu_e$

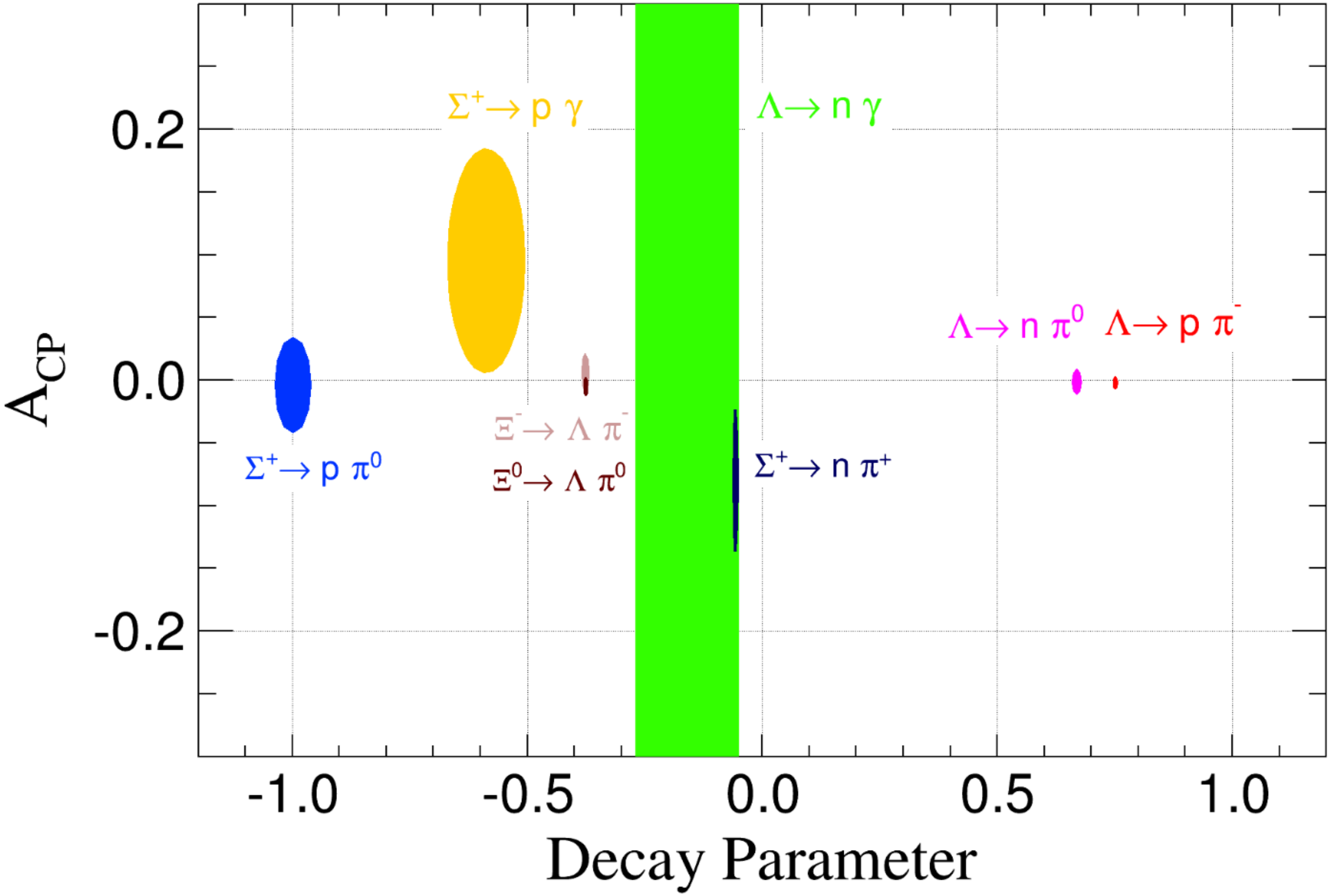
$B(\Xi^0 \to \Sigma^- e^+ \nu_e) < 1.6 \times 10^{-4}$ (90% CL)

PRD 107, 012002 (2023)





Summary of BESIII achievement on hyperon decay



Summary of BESIII achievement on hyperon decay

Parameters	$\Lambda\bar{\Lambda}$ (PRL 129, 131801(2022))	$\Sigma^+\bar{\Sigma}^-$ (PRL 125,052004(2020))	$\Xi^-\bar{\Xi}^+$ (Nature 606,64(2022))	$\Xi^0\bar{\Xi}^0$ (arXiv:2305.09218v1)
α_{Ξ^-/Ξ^0}	-	-	$-0.376 \pm 0.007 \pm 0.003$	$-0.3750 \pm 0.0034 \pm 0.0016$
$\alpha_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$0.371 \pm 0.007 \pm 0.002$	$0.3790 \pm 0.0034 \pm 0.0021$
ϕ_{Ξ^-/Ξ^0}	-	-	$0.011 \pm 0.019 \pm 0.009$	$0.0051 \pm 0.0096 \pm 0.0018$
$\phi_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$-0.021 \pm 0.019 \pm 0.007$	$-0.0053 \pm 0.0097 \pm 0.0019$
$A_{CP}(\Xi^-/\Xi^0)$	-	-	$0.006 \pm 0.013 \pm 0.006$	$-0.0054 \pm 0.0065 \pm 0.0031$
$\Delta\phi_{CP}(\Xi^-/\Xi^0)$	-	-	$-0.005 \pm 0.014 \pm 0.003$	$-0.0001 \pm 0.0069 \pm 0.0009$
$\alpha_{\Lambda/\Sigma^+}$	$0.7519 \pm 0.0036 \pm 0.0024$	$-0.998 \pm 0.037 \pm 0.009$	$0.757 \pm 0.011 \pm 0.008$	$0.7551 \pm 0.0052 \pm 0.0023$
$\alpha_{\bar{\Lambda}/\bar{\Sigma}^-}$	$-0.7559 \pm 0.0036 \pm 0.0030$	$0.990 \pm 0.037 \pm 0.011$	$-0.763 \pm 0.011 \pm 0.007$	$-0.7448 \pm 0.0052 \pm 0.0023$
$A_{CP}(\Lambda/\Sigma^+)$	$-0.0025 \pm 0.0046 \pm 0.0012$	$-0.004 \pm 0.037 \pm 0.010$	$-0.004 \pm 0.012 \pm 0.009$	$0.0069 \pm 0.0058 \pm 0.0018$

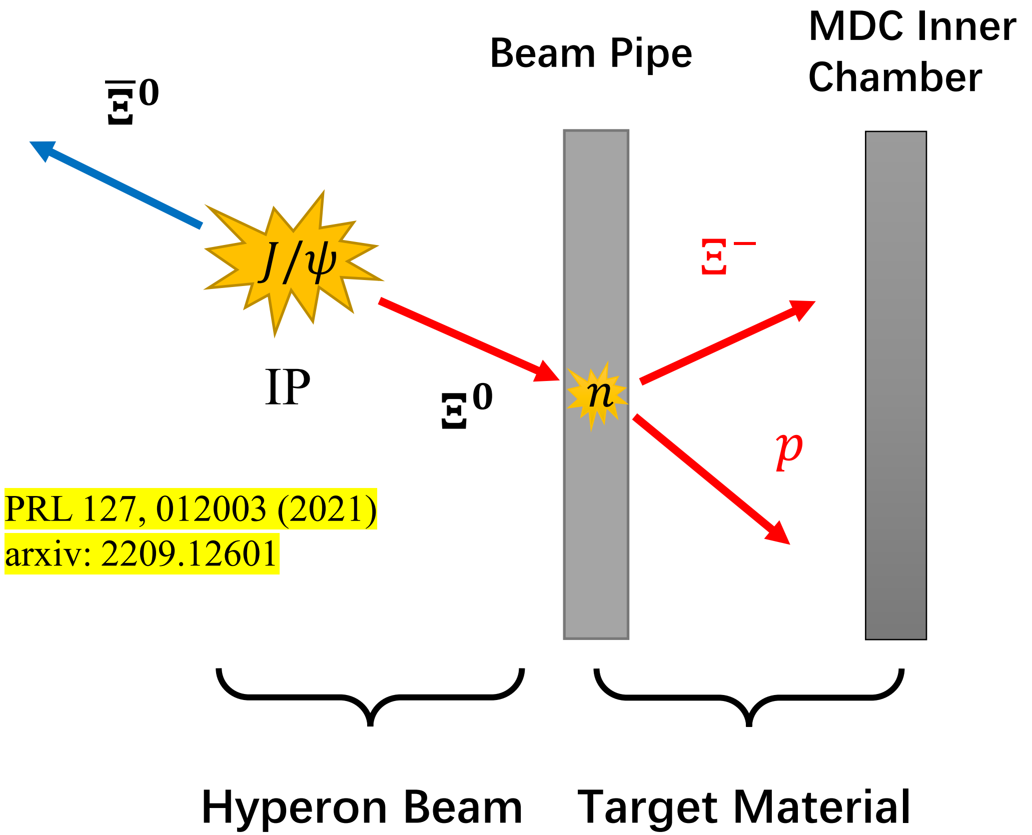
The most precise CP measurement at BESIII: $A_{CP}^{\Lambda} = -0.0025 \pm 0.0046 \pm 0.0012$

Systematic uncertainties are well controlled!

- Excellent performance of BESIII detectors.
- Data-driven method to study data-MC inconsistency.

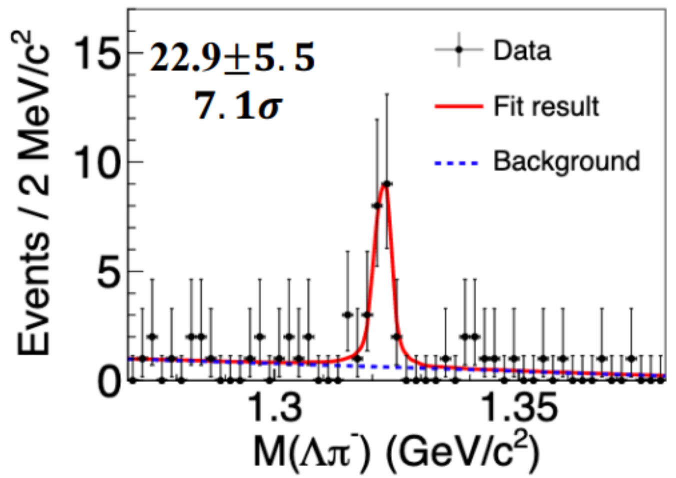
Hyperon physics in future plans

A novel method to study hyperon-nucleus interaction at BESIII !



PRL 127, 012003 (2021)
arxiv: 2209.12601

arXiv:2304.13921(Accepted by PRL)



$\Xi^0 n \to \Xi^- p$ is observed for the first time

For Ξ^0 momentum is 0.818 GeV/c

$$\sigma(\Xi^0 n \to \Xi^- p) = (7.4 \pm 1.8_{\rm stat} \pm 1.5_{\rm sys})\ {\rm mb}$$

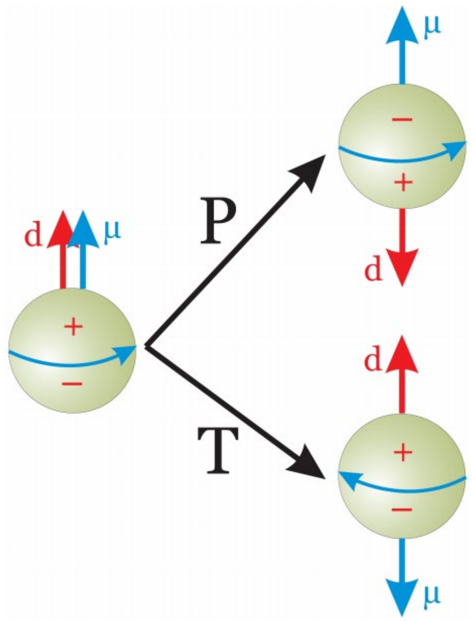
(assuming effective number of reaction neutrons in ^{9}Be is 3)

$$\sigma(\Xi^0 + {}^9{\rm Be} \to \Xi^- + p + {}^8{\rm Be}) = (22.1 \pm 5.3_{\rm stat} \pm 4.5_{\rm sys})\ {\rm mb}$$

The first study of hyperon–nucleon interaction in electron–positron collisions!
More results are on the way.

Searching for hyperon EDM at BESIII

μ: magnetic dipole moment
d: electric dipole moment

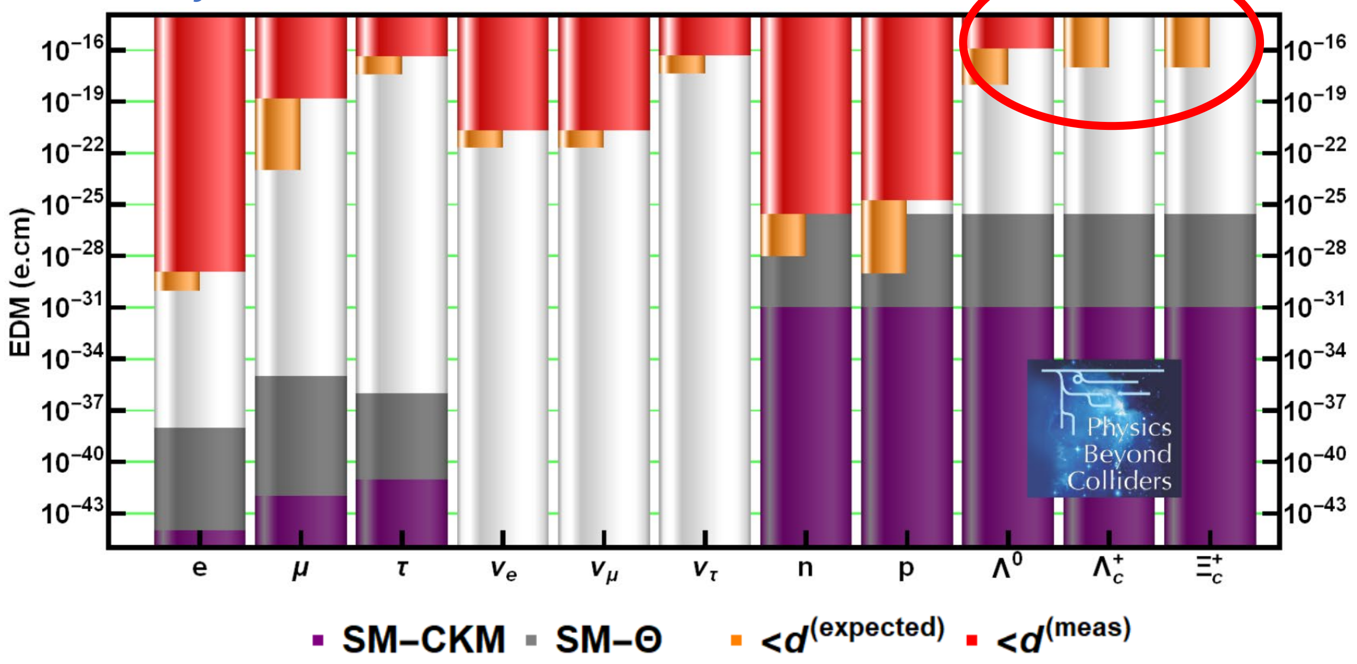


Non-zero EDM will violate P and T symmetry:
T violation ↔ CP violation, if CPT holds.

Systematic measurement of the EDMs of the hyperon family!

Only the EDM of Λ in the hyperon family has been measured (with low precision). Based on massive quantum-correlated hyperon pairs, BESIII is expected to improve the measurement precision of the Λ EDM by a factor of **1000**, and provide the first measurement results of the EDMs of Σ, Ξ, Ω, and other hyperons

J.Phys.G **47 (2020) 1, 010501**



Summary and Outlooks

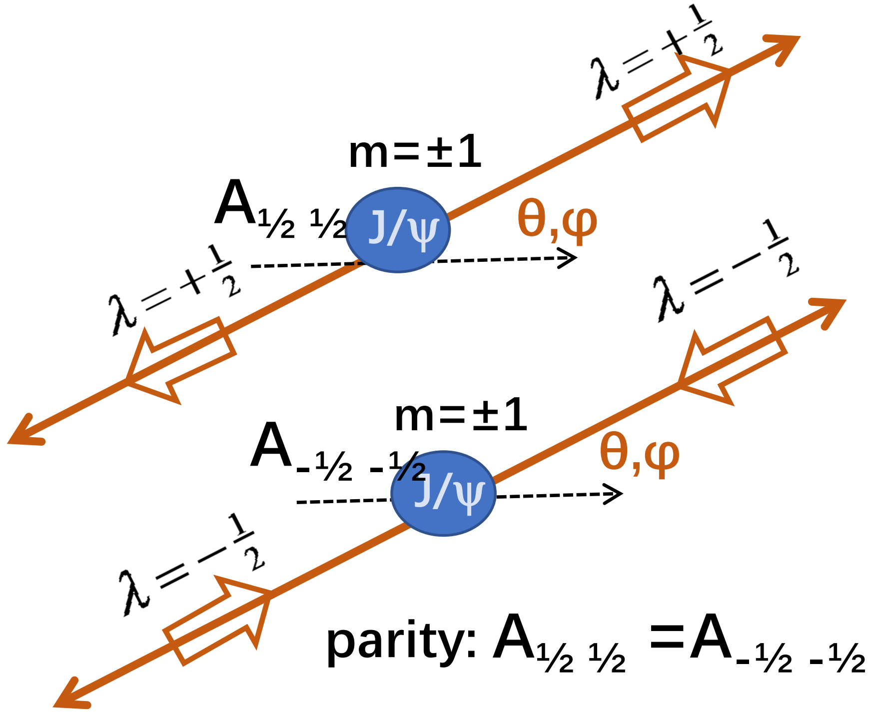
- Highlights of hyperon physics at BESIII:
  - Precision measurements of hyperon decay parameters, polarization and CP asymmetry:
    - complementary to CPV studies with Kaons
    - BESIII has already rewritten the PDG book for Λ and Ξ decays
    - results of $\Sigma^{\pm}, \Xi$ with 10 billion J/ψ will be coming soon
  - Hyperon-nucleus interaction:
    - BESIII can provides unique high quality sources of (anti)-hyperon and $\bar{n}$
    - $YN, \bar{Y}N, NN, \bar{N}N$ interaction, hypernuclei
  - Hyperon electric dipole moments measurements
    - 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}

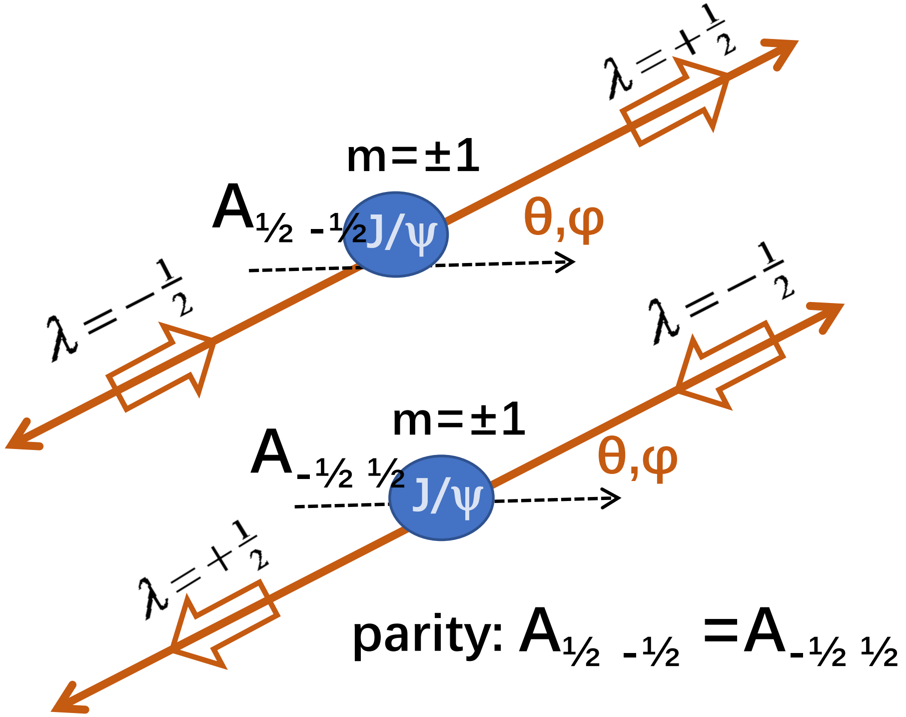
www.thank you.com

Backup

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

Production: 2 independent helicity amplitudes: $A_{½\ ½}$, $A_{½\ -½}$





ΔΦ= complex phase between $A_{½\ ½}$ and $A_{½\ -½}$

$$\frac{d|\mathcal{M}|^2}{d\cos\theta} \propto (1+\alpha_{J/\psi}\cos^2\theta), \quad \text{with} \quad \alpha_{J/\psi} = \frac{|A_{1/2,-1/2}|^2 - 2|A_{1/2,1/2}|^2}{|A_{1/2,-1/2}|^2 + 2|A_{1/2,1/2}|^2}$$

EM form-factors and Helicity Amplitudes

Phys.Rev.D99,056008

$$h_2 \equiv A_{1/2,-1/2} = A_{-1/2,1/2} = \sqrt{1+\alpha_\psi}\, e^{-i\Delta\Phi}$$

$$h_1 \equiv A_{1/2,1/2} = A_{-1/2,-1/2} = \sqrt{1-\alpha_\psi}\,/\sqrt{2}$$

Phys.Lett.B772,16

$$\alpha_\psi = \frac{s|G_M|^2 - 4M^2|G_E|^2}{s|G_M|^2 + 4M^2|G_E|^2}$$

$$\frac{G_E}{G_M} = e^{i\Delta\Phi}\left|\frac{G_E}{G_M}\right|$$

where s is the square of $p_B + p_{\bar{B}}$ and M is the mass of $B(\bar{B})$.

Relation:

$$h_2 = \frac{\sqrt{2s}}{\sqrt{s|G_M|^2 + 4M^2|G_E|^2}}\, G_M$$

$$h_1 = \frac{2M}{\sqrt{s|G_M|^2 + 4M^2|G_E|^2}}\, G_E$$

CPV observables in $\Xi^- \rightarrow \Lambda\pi$ decay

decay rate difference

$$\frac{\Gamma_{\bar{\Lambda}\pi^+} - \Gamma_{\Lambda\pi^-}}{\Gamma} \equiv 0$$

← $\Lambda\pi$ final states are purely Ispin=1, only $\Delta I=1/2$ transitions allowed, no $\Delta I=3/2$ transition possible

decay asymmetry difference

$$\alpha_{\square} = \pm \frac{2\,\mathrm{Re}(S^* P)}{|S|^2 + |P|^2} = \pm \frac{2|S||P|\cos\left(\Delta_S \pm \phi_{CP}\right)}{|S|^2 + |P|^2}$$

$$\frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S \tan\phi_{CP}$$

← in this case, the strong phase ($\Delta_s = \delta_S - \delta_P$) is measureable (see below)

final-state polarization difference

$$\beta_{\square} = \pm \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2} = \pm \frac{2|S||P|\sin\left(\Delta_S \pm \phi_{CP}\right)}{|S|^2 + |P|^2}$$

$$\frac{\beta_- + \beta_+}{\alpha_- - \alpha_+} = \frac{\cos\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\phi_{CP}$$

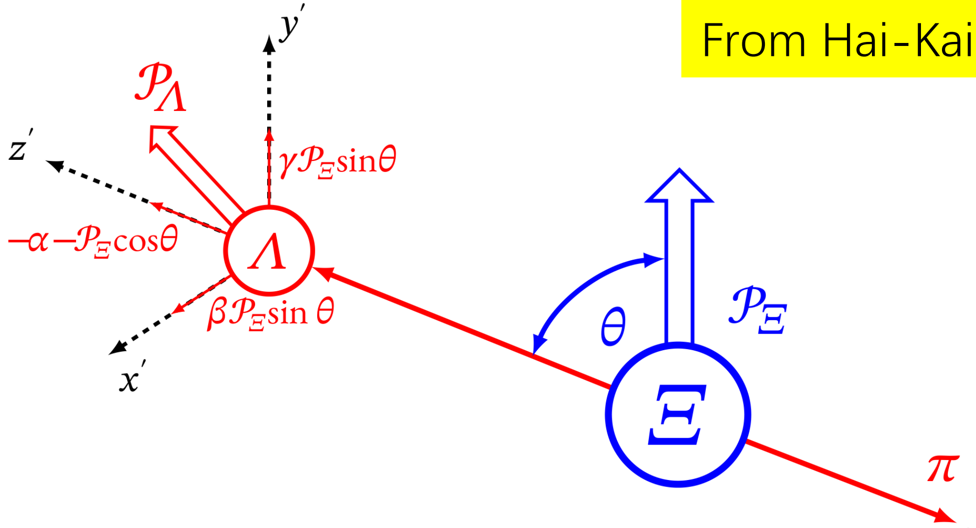
← Strong phase cancels out

$$\frac{\beta_- - \beta_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \cos\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S$$

← measures the strong phase

} big advantage for Ξ over Λ

From Hai-Kai Sun



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

$$\beta = \sqrt{1-\alpha^2}\sin\phi_\Xi \qquad \gamma = \sqrt{1-\alpha^2}\cos\phi_\Xi$$

$$\alpha^2 + \beta^2 + \gamma^2 = 1 \qquad \tan\phi_\Xi = \frac{\beta}{\gamma}$$

Both α and ϕ_Ξ of $\Xi(\bar{\Xi})$ can be measured via $J/\psi \to \Xi\bar{\Xi}$ at BESIII!

$$\alpha_\mp = \pm\frac{2\mathrm{Re}(S^* \cdot P)}{|S|^2 + |P|^2} = \pm\frac{|S||P|\cos(\Delta_s \pm \Delta_w)}{|S|^2 + |P|^2} \qquad \beta_\mp = \pm\frac{2\mathrm{Im}(S^* \cdot P)}{|S|^2 + |P|^2} = \pm\frac{|S||P|\sin(\Delta_s \pm \Delta_w)}{|S|^2 + |P|^2}$$

Sandip PAKVASA

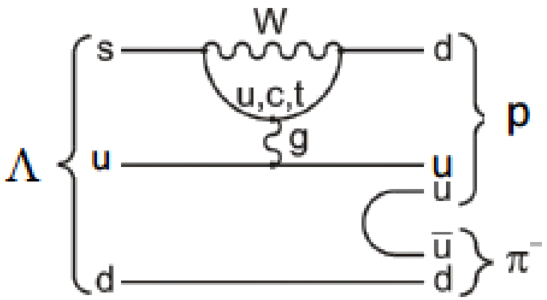
X.G. He

John Donoghue

$$\frac{\beta_- - \beta_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_s\cos\Delta_w}{\cos\Delta_s\cos\Delta_w} = \tan\Delta_s \qquad \frac{\beta_- + \beta_+}{\alpha_- - \alpha_+} = \frac{\cos\Delta_s\sin\Delta_w}{\cos\Delta_s\cos\Delta_w} = \tan\Delta_w$$

Constraints from Kaon decays

He & Valencia PRD 52, 5257

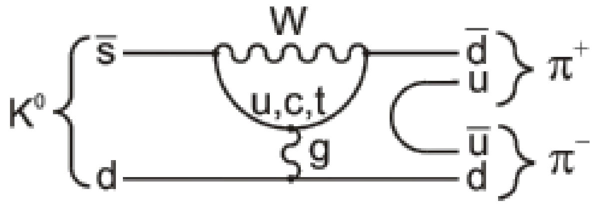


S- and P-waves
(parity violating
& conserving)

$\Lambda \to p\pi^-$	A_{NP}	
S-wave	$<6\times10^{-5}$	parity violating
P-wave	$<3\times10^{-4}$	parity conserving

$A_{SM} \sim 10^{-5}$

$Re(\varepsilon'/\varepsilon)=(1.6+0.3)\times10^{-3}$



S-wave only
(parity violating)

CPV measurement in Kaon system strongly constrains NP in S-waves, but no P-waves.
Thus, searches of CPV in hyperon are complementary to those with Kaons.