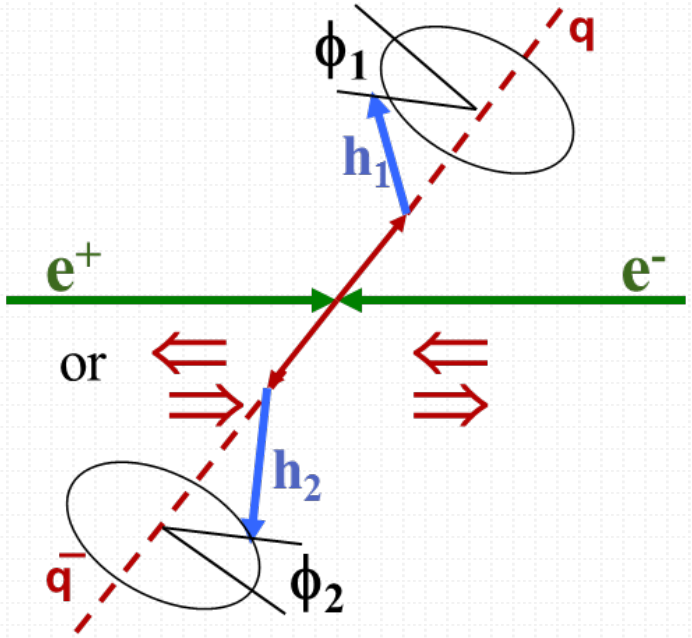
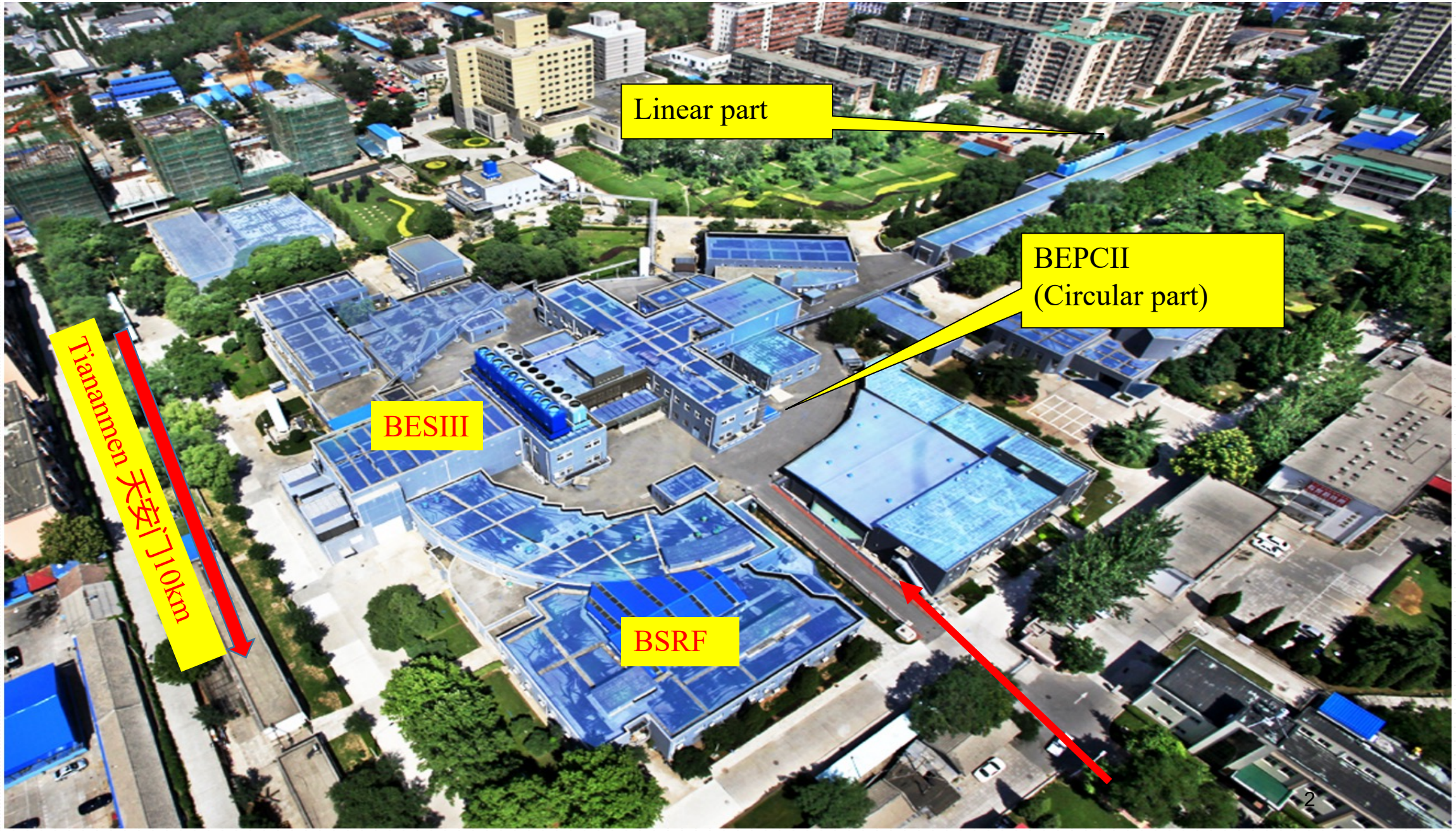
# Paradigm-changing studies of spin entangled hyperons and antihyperons at BESIII



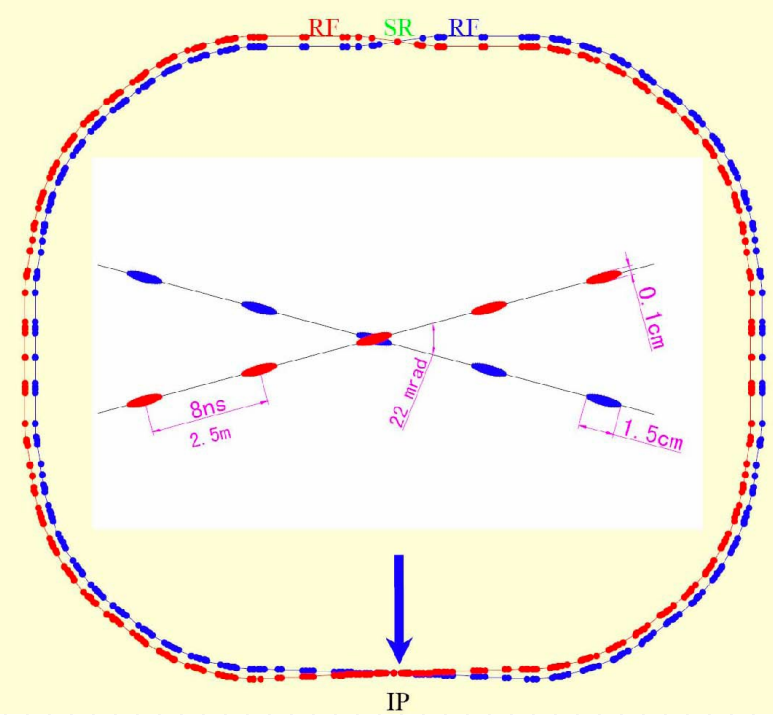

Hai-Bo Li
(On behalf of the BESIII collaboration)
Institute of High Energy Physic

**ICFP2026**
**October 23-26, 2026, Beijing**

# Beijing Electron-Positron Collider II (BEPCII)



# BEPCII storage rings: a $\tau$-charm factory




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

Beam energy: 1…. 2.45 GeV

Optimum energy 1.89 GeV

Beam current 0.91 A

Crossing angle 11 mrad




Design luminosity @3.77GeV $10^{33} cm^{-2} s^{-1}$

Achieved @ 3.77GeV: . $1.1\times10^{33}\, cm^{-2} s^{-1}$

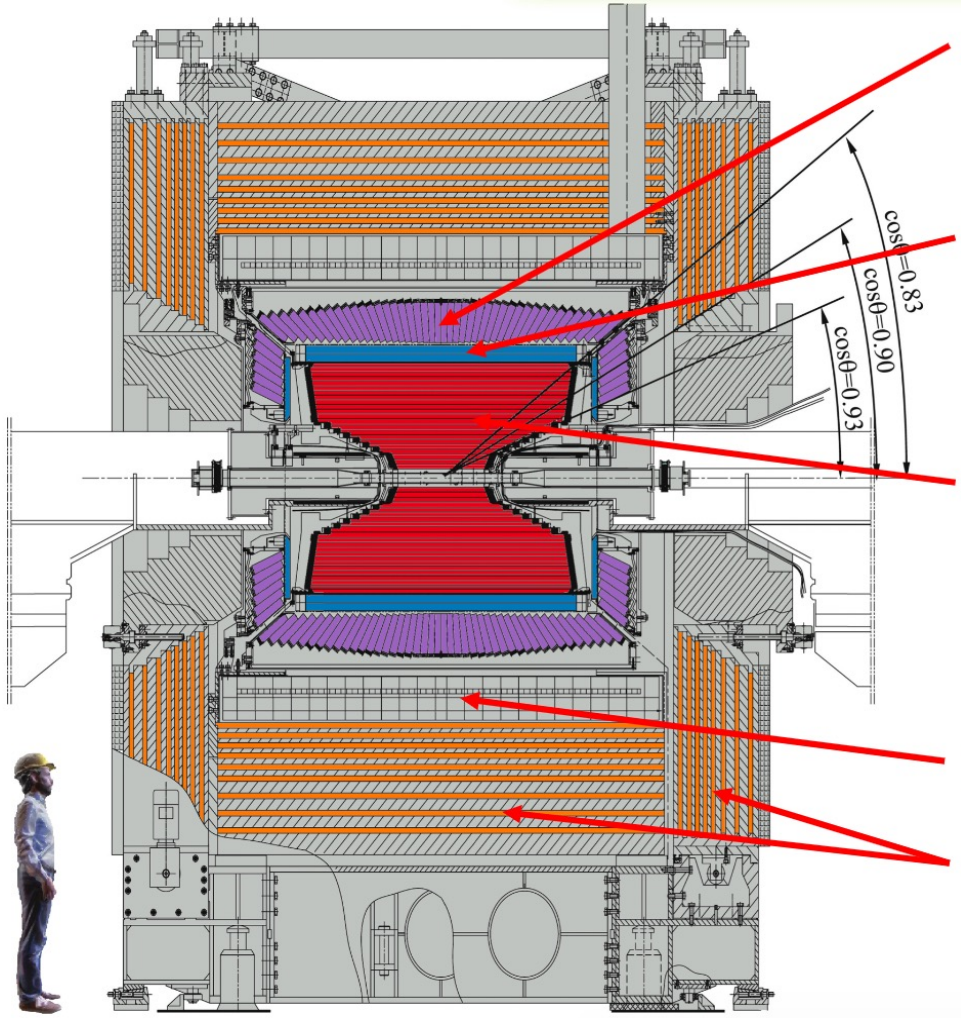
Beam energy measurement:

Laser Compton backscattering

$\Delta E/E \approx 5\times10^{-5}$

( 50 keV at $\tau^+\tau^-$threshold)

# BESIII




EMC: CsI crystals
ΔE/E = 2.5% @ 1 GeV - Barrel
ΔE/E = 5.0% @ 1 GeV - Endcaps

TOF:
$\sigma_T$ = 80 ps Barrel
$\sigma_T$ = 110 (60) ps Endcap

MDC: small cell & He gas
$\sigma_{xy}$= 130 μm
$\sigma_p/p$ = 0.5% @1GeV
dE/dx = 6%

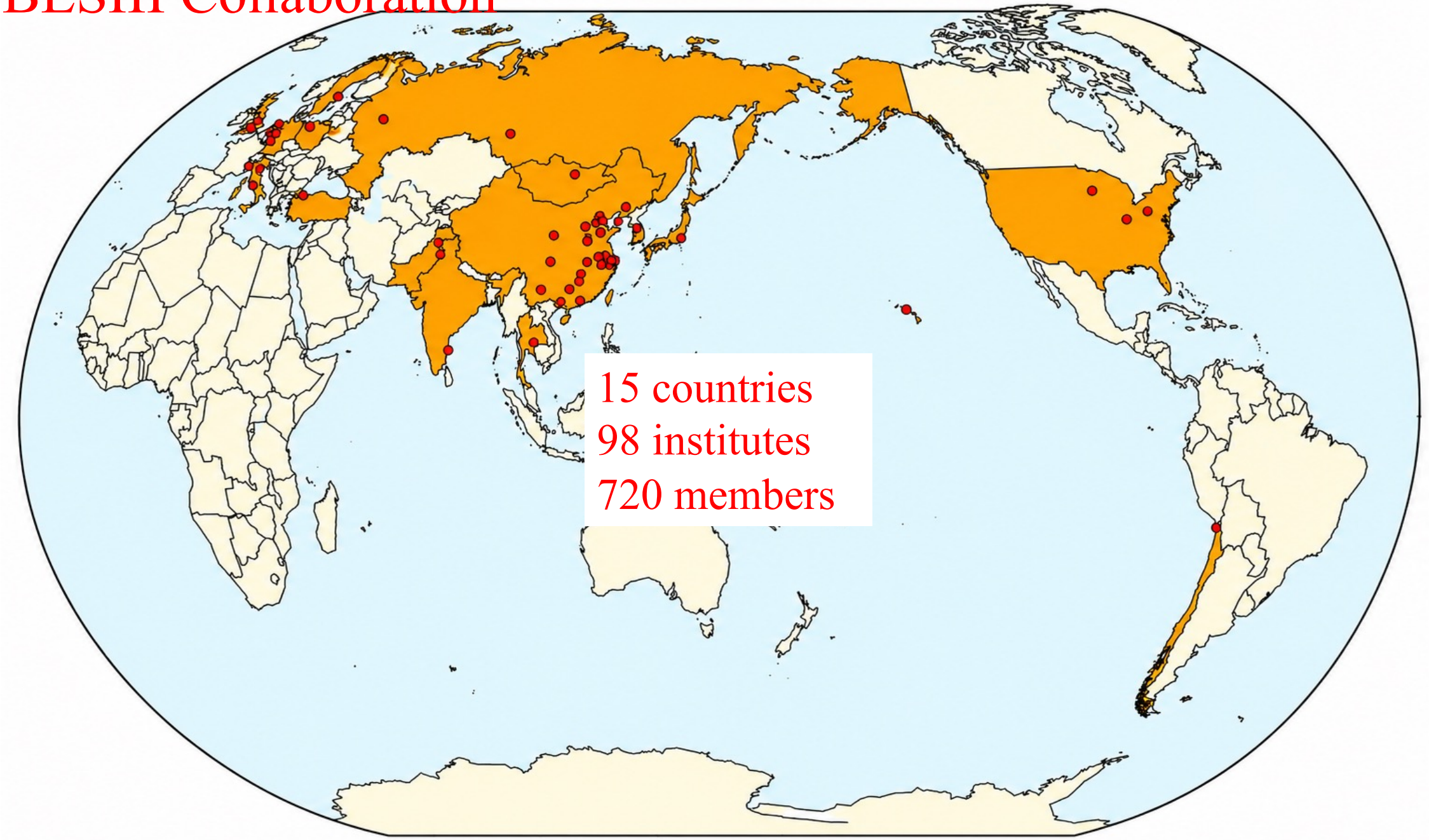
Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers

Extremely reliable operation of detector and readout electronics

# BESIII Collaboration



# BEPCII upgrade (BEPCII-U) in 2024

Luminosity reached $1.1\times10^{33}\ cm^{-2}s^{-1}$

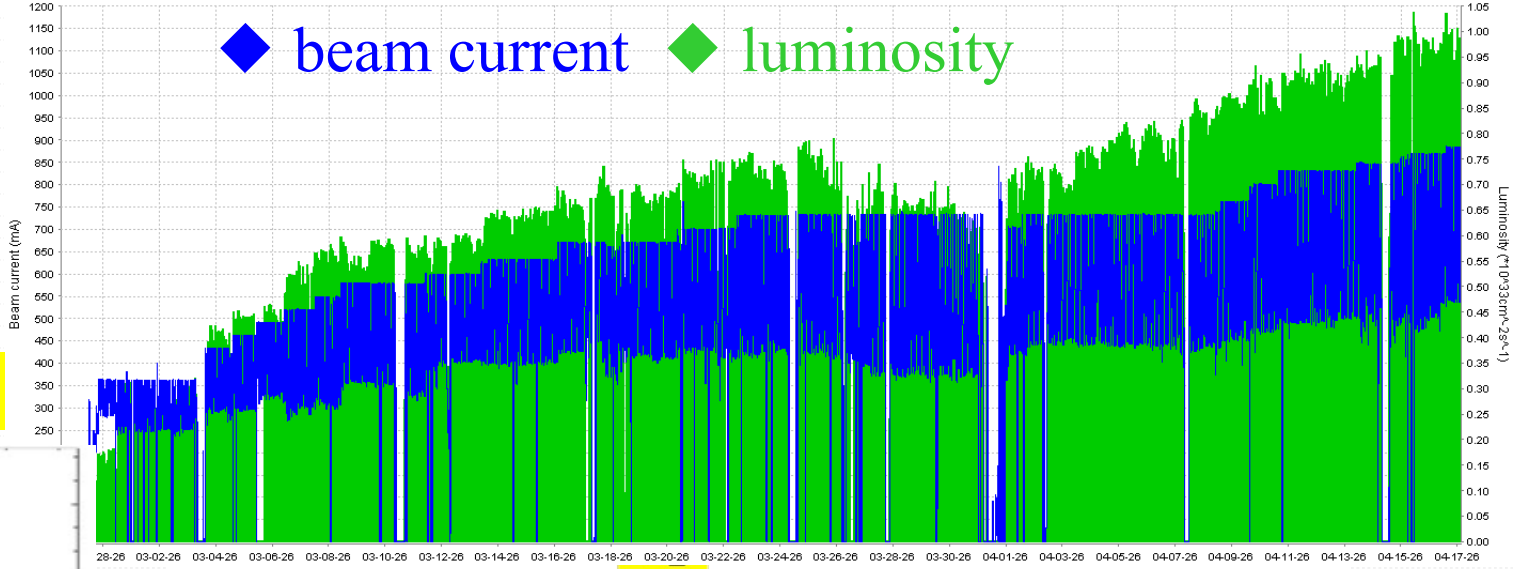
@$E_{beam}$=2.35 GeV (Pre-upgrade: **$0.35\times10^{33}cm^{-2}s^{-1}$**)

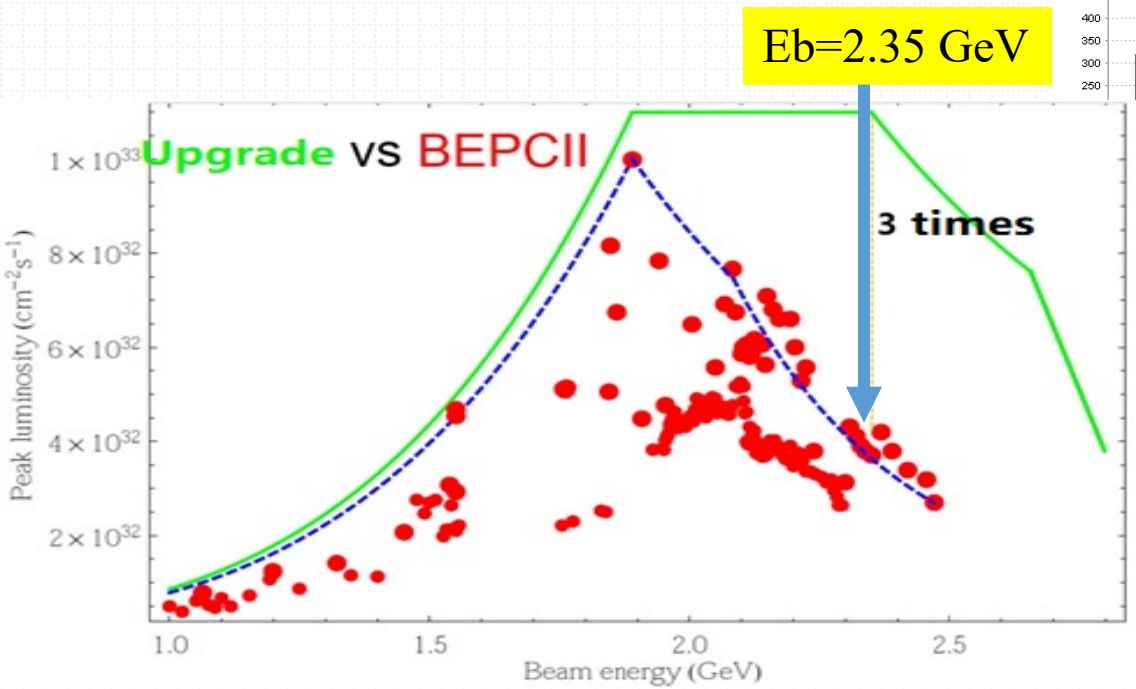
BEPCII upgrade (installation: 2024. 7- 2024. 12)

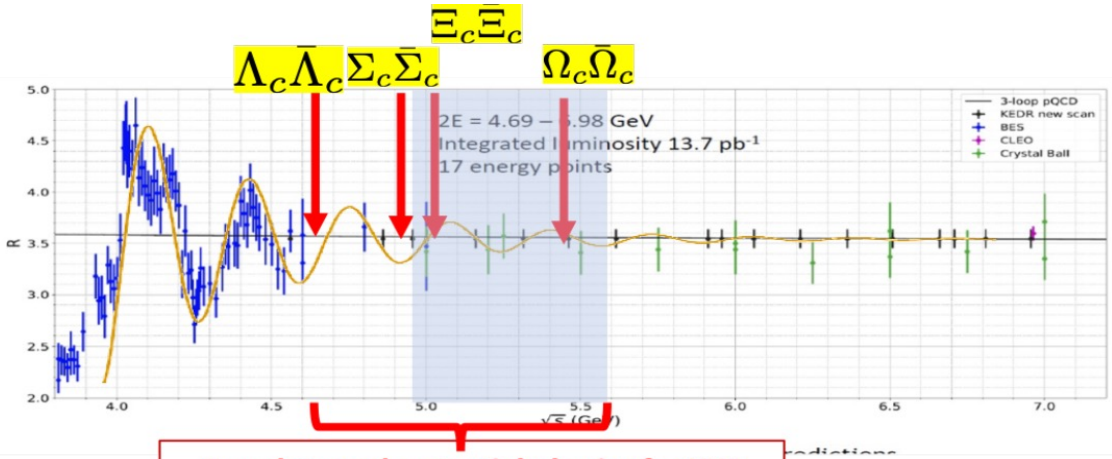
Highest beam energy: 2.8 GeV

Luminosity: $1.1\times10^{33}$ $cm^{-2}s^{-1}$ (4.0 ~ 5.0 GeV)

$(0.4\text{-}0.7)\times10^{33}$ $cm^{-2}s^{-1}$ (5.0 ~ 5.6GeV)

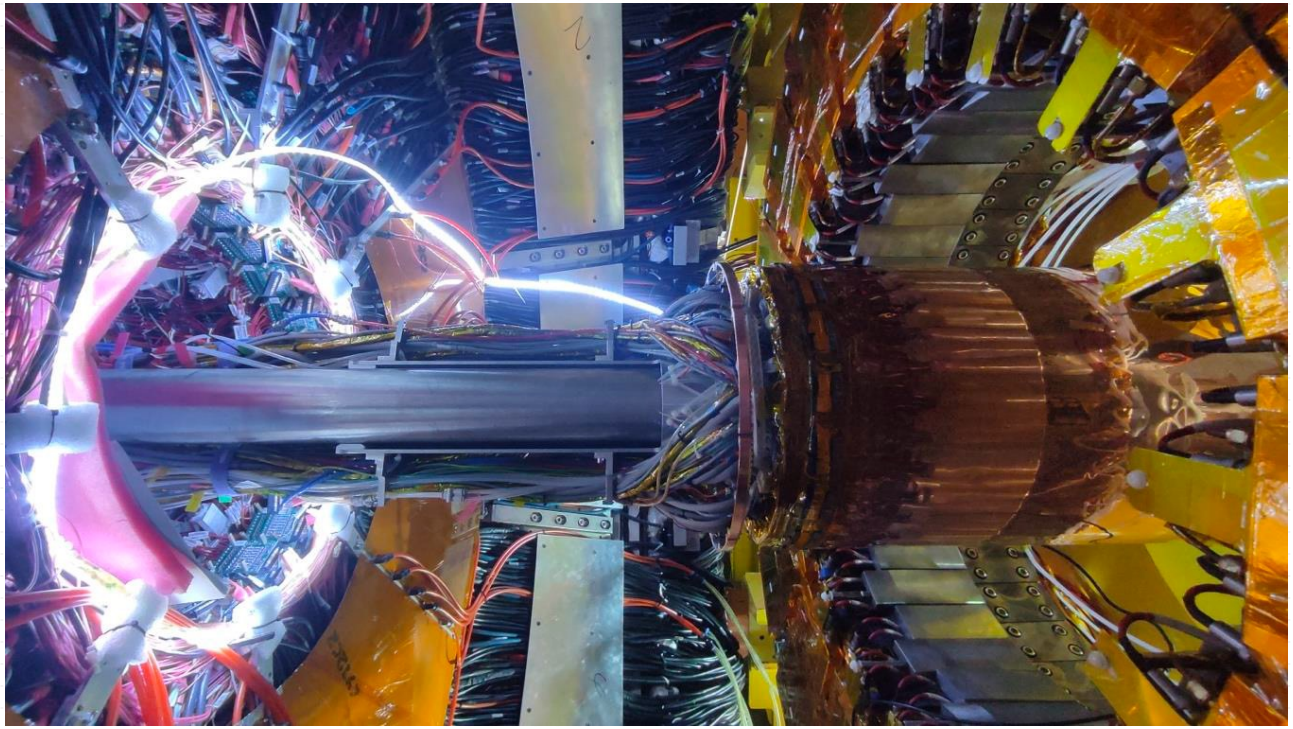



**Few data and potential physics for XYZ and charmed baryons**

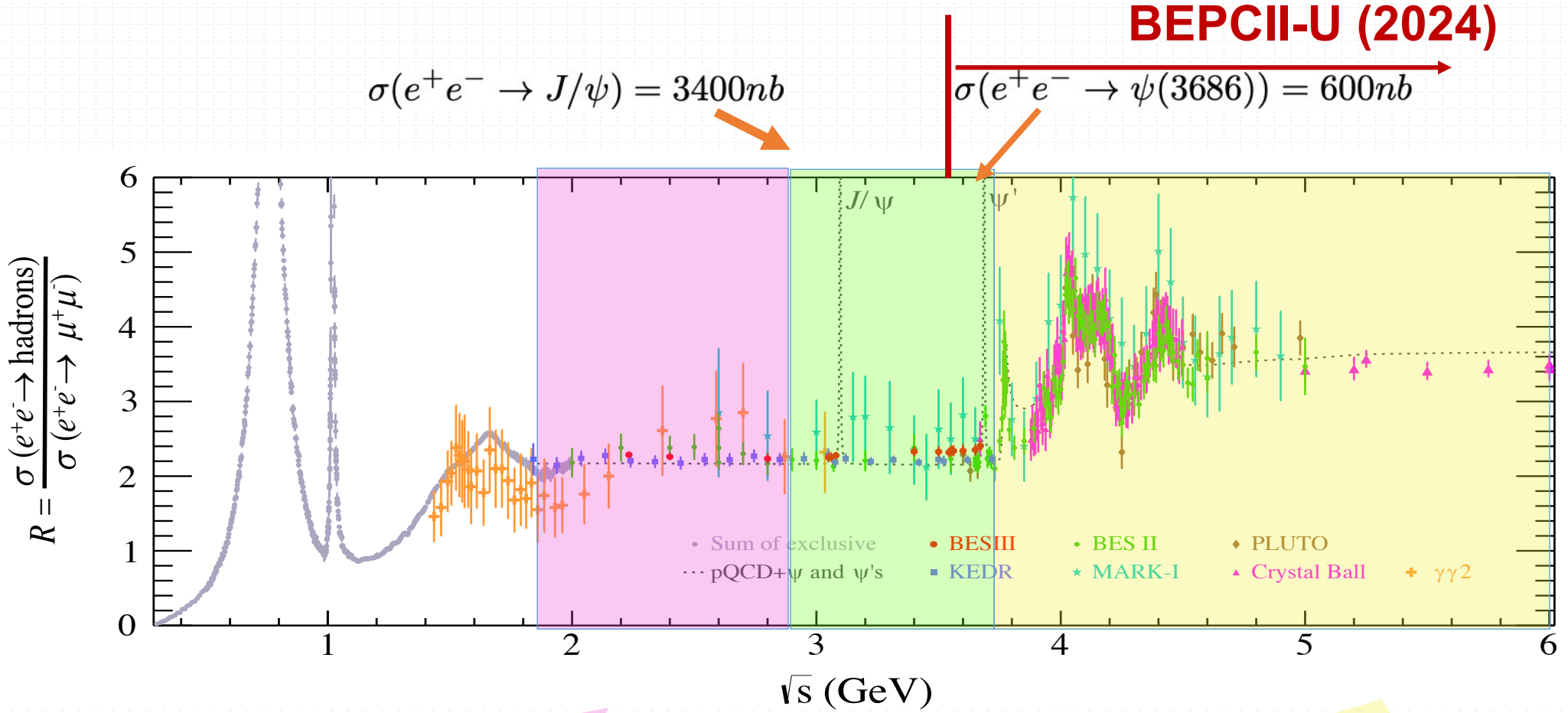
# The CGEM-IT: The new inner tracker of BESIII





- ✓ INFN-led international collaboration funded by MAECI-MOST, European commission
- ✓ Installed in 2024, during the summer shutdown.
- ✓ First ever non-Chinese detector on floor in a Chinese experiment

# Rich Physics at $\tau$-charm Energy Region



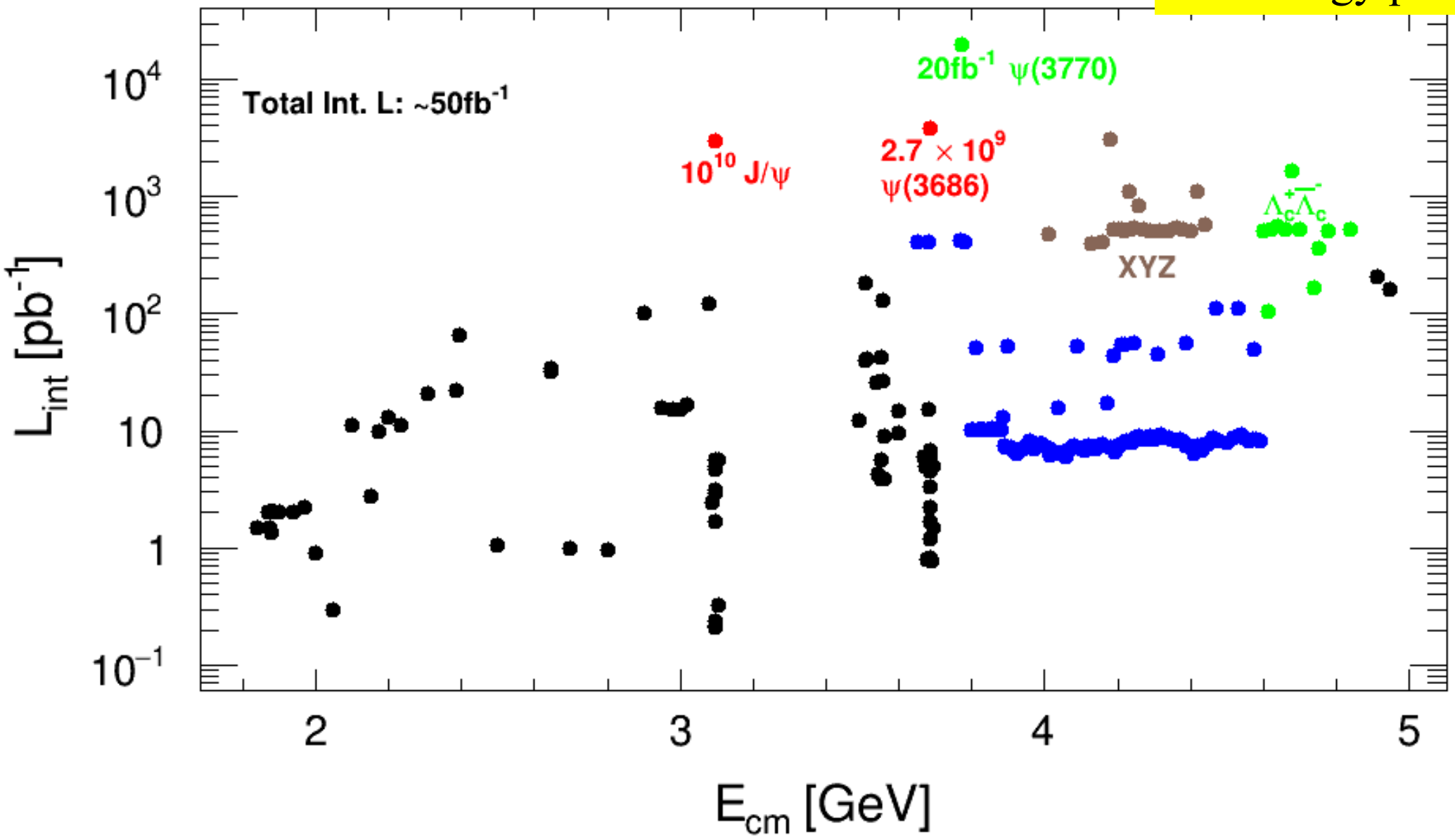

- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with $\tau$ lepton

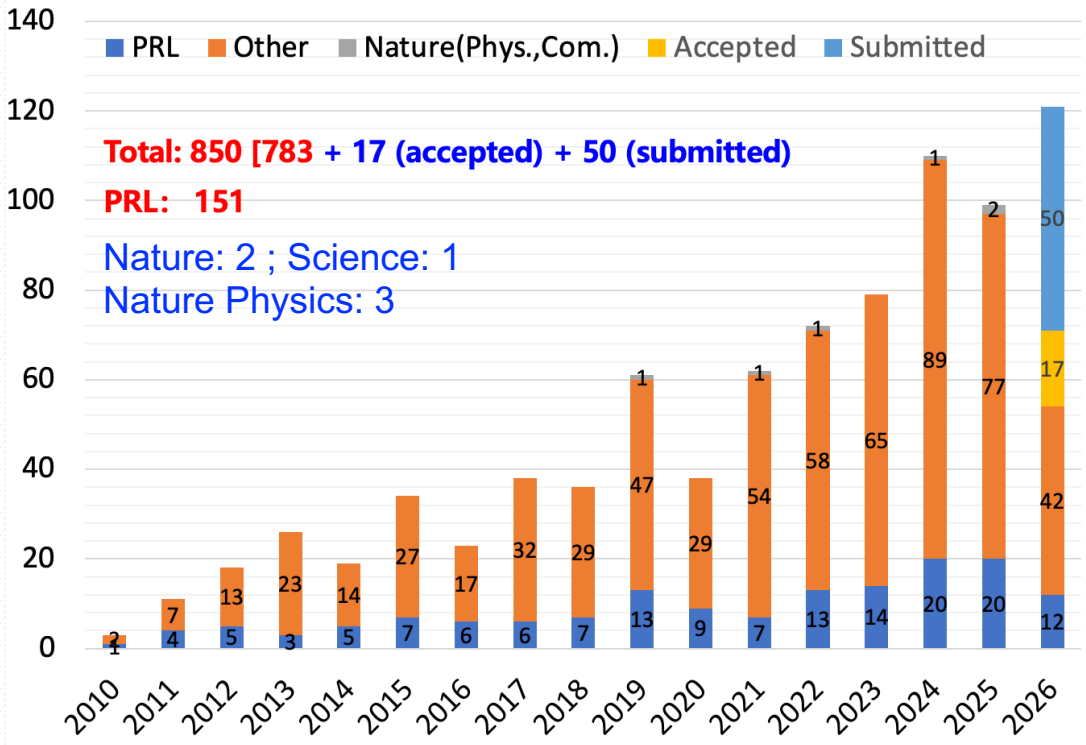
- XYZ particles
- Charm mesons
- Charm baryons

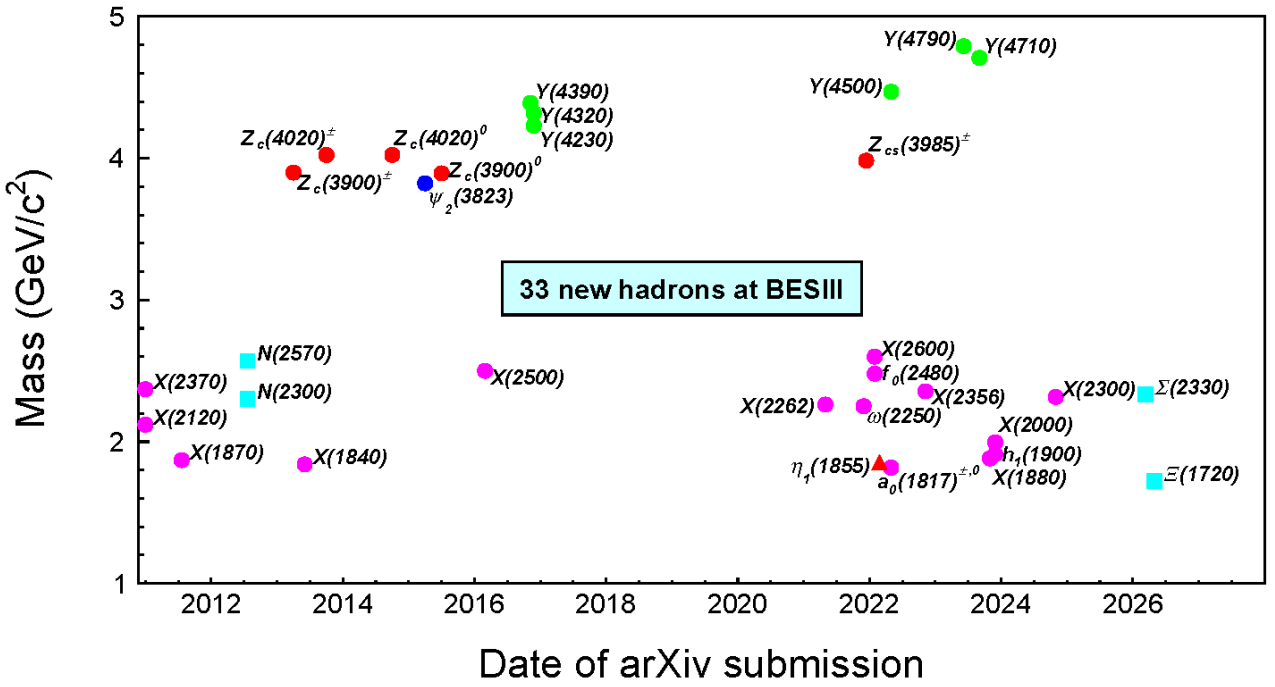
# 16 years data-taking at BESIII

223 energy points



# BESIII achievements

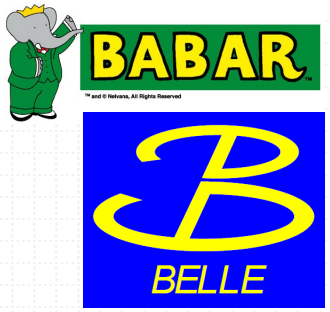



since 2022: output of BESIII comparable to ATLAS and CMS (!) — collaborations 4 to 5 our size!

# Roadmap of CP violation in flavored hadrons

- **All of them are consistent with CKM theory in the SM, but too small to explain the matter-dominant world.**
- **Before 2025, there is no observation of CPV in the baryon system.**




$5.2\sigma$ CPV in $\Lambda_b$ decay:
$\Lambda_b \to p\pi^+\pi^-K^-$

$K$ meson $CPV$ — 1964

$B$ meson $CPV$ — 2001

$D$ meson $CPV$ — 2019

$\Lambda_b$ baryon — 2025

Hyperon/charmed baryon?

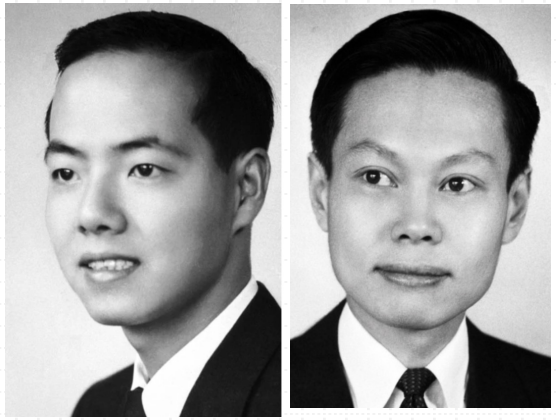
James Watson Cronin



Val Logsdon Fitch


[1] Phys. Rev. 104 (1956) 254-258
[2] Phys. Rev. 105 (1957) 1413-1414
[3] Phys. Rev. Lett., 1964, 13: 138-140
[4] Phys. Rev. Lett., 2001, 87: 091801
[5] Phys. Rev. Lett., 2001, 87: 091802
[6] Phys. Rev. Lett., **122**, 211803 (2019)
[7] Nature **643** (2025) 8074, 1223-1228

# Non-leptonic 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 $\pi$:

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

Transitions:
S (parity odd) final state in s-wave
P (parity even) final state in p-wave

The measurable decay parameters:

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

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

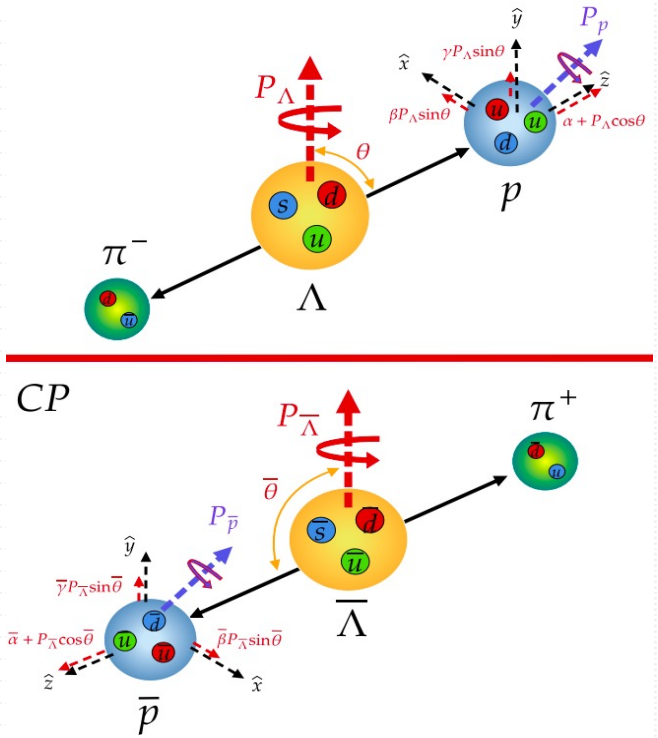
$$\beta_Y = (1-\alpha_Y^2)^{\frac{1}{2}} sin\phi_Y\,, \quad \gamma_Y = (1-\alpha_Y^2)^{\frac{1}{2}} cos\phi_Y$$

Hyperon decay

$$S = |S|\exp(i\xi_S + i\delta_S)$$
$$\mathrm{P} = |\mathrm{P}|\exp(i\xi_P + i\delta_P)$$

Anti-hyperon decay

$$\bar{S} = -|S|\exp(-i\xi_S + i\delta_S)$$
$$\bar{P} = \ |\mathrm{P}|\exp(-i\xi_P + i\delta_P)$$




$CP$ convervation: $\alpha_Y = -\bar{\alpha}_Y, \beta_Y = -\bar{\beta}_Y, \phi_Y = -\bar{\phi}_Y$

# CP observables 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

Not sensitive to $CPV$

**Easy to measure**

Polarization of decayed baryon needs to be measured

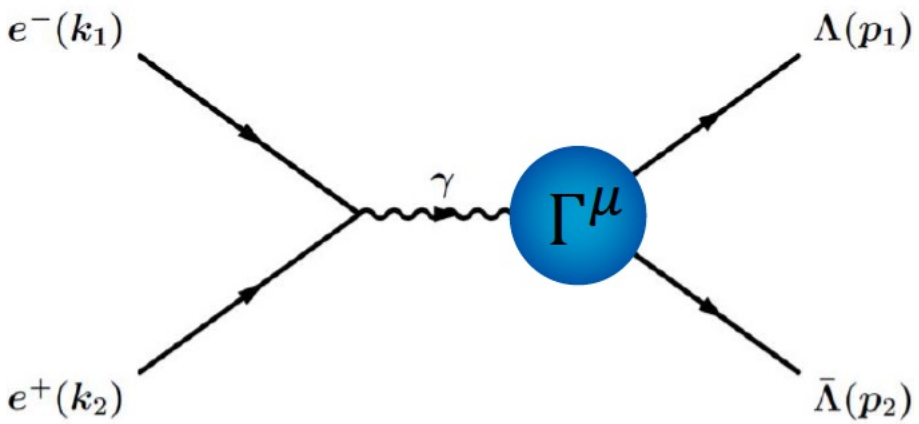
strong phase weak phase

| | | SM Predictions |
|---|---|---|
| **Decay width difference** | $\Delta_{CP} = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}} \approx \sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}}\sin(\delta_P-\delta_S)\sin(\xi_P-\xi_S)$ | $-5.4\times10^{-7}$ |
| **Decay parameter difference** | $A_{CP} = \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} \approx -\tan(\delta_P-\delta_S)\,tan(\xi_P-\xi_S)$ | $-0.5\times10^{-4}$ |
| **Decay parameter difference** | $B_{CP} = \frac{\beta+\bar{\beta}}{\alpha-\bar{\alpha}} \approx tan(\xi_P-\xi_S)$ | $3.0\times10^{-3}$ |

$\Xi^-, \Xi^0, \Omega^-$ cascade decay

$|\Delta I| = \frac{1}{2}$ limit

# Entangled and Polarized hyperon pairs produced in $e^+e^-$ collisions




$$\Gamma^\mu(p_1,p_2) = -ie\left[\gamma^\mu F_1(s) + i\frac{\sigma^{\mu\nu}}{2M_B}q_\nu F_2(s)\right]$$

$$s = (p_1 + p_2)^2 \qquad q = p_1 - p_2$$

Helicity Form Factors: $G_M(s) = F_1(s) + F_2(s), \quad G_E(s) = F_1(s) + \tau F_2(s)$

helicity non-flip helicity flip

- ✓ The same description for continuum and at resonances
- ✓ Form Factors are complex

$$\Delta\Phi = \mathrm{Arg}\left(\frac{G_E}{G_E}\right)$$

Angular distribution:

$$\alpha_\psi = \frac{\tau|G_M|^2 - |G_E|^2}{\tau|G_M|^2 + |G_E|^2}$$

$$\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_\psi \cos^2\theta \qquad -1 < \alpha_\psi < 1$$

# If $\Delta\Phi \neq 0$, $\Lambda$ and $\overline{\Lambda}$ are transversely polarized

Correlated 5-dim. angular distribution in differential cross-section of this process:

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

$$\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) = 1+\alpha_\psi\cos^2\theta_\Lambda$$

Unpolarized part

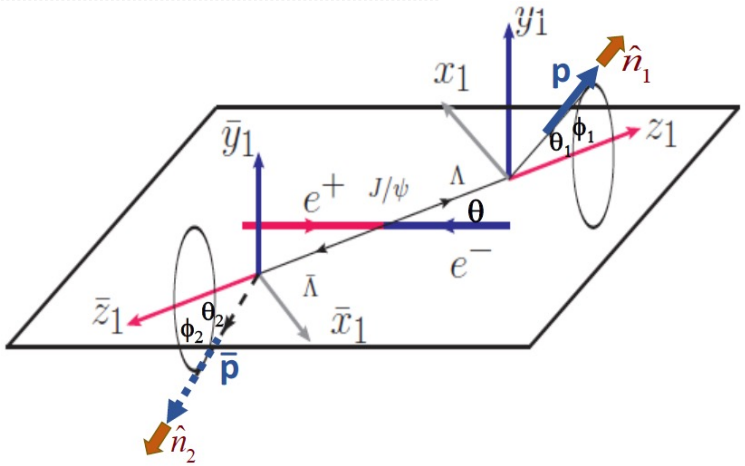
Spin correlated part

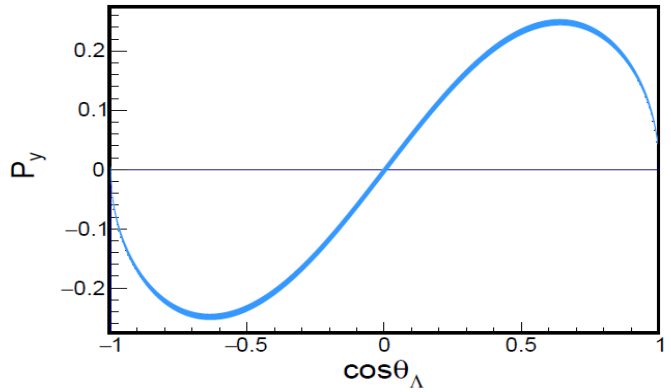
$$+\alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right]$$

$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}\right)$$

$$+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\,\sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_+n_{2,y}\right),$$

Spin Polarized part




Spin correlated term and polarization term can be used to determine $\alpha_-$ and $\alpha_+$ simultaneously and precisely.

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

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)

# Search for CPV in $\Lambda \to p\pi^-$ with $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

[1] 1.3 billion: Nature Phys 15(2019)631
[2] 10 billion: Phys. Rev. Lett. 129 (2022) 13, 131801

3.2 M $\Lambda\bar{\Lambda}$ pairs were reconstructed.(0.1% bkg)

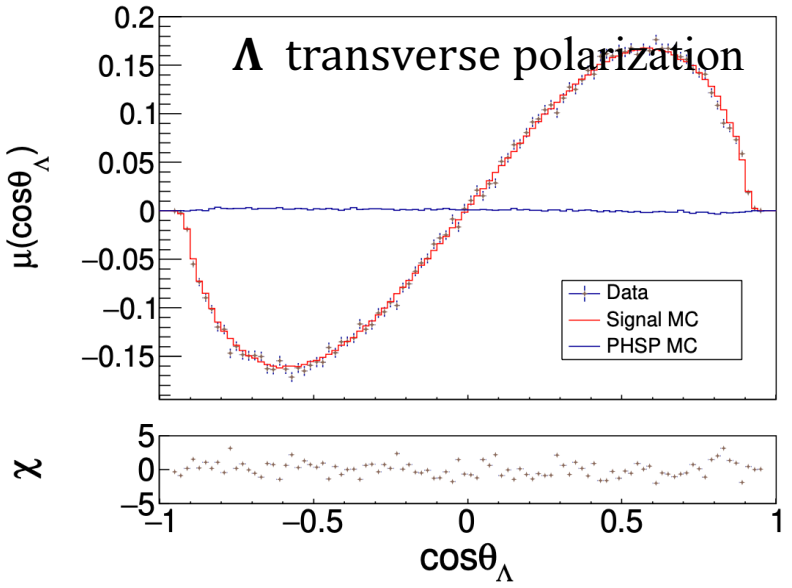
Most precise decay parameters:

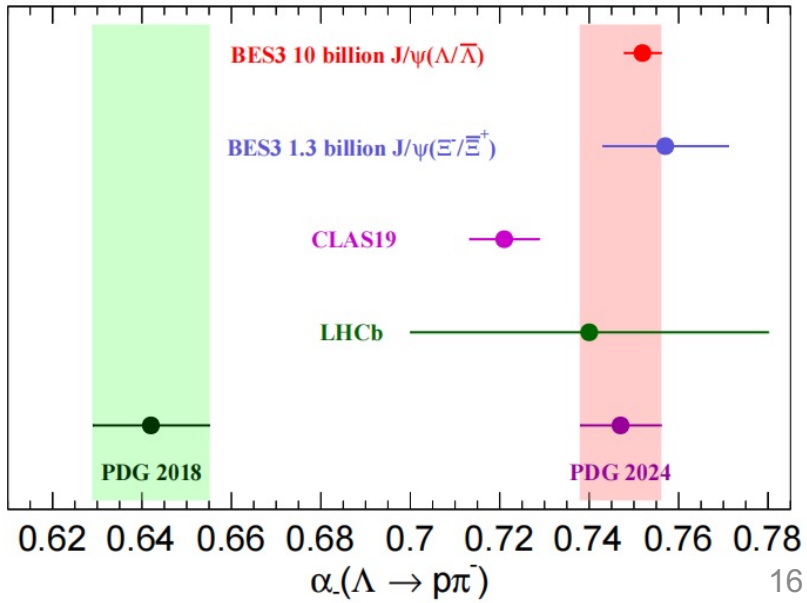
$$\Delta\Phi = 0.7521(42)(66)$$

$$\alpha_- = \ 0.7519(36)(24)$$

$$\alpha_+ = -0.7559(36)(30)$$

$$\alpha_{avg} = 0.7542(10)(24)$$



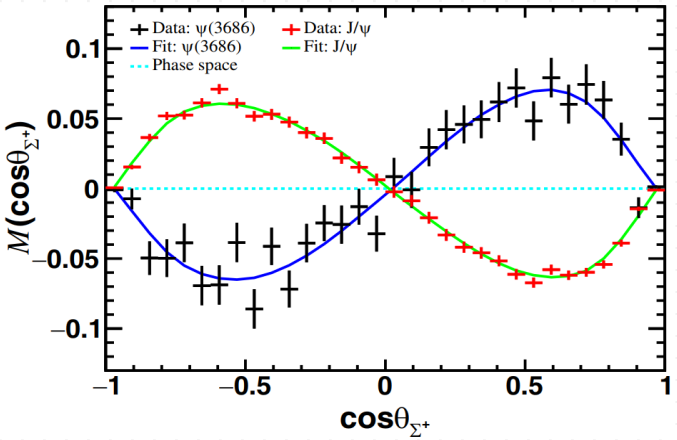




- Most precise measurement of Λ decay parameter
- Most precise $A_{CP}$ measurement in hyperon decay:

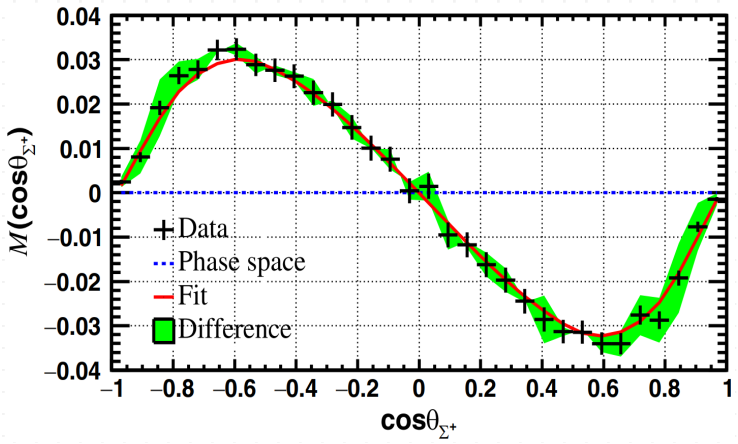
$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = (-2.5 \pm 4.6 \pm 1.1)\times 10^{-3}$$

# Search for CPV in $\Sigma^+$ decay (10 billion $J/\psi$ )

[1] $J/\psi[\psi(3686)] \to \Sigma^+\bar{\Sigma}^- \to p\pi^0\bar{p}\pi^0$ [2] $J/\psi \to \Sigma^+(\to n\pi^+)\bar{\Sigma}^-(\to \bar{p}\pi^0) + c.c.$




10B $J/\psi$ and 2.7B $\psi(3686)$




The most precise decay parameters:

$\alpha_0(\Sigma^+ \to p\pi^0) = -0.975(11)(2)$

$\bar{\alpha}_0(\bar{\Sigma}^- \to \bar{p}\pi^0) = 0.999(11)(4)$

$\alpha_+(\Sigma^+ \to n\pi^+) = 0.0481(31)(19)$

$\alpha_-(\bar{\Sigma}^- \to \bar{n}\pi^-) = -0.0565(47)(22)$

$\Delta\Phi_{J/\psi} = -0.2744(33)(10)$ rad $\quad \Delta\Phi_{J/\psi} = -0.2772(44)(41)$ rad

$\Delta\Phi_{\psi(3686)} = 0.427(22)(3)$ rad

Opposite direction of the $\Sigma^+$ polarization in $J/\psi$ and $\psi(3686)$

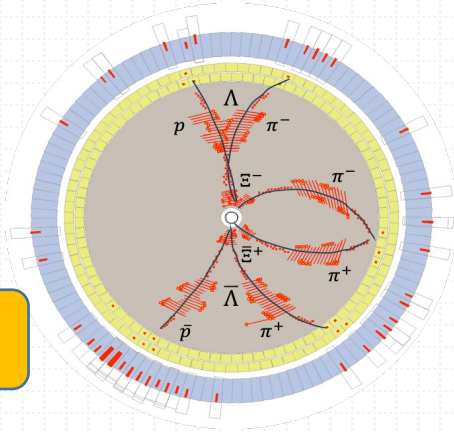
The most precise CP test in $\Sigma$ sector:

$$A_{CP}(\Sigma^+ \to p\pi^0) = \frac{\alpha_0+\bar{\alpha}_0}{\alpha_0-\bar{\alpha}_0} = (-1.18 \pm 0.83 \pm 0.28) \times 10^{-2}$$

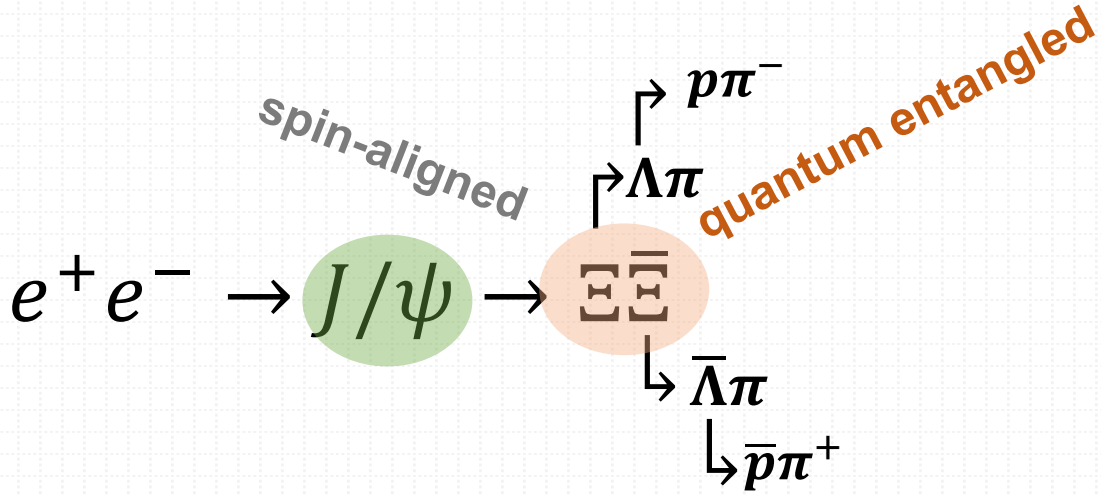
$$A_{CP}(\Sigma^+ \to n\pi^+) = \frac{\alpha_+ + \bar{\alpha}_-}{\alpha_+ - \bar{\alpha}_-} = (-8.0 \pm 5.2 \pm 2.8) \times 10^{-2}$$


[1]Phys.Rev.Lett. 135 (2025) 14, 141804
[2]Phys.Rev.Lett. 131 (2023) 19, 191802

# Search for CPV in Ξ decay




Phys. Rev. D 99, 056008 (2019)
Phys. Lett. B 772, 16 (2017)




Through the sequential decays of Ξ, the $B_{CP}$ (CPV phase) can be directly measured!

$$\omega = (\alpha_\psi, \Delta\Phi, \alpha_\Xi, \phi_\Xi, \alpha_{\bar{\Xi}}, \phi_{\bar{\Xi}}, \alpha_\Lambda, \alpha_{\bar{\Lambda}})$$

Hyperon Production | Hyperon decays

$$W(\xi;\omega) = \sum_{\mu,\bar{\nu}} C_{\mu\bar{\nu}} \sum_{\mu'\bar{\nu}'} a^{\Xi}_{\mu,\mu'} a^{\bar{\Xi}}_{\bar{\nu},\bar{\nu}'} a^{\Lambda}_{\mu',0} a^{\bar{\Lambda}}_{\bar{\nu}',0}$$

$$\xi = (\theta_\Xi, \theta_\Lambda, \phi_\Lambda, \theta_{\bar{\Lambda}}, \phi_{\bar{\Lambda}}, \theta_p, \phi_p, \theta_{\bar{p}}, \phi_{\bar{p}})$$

**CPV tests in hyperon decays**

$\Xi^- \to \Lambda\pi^-$

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

$\bar{\Xi}^+ \to \bar{\Lambda}\pi^+$

$$\bar{S} = |S|\exp(-i\xi_S + i\delta_S)$$
$$\bar{P} = -|P|\exp(-i\xi_P + i\delta_P)$$

CP-odd phases

$$A_{CP} := \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} \text{ and } B_{CP} := \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}}$$

$$A_{\rm CP} = -\tan(\delta_P - \delta_S)\tan(\xi_P - \xi_S)$$
$$B_{\rm CP} = \tan(\xi_P - \xi_S)\ ,$$

The ***perfect*** reaction for hyperon *CPV* searches!

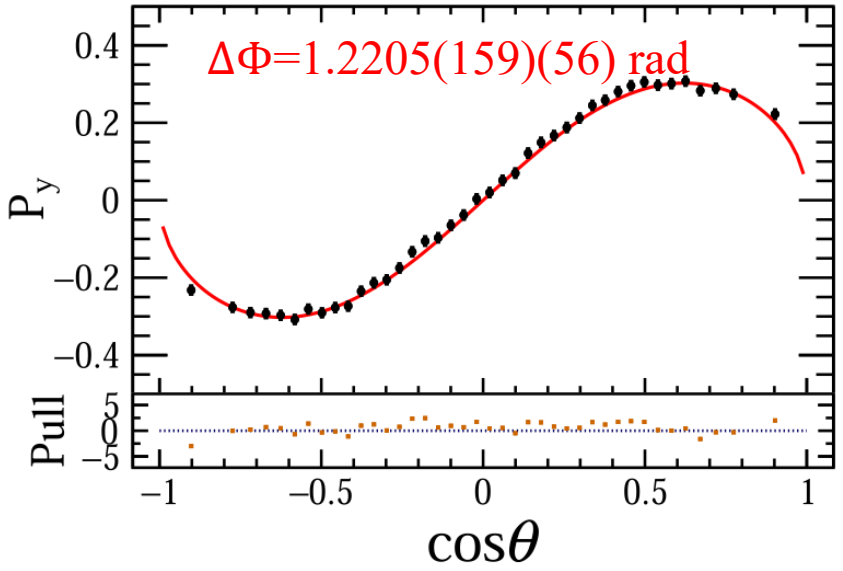
# Search for CPV in $\Xi^- \to \Lambda\pi^-$ with $e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+$

Nature 606 (2022) 64-69, 1.3 billion J/$\psi$ : 73 K $\Xi^-\bar{\Xi}^+$ pairs

PRL 136, 201802 (2026) : $10^{10}$ J/$\psi$ : 5.8×$10^5$ $\Xi^-\bar{\Xi}^+$pairs (0.3% bkg)

The most precise decay parameters:

$\alpha_\Xi = -0.3813(26)(5)$
$\bar{\alpha}_\Xi = \ \ 0.3873(26)(6)$
$\Phi_\Xi = -0.0008(72)(10)$ rad
$\bar{\Phi}_\Xi = \ \ 0.0020(72)(6)$ rad
$\alpha_\Lambda = \ \ 0.7434(39)(15)$
$\bar{\alpha}_\Lambda = -0.7478(38)(15)$




Three CPV tests:

$A_{CP}^{\Xi} := \frac{\alpha_\Xi + \bar{\alpha}_\Xi}{\alpha_\Xi - \bar{\alpha}_\Xi} = (-7.8 \pm 4.8 \pm 0.8) \times 10^{-3}$

$A_{CP}^{\Lambda} := \frac{\alpha_\Lambda + \bar{\alpha}_\Lambda}{\alpha_\Lambda - \bar{\alpha}_\Lambda} = (-2.9 \pm 4.3 \pm 0.7) \times 10^{-3}$

$\Delta\Phi_{CP}^{\Xi} := \frac{\Phi_\Xi + \bar{\Phi}_\Xi}{2} = (0.6 \pm 5.1 \pm 0.2) \times 10^{-3}$ rad

The weak CP and strong phases are extracted :

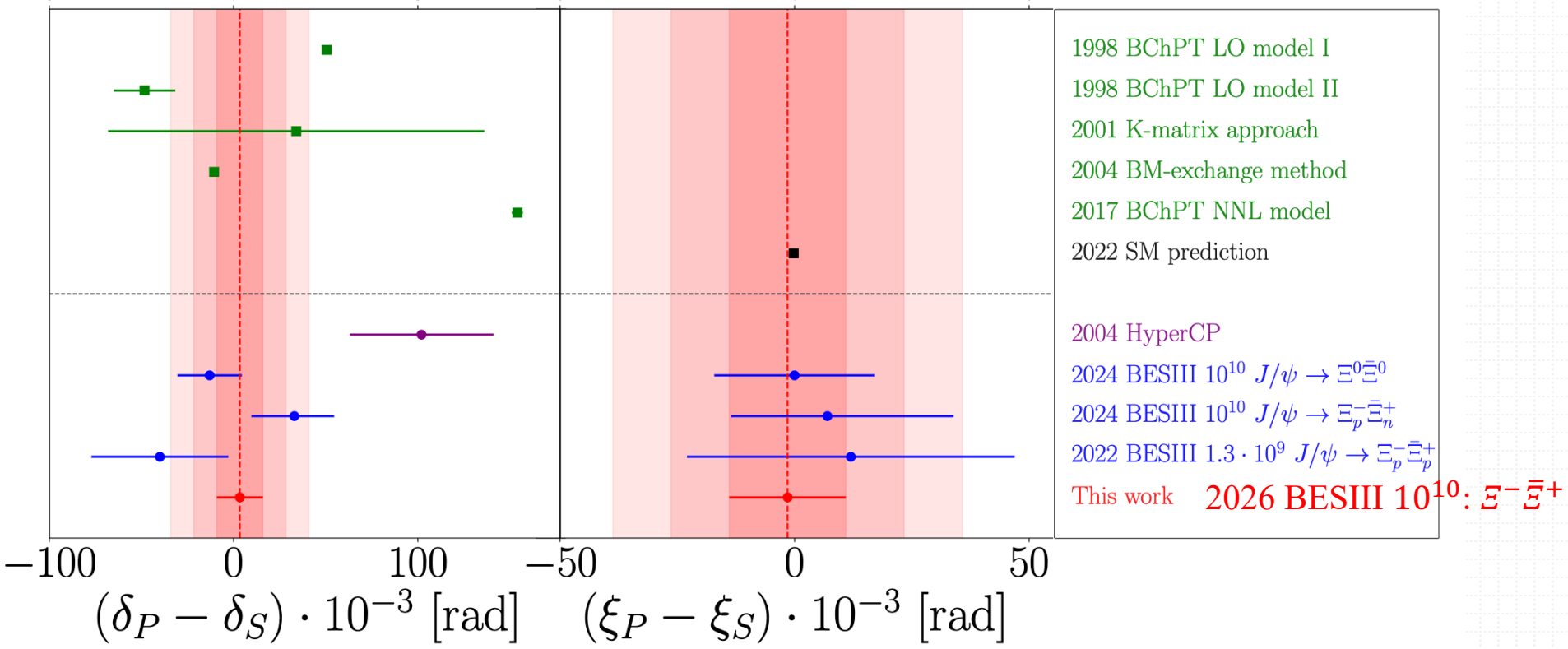
$(\boldsymbol{\xi_P - \xi_S}) = (-0.2 \pm 1.2 \pm 0.1) \times 10^{-2}$ rad
$(\boldsymbol{\delta_P - \delta_S}) = (0.3 \pm 1.2 \pm 0.2) \times 10^{-2}$ rad

$J/\psi \to \Xi^0\bar{\Xi}^0$ [PRD108(2023)L031106]:

$A_{CP}^{\Xi 0} = (-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$
$A_{CP}^{\Lambda} = (6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$
$\Delta\Phi_{CP}^{\Xi 0} = (-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$ rad

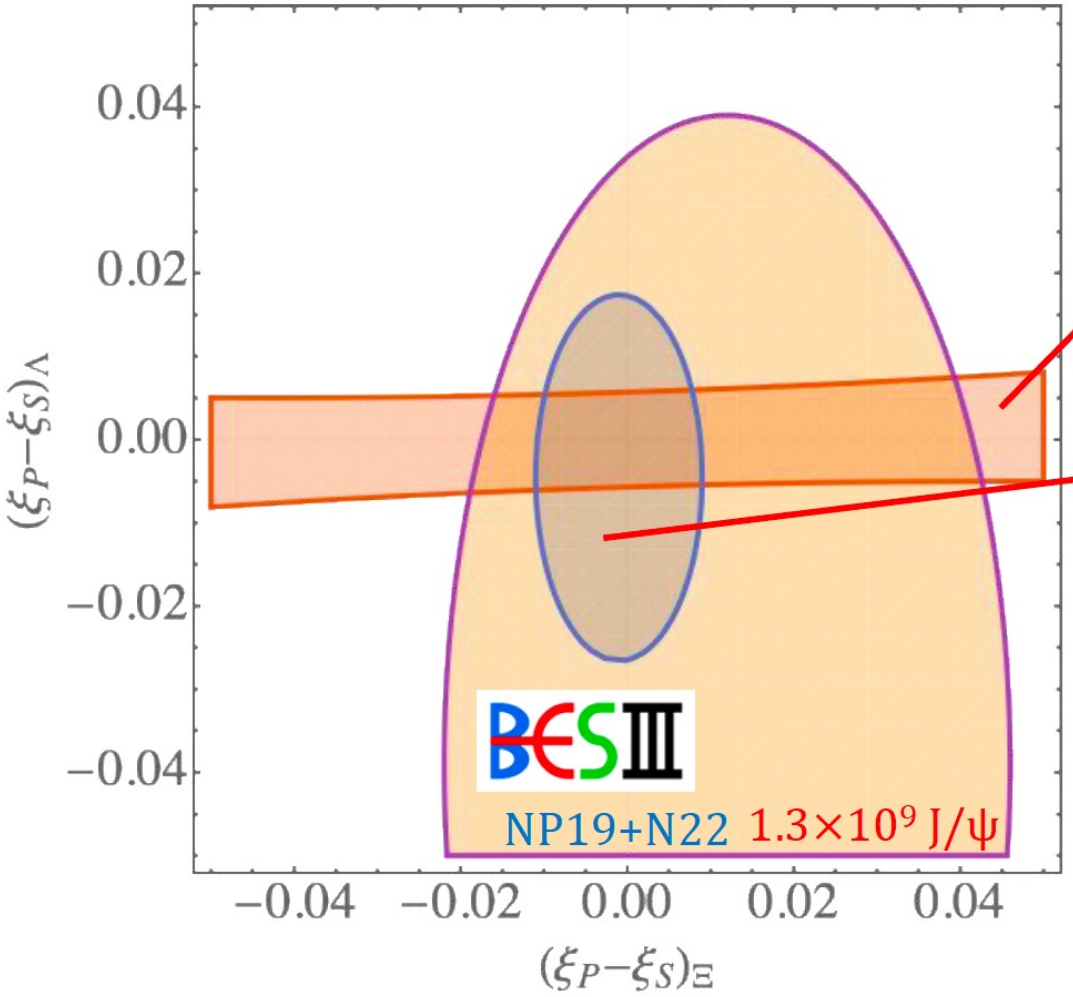
# CP tests in hyperon decays with 10 billion $J/\psi$

PRL 129 (2022) 131801 : $32\times10^5$ $\Lambda\bar{\Lambda}$ pairs (0.1% bkg)
PRD 108 (2023) L031106: $3.3\times10^5$ $\Xi^0\bar{\Xi}^0$pairs (2% bkg)
PRL 136 (2026) 201802: $5.8\times10^5$ $\Xi^-\bar{\Xi}^+$pairs (0.3% bkg)



# Hyperon weak phases

From Andrzej Kuspc@FPCP26




HyperCP PRL 93 (2004) 262001

**HyperCP** $\&(\delta_P-\delta_S)_{\Lambda\pi}$

$1.2\times10^8$ $\Xi^-$ $4.1\times10^7$ $\bar{\Xi}^+$

BESIII $10^{10}$ J/ψ

$\left(\xi_P^\Lambda-\xi_S^\Lambda\right)=(-0.6\pm2.2)\times10^{-2}$

$\left(\xi_P^\Xi-\xi_S^\Xi\right)=(-0.1\pm1.0)\times10^{-2}$

PRL 136, 201802
+PRL129

$6\times10^5$ $\Xi^-\bar{\Xi}^+$ and $3.2\times10^6$ $\Lambda\bar{\Lambda}$

$$-3.8\times10^{-4}<(\xi_P-\xi_S)_\Xi^{\mathrm{SM}}<-0.3\times10^{-4}$$

$$-2.4\times10^{-4}<(\xi_P-\xi_S)_\Lambda^{\mathrm{SM}}<2.0\times10^{-4}$$

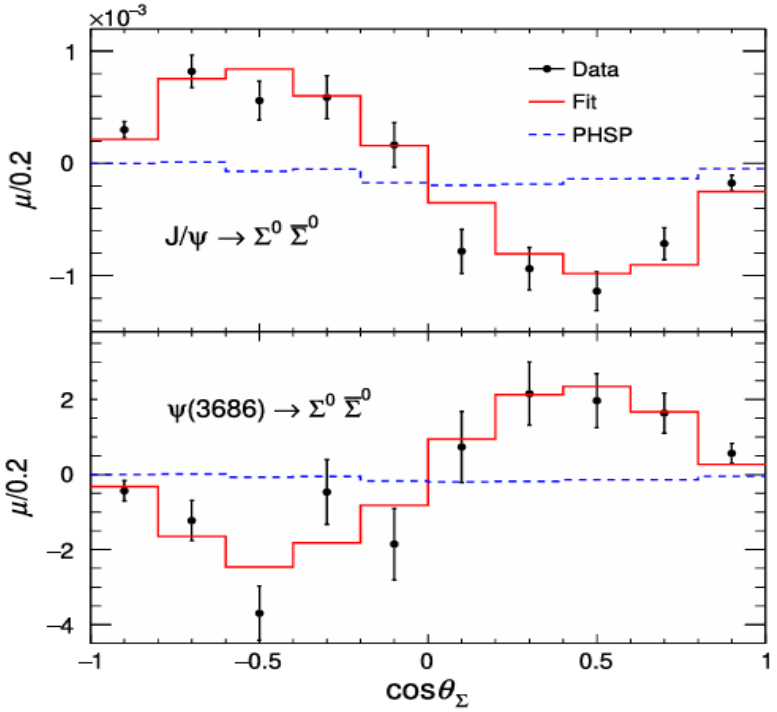
Nature 606 (2022) 64-69, 1.3 billion J/$\psi$ : 73 K $\Xi^-\bar{\Xi}^+$ pairs
PRL 136,201802 , 10 billion J/$\psi$ : 580 K $\Xi^-\bar{\Xi}^+$ pairs

# CP test in $\Sigma^0 \to \Lambda\gamma$ decay

$e^+e^- \to J/\psi, \psi(3686) \to \Sigma^0(\to \Lambda\gamma)\bar{\Sigma}^0(\to \bar{\Lambda}\gamma), \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

Phys. Rev. Lett. 133 (2024) 10, 101902

10 B $J/\psi$ and 2.7 B $\psi(3686)$ : 1.1 million $\Sigma^0\bar{\Sigma}^0$ pairs




$\Delta\Phi_{J/\psi} = -0.0828(68)(33)$ rad

$\Delta\Phi_{\psi(3686)} = 0.512(85)(34)$ rad

Opposite directions of the $\Sigma^0$ polarization,
Similar behavior is observed in $\Sigma^+$, but not in $\Lambda$ or $\Xi$.

The first attempt to measure the P-violating decay parameter of $\Sigma^0 \to \Lambda\gamma$:

$$\alpha_{\Sigma^0} = -0.0017(21)(18)$$
$$\bar{\alpha}_{\Sigma^0} = 0.0021(20)(22)$$

The first CP test in $\boldsymbol{\Sigma^0 \to \Lambda\gamma}$ **decay**.

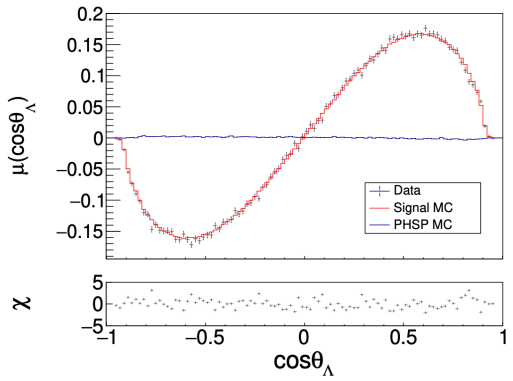
$$A_{CP}^{\Sigma^0} := \alpha_{\Sigma^0} + \bar{\alpha}_{\Sigma^0} = (-0.4 \pm 2.9 \pm 1.3) \times 10^{-3}$$

# Spin polarizations of different hyperons

$$\mu(\cos\theta_\Lambda) \approx \frac{1+\alpha_{J/\psi}\cos^2\theta_\Lambda}{3+\alpha_{J/\psi}} P_y(\theta_\Lambda)$$

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

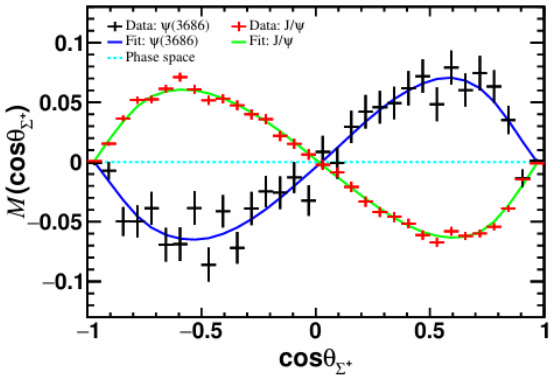
PRL129, 131801(2022)




$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)$ rad

## $\psi \to \Sigma^+\bar{\Sigma}^-$

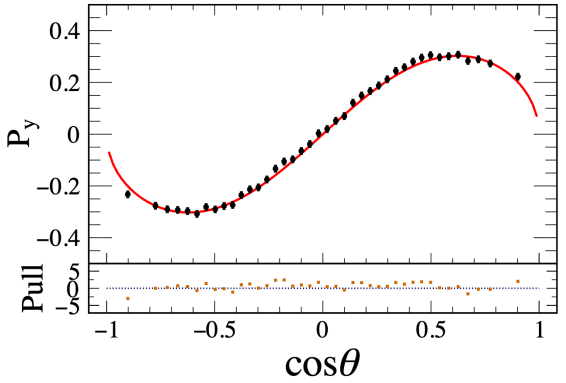
PRL135, 141804 (2025)




$\Delta\Phi(J/\psi) = (-0.2744 \pm 0.0033 \pm 0.0010)$rad
$\Delta\Phi(\psi(2S)) = (0.427 \pm 0.022 \pm 0.003)$rad

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

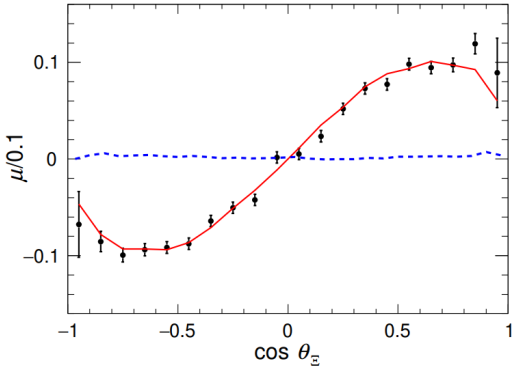
Phys. Rev. Lett. 136, 201802 (2026)




$\Delta\Phi = (1.2205 \pm 0.0159 \pm 0.0056)$ rad

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

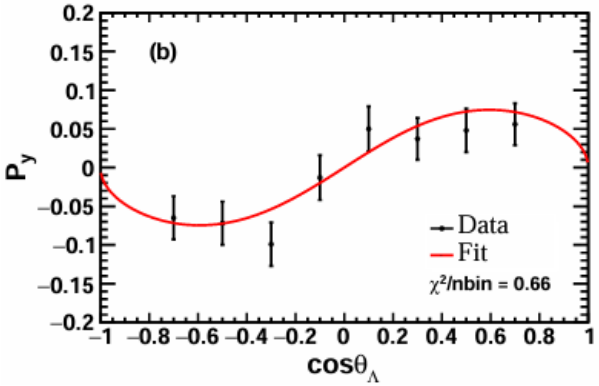
Phys. Rev. D 108, L031106 (2023)




$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018)$ rad

## $\psi(3686) \to \Lambda\bar{\Lambda}$

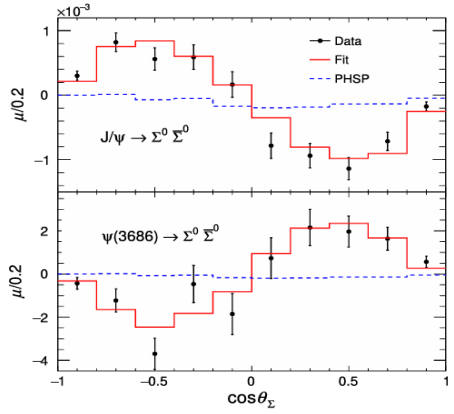
arXiv:2509.15276




$\Delta\Phi = (0.366 \pm 0.064 \pm 0.013)$ rad

## $\psi \to \Sigma^0\bar{\Sigma}^0$

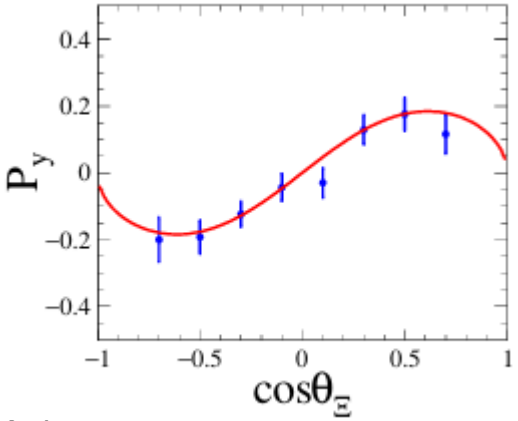
Phys. Rev. Lett. 133 (2024) 10, 101902




$\Delta\Phi(J/\psi) = (-0.0828 \pm 0.0068 \pm 0.0033)$rad
$\Delta\Phi(\psi(2S)) = (0.512 \pm 0.085 \pm 0.034)$rad

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

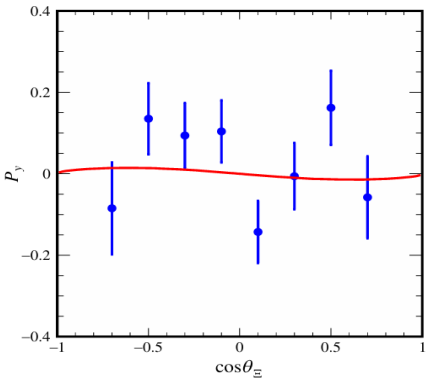
Phys. Rev. D 106, L091101 (2022)




$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)$ rad

## $\psi(3686) \to \Xi^0\bar{\Xi}^0$

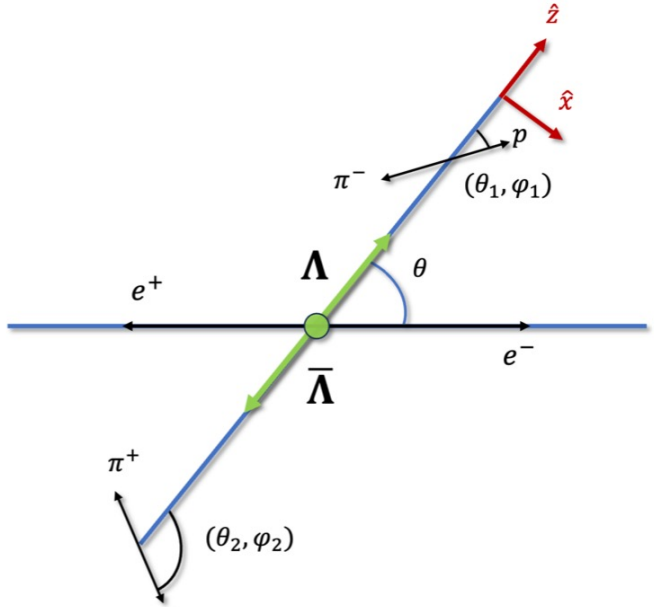
Phys. Rev. D 108, L011101 (2023)

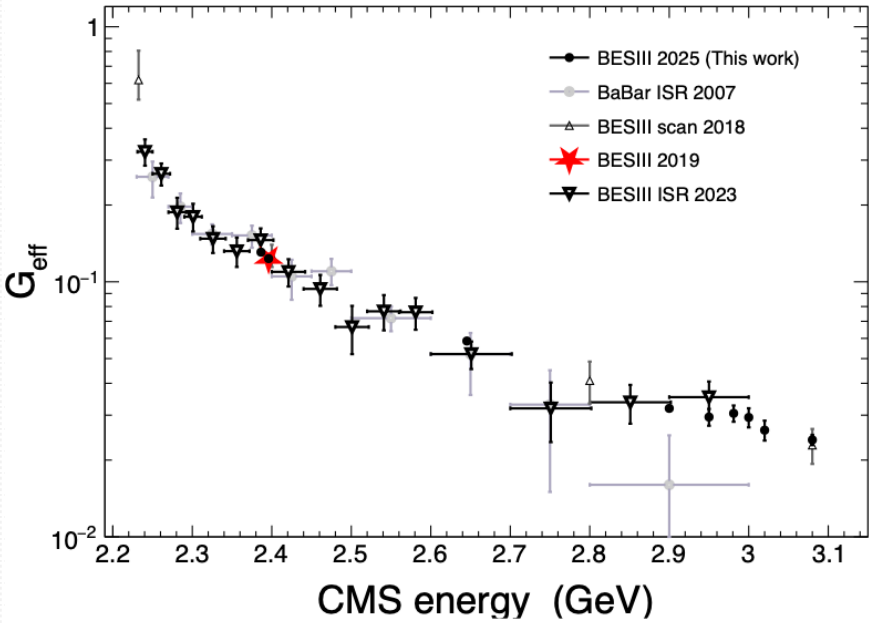


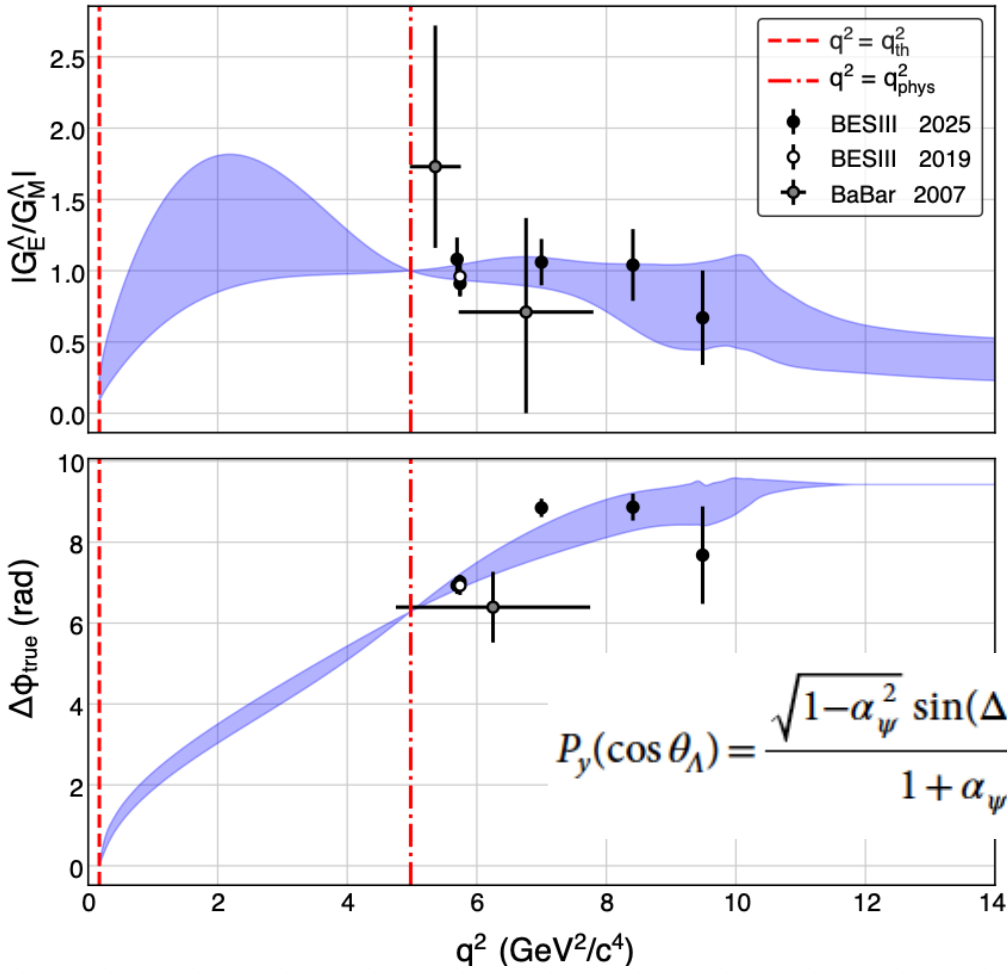

$\Delta\Phi = (-0.050 \pm 0.150 \pm 0.020)$ rad

# Energy-dependent polarization in $e^+e^- \to \Lambda\,\bar{\Lambda}$

*Phys.Rev.Lett.* 135 (2025) 191902



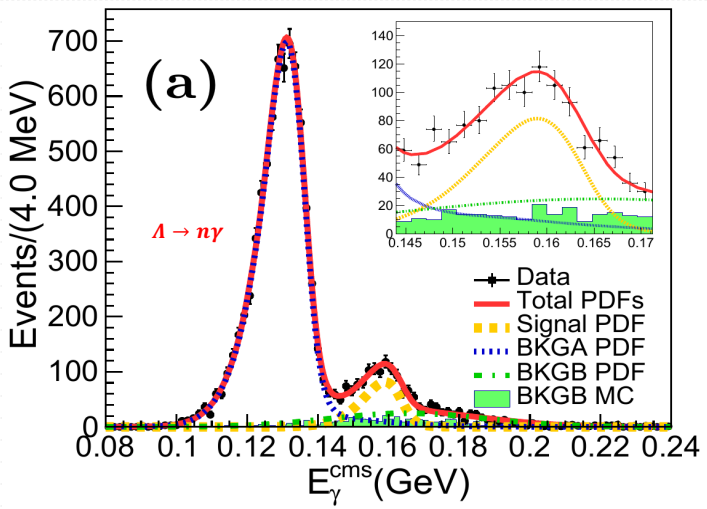



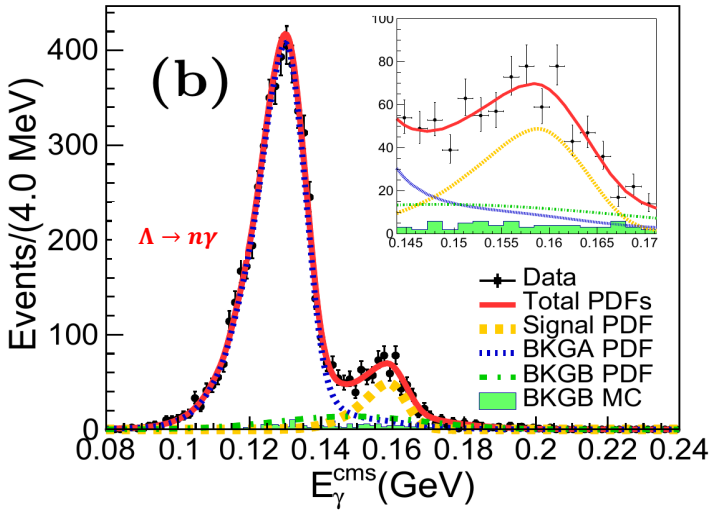



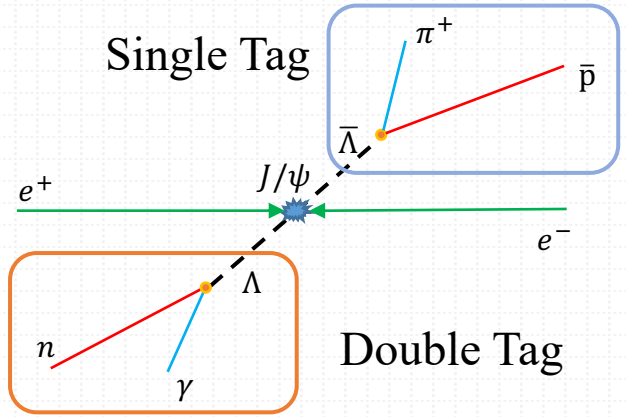

$$P_y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda \sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

The modulus of the ratio between the electric and magnetic form factor, remains fairly constant across the considered energy range, the relative phase changes by more than 90° between 2.40 and 2.65 GeV.

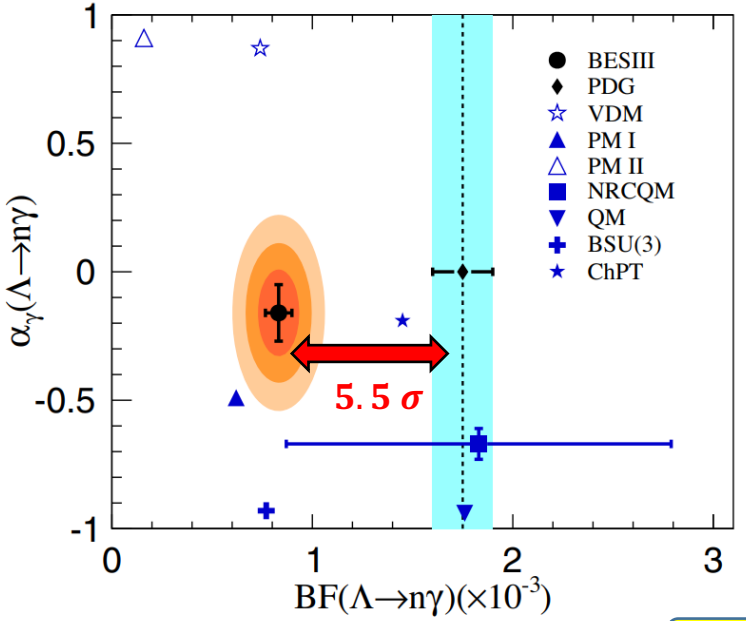
# Radiative decay: $\Lambda \to n\gamma$ in $J/\psi \to \Lambda\bar{\Lambda}$




1221 ± 80 events observed




The most precise decay rate and
the first measurement of up-down asymmetry:

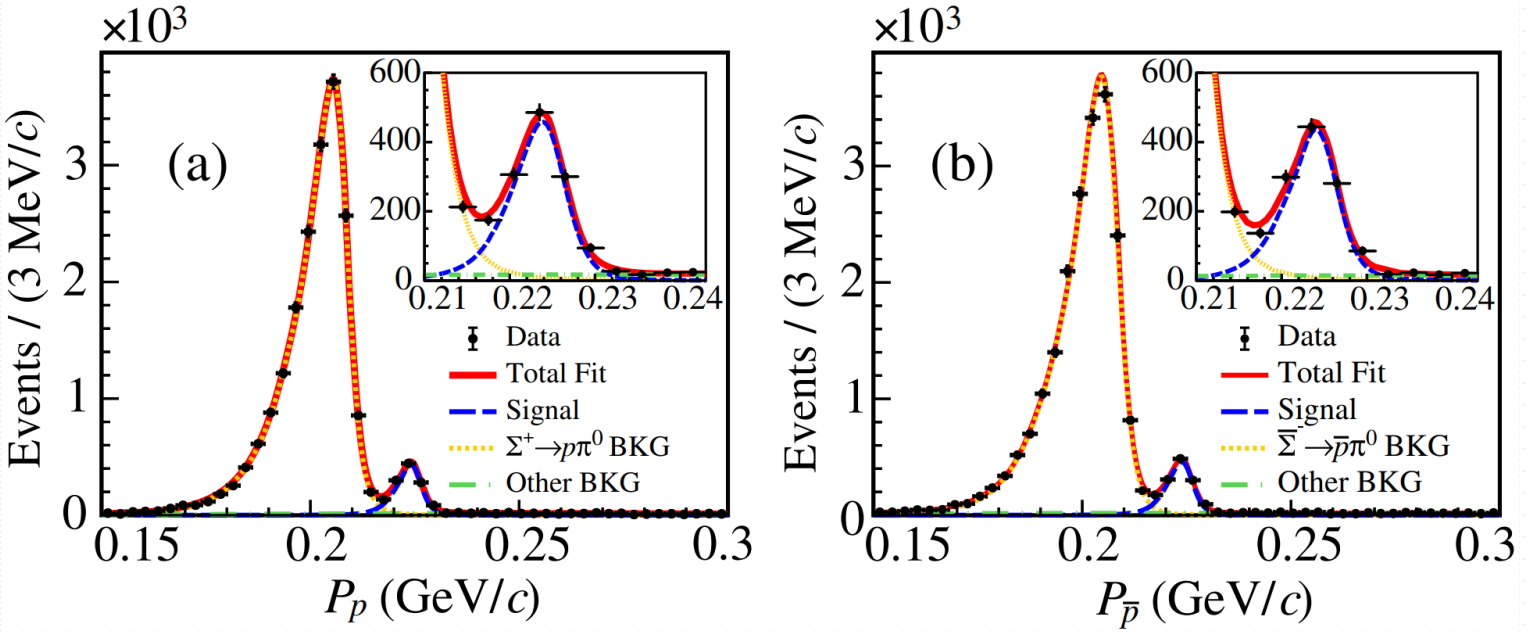
$$\mathcal{B}(\Lambda \to \gamma n) = (0.832 \pm 0.038 \pm 0.054) \times 10^{-3}$$

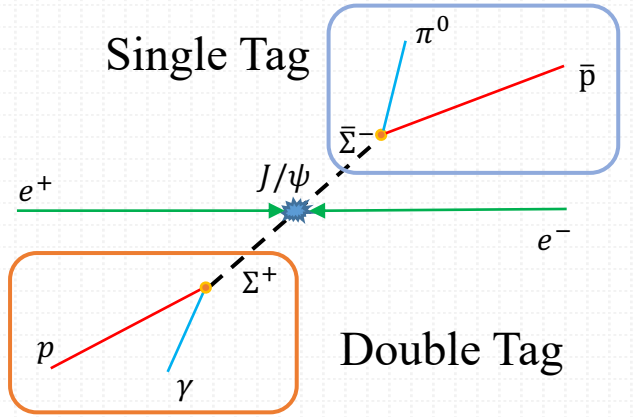
$$\alpha_\gamma = -0.16 \pm 0.10 \pm 0.05$$

BF of $\Lambda \to n\gamma$, with improved precision, is smaller than PDG value by $5.5\sigma$

Phys. Rev. Lett. 129, 212002 (2022)

# Radiative decay: $\Sigma^+ \to p\gamma$ in $J/\psi \to \Sigma^+\bar{\Sigma}^-$



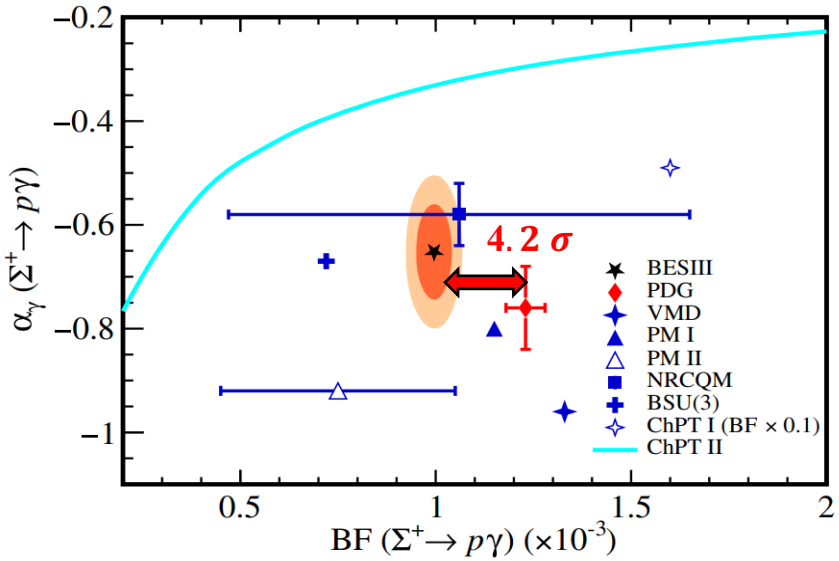

2495 ± 77 events observed

The most precise branching fraction and decay parameter of $\Sigma^+ \to p\gamma$:

- $\mathcal{B}(\Sigma^+ \to p\gamma) = (0.996 \pm 0.021 \pm 0.018)\times 10^{-3}$
- $\alpha_\gamma = -0.652 \pm 0.056 \pm 0.020$

The CP asymmetry is calculated to be:

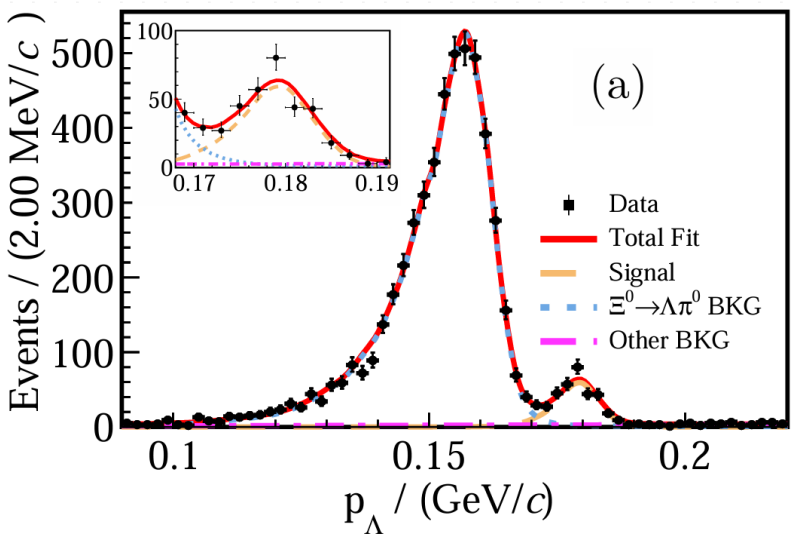
- $A_{CP} = (\alpha_- + \alpha_+)/(\alpha_- - \alpha_+) = 0.095 \pm 0.087 \pm 0.018$
- $\Delta_{CP} = (\mathcal{B}_+ - \mathcal{B}_-)/(\mathcal{B}_+ + \mathcal{B}_-) = 0.006 \pm 0.011 \pm 0.004$

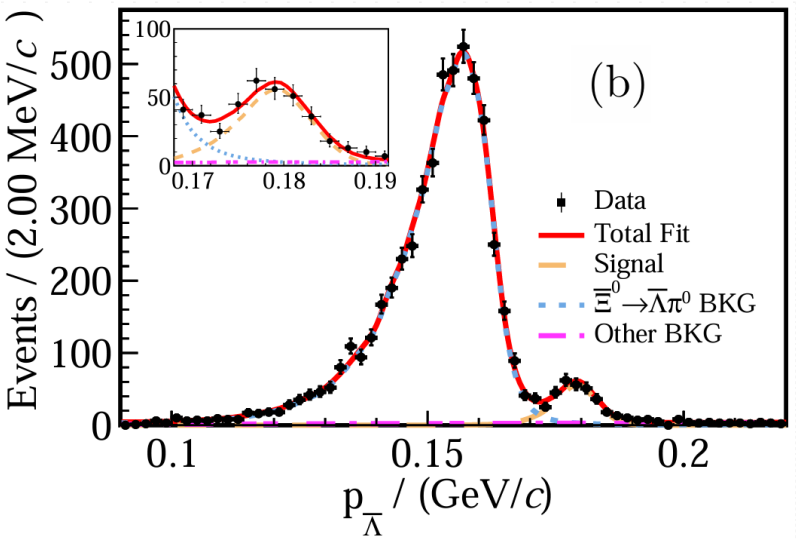


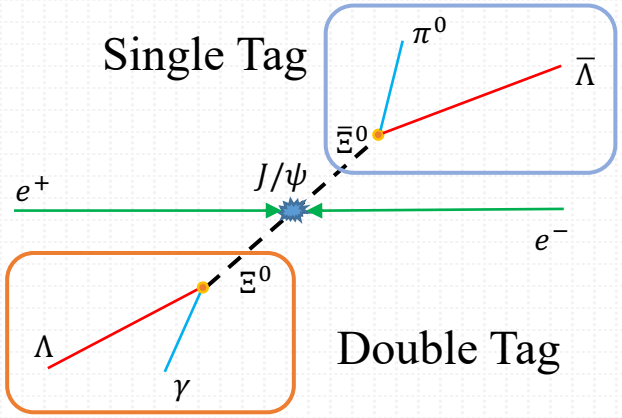

The decay rate deviates from previous value by 4.2$\sigma$

Phys. Rev. Lett. 130, 211901(2023)

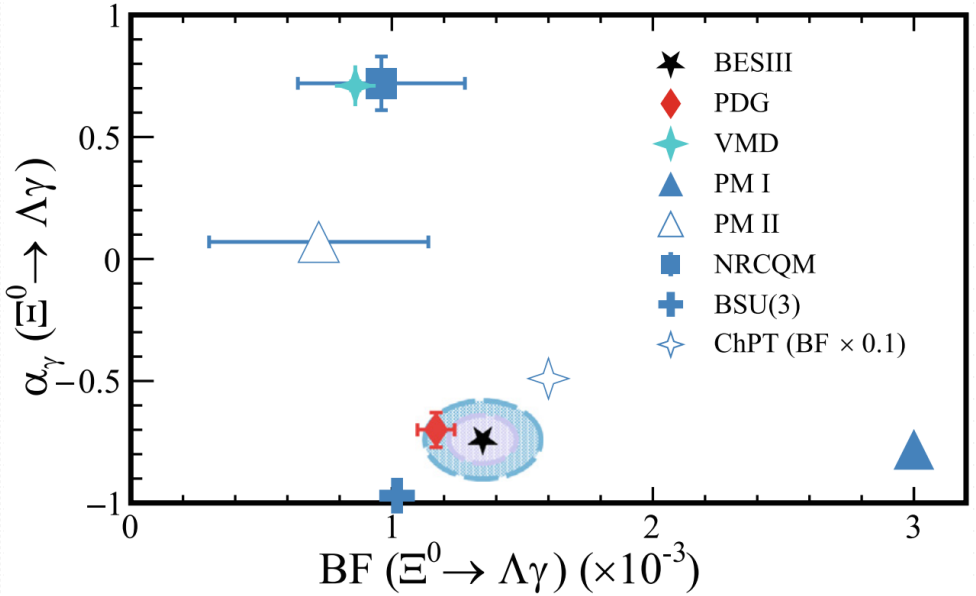
# Radiative decay: $\Xi^0 \to \Lambda\gamma$ in $J/\psi \to \Xi^0\bar{\Xi}^0$




638 ± 46 events observed



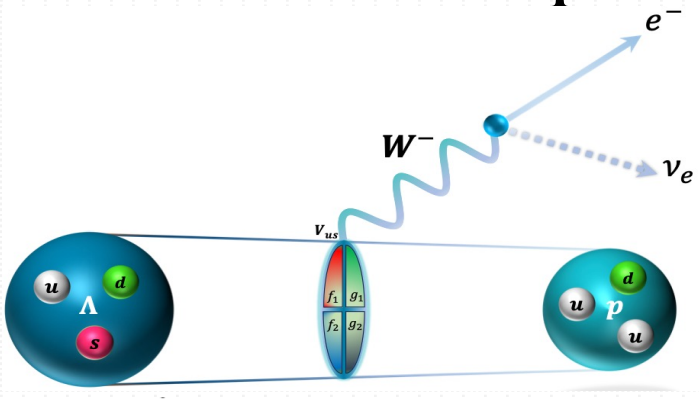

| Channels | $\Xi^0 \to \Lambda\gamma$ | $\bar{\Xi}^0 \to \bar{\Lambda}\gamma$ |
|---|---|---|
| BF($10^{-3}$) | $1.348 \pm 0.090 \pm 0.054$ | $1.326 \pm 0.098 \pm 0.066$ |
| Combined BF($10^{-3}$) | $1.347 \pm 0.066 \pm 0.054$ | |
| $\alpha_\gamma(\bar{\alpha}_\gamma)$ | $-0.652 \pm 0.092 \pm 0.016$ | $0.830 \pm 0.080 \pm 0.044$ |
| Combined $\alpha_\gamma$ | $-0.741 \pm 0.062 \pm 0.019$ | |

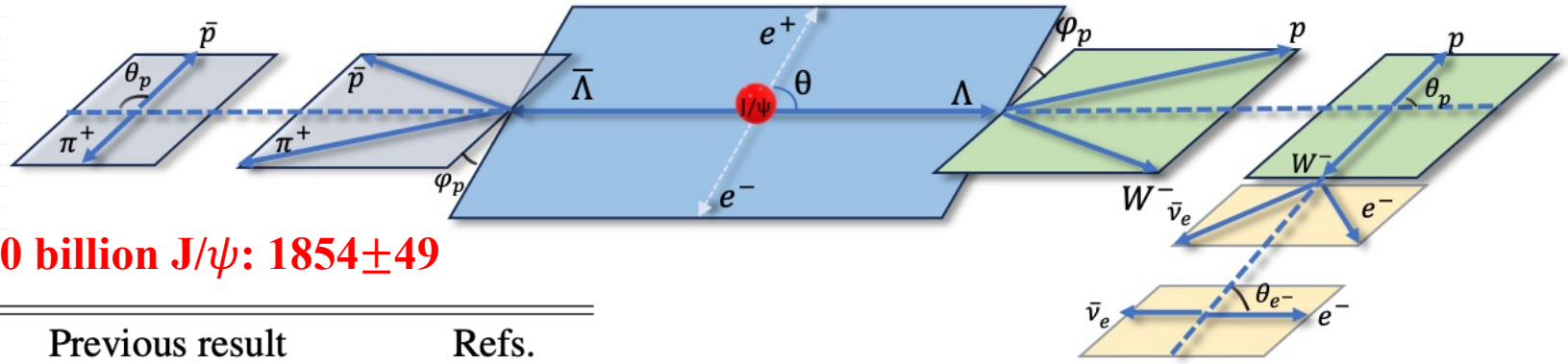
First CP test in $\Xi^0 \to \Lambda\gamma$: $A_{CP} = -0.120 \pm 0.084 \pm 0.029$

Sci. Bull. 70 (2025) 454-459

# Semileptonic decay: $\Lambda \to pe^-\bar{\nu}_e$ in $J/\psi \to \Lambda\bar{\Lambda}$

BESIII: arXiv:2509.09266
*Nature* 657 (2026) 8130, 92-97




**10 billion J/$\psi$: 1854±49**

| Observable | This work | Previous result | Refs. |
|---|---|---|---|
| $\mathcal{B}(\Lambda \to pe^-\bar{\nu}_e)$ | $(8.16 \pm 0.22 \pm 0.15) \times 10^{-4}$ | $(8.34 \pm 0.14) \times 10^{-4}$ | [PDG2024] |
| $g_{av}^-$ | $0.742^{+0.075}_{-0.057} \pm 0.009$ | $0.718 \pm 0.015$ | [PDG2024] |
| $g_{av}^+$ | $-0.706^{+0.069}_{-0.073} \pm 0.014$ | – | |
| $\langle g_{av} \rangle$ | $0.729^{+0.048}_{-0.047} \pm 0.007$ | – | |
| $g_w^-$ | $0.93 \pm 0.51 \pm 0.17$ | $0.15 \pm 0.30$ | [FNAL,1990] |
| $g_w^+$ | $0.89 \pm 0.49 \pm 0.20$ | – | |
| $\langle g_w \rangle$ | $0.89 \pm 0.35 \pm 0.14$ | – | |
| $\lvert V_{us} \rvert_{\mathrm{SU(3)}}$ | $0.2199 \pm 0.0094$ | $0.2224 \pm 0.0034$ | [9, 34] |
| $\lvert V_{us} \rvert_{\mathrm{LQCD}}$ | $0.2332 \pm 0.0042$ | | |
| $\lvert V_{us} \rvert \cdot \sqrt{f_1^2 + 3g_1^2}$ | $0.4543 \pm 0.0076$ | – | |
| $\langle g_{av} \rangle$ | $0.706^{+0.089}_{-0.086}$ | – | |
| $\langle g_w \rangle$ | $0.77^{+0.53}_{-0.49}$ | – | |
| $\langle g_{av2} \rangle$ | $-0.19^{+0.65}_{-0.63}$ | – | |

First absolute BF measurement

$$\mathcal{B} = \frac{\tau_\Lambda}{\hbar} G_F^2 |V_{us}|^2 \frac{\delta^5 {M_\Lambda}^5}{60\pi^3} \{f_1^2 + 3g_1^2 + \mathcal{O}(\delta)\}$$

with $\delta = (M_\Lambda - M_p)/M_\Lambda \sim 0.159$ for $\Lambda \to p\ell^-\bar{\nu}_\ell$

Main parameters measured:

axial vector: $g_{av} \equiv \frac{g_1}{f_1}$;

weak magnetism: $g_w \equiv \frac{f_2}{f_1}$;

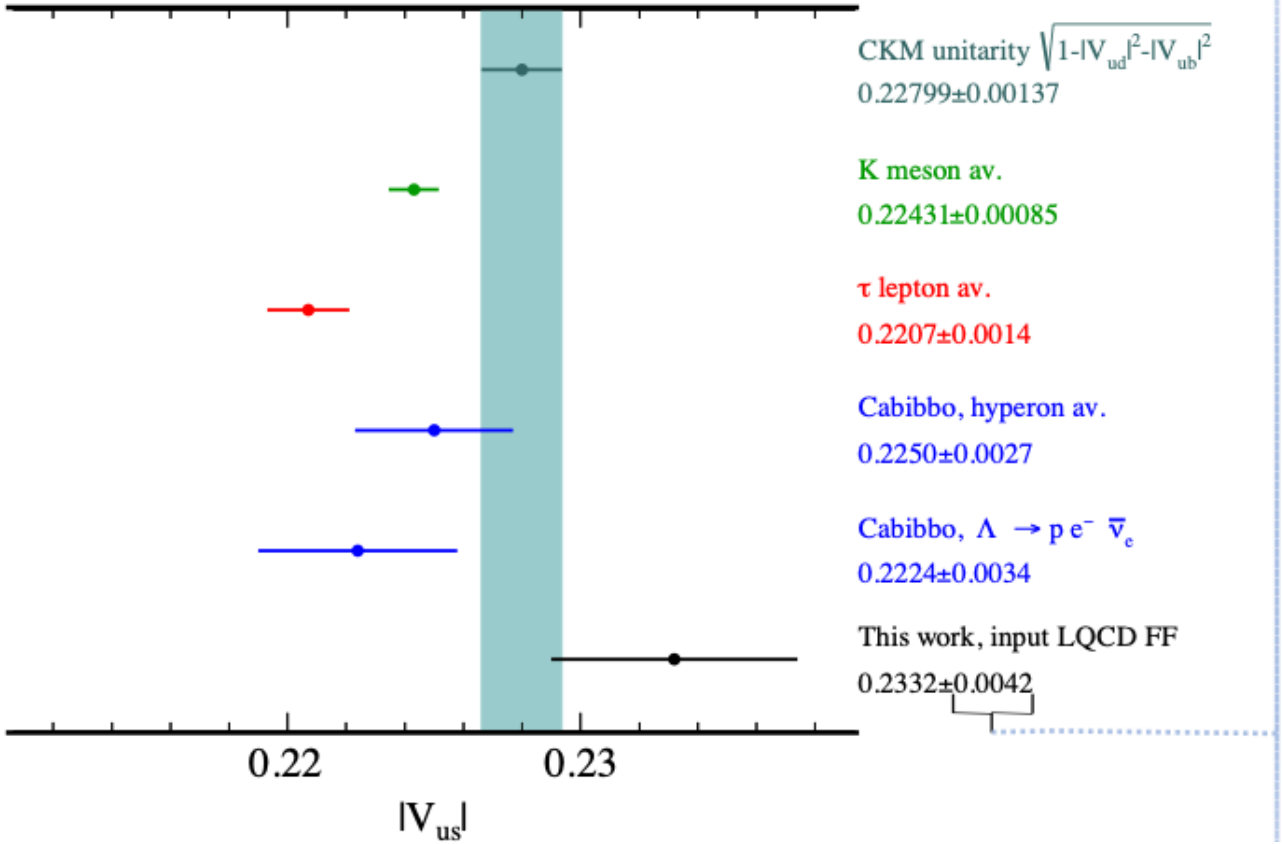
weak electricity: $g_{av2} \equiv \frac{g_2}{f_1}$

# |Vus| from $\Lambda \to p e^- \bar{\nu}_e$ in $J/\psi \to \Lambda\bar{\Lambda}$

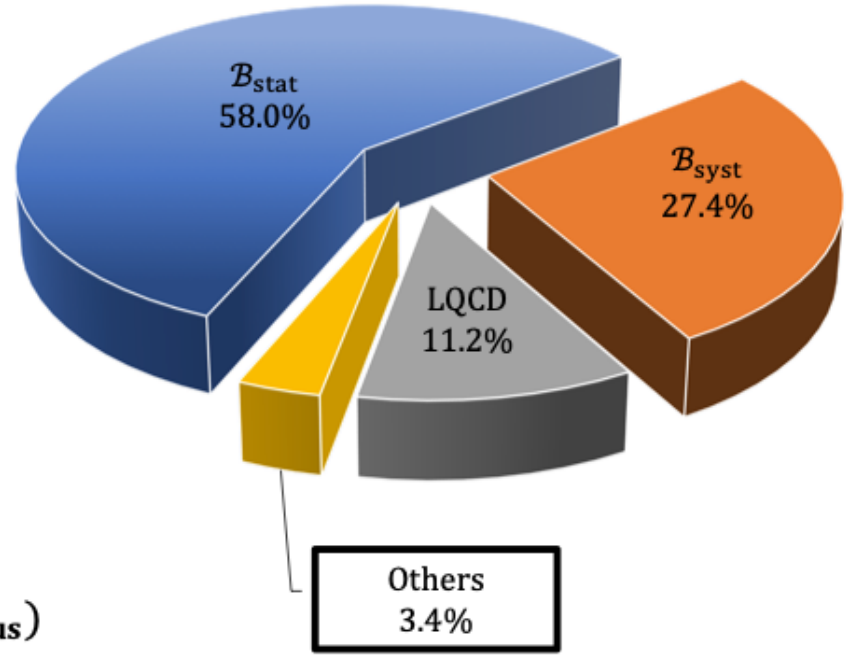
Using LQCD FF prediction [hep-lat/2507.09970]:

BESIII: arXiv:2509.09266
*Nature* 657 (2026) 8130, 92-97

$$|V_{us}|_{\rm LQCD} = 0.2332 \pm 0.0039_{\rm BESIII\,BF} \pm 0.0004_{\tau_\Lambda} \pm 0.0006_{\rm RC} \pm 0.0014_{\rm LQCD} \quad (1.2\sigma)$$

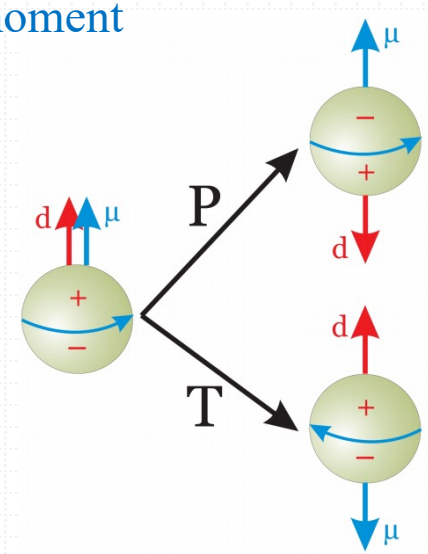


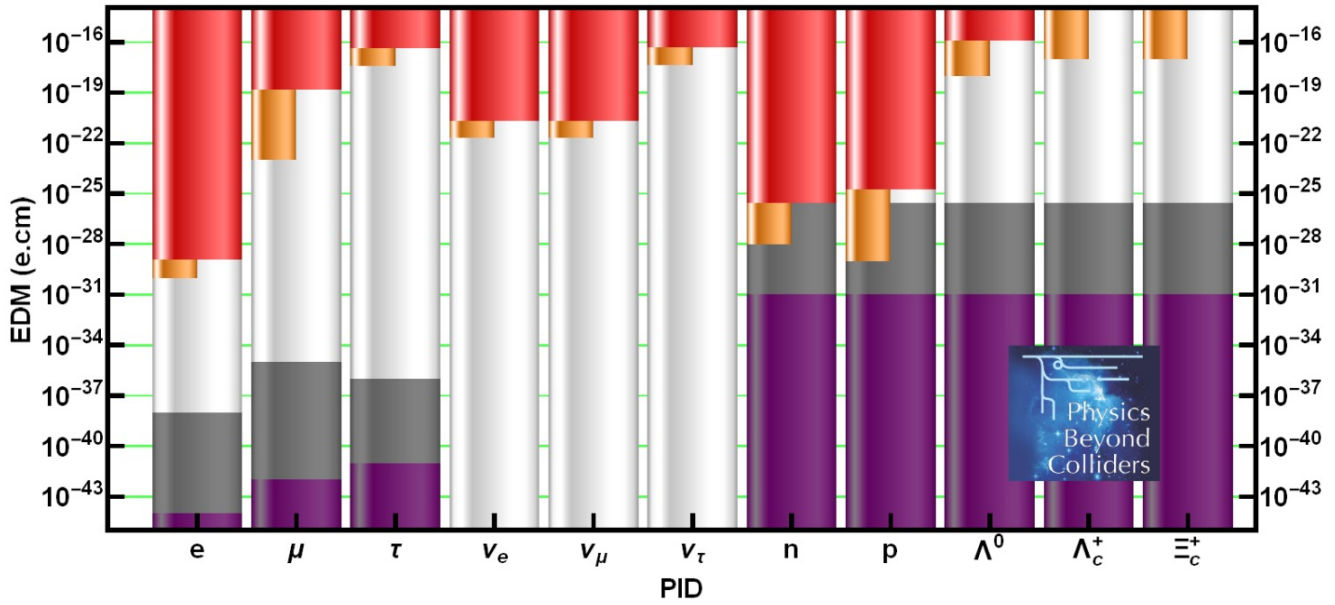

$\sigma^2(V_{us})$



# Search for hyperon EDM at BESIII

μ: magnetic moment
d: EDM




A non-zero intrinsic EDM would violate both parity (P) and time-reversal (T) symmetries.

- When CPT symmetry is conserved, T violation is equivalent to CP violation.

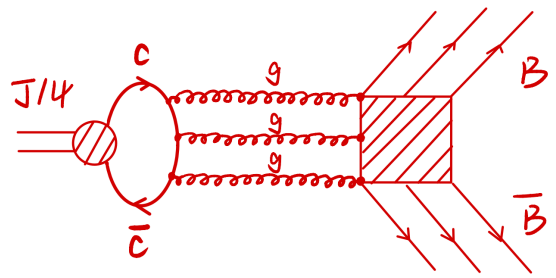
J. Phys. G 47 (2020) 1, 010501

# Searching for hyperon EDM at BESIII

X.G. He, J.P. Ma, Phys. Lett. B 839(2023)137834
X.G. He, J.P. Ma, B. McKellar, Phys. Rev. D 47 (1993) R1744-R1746

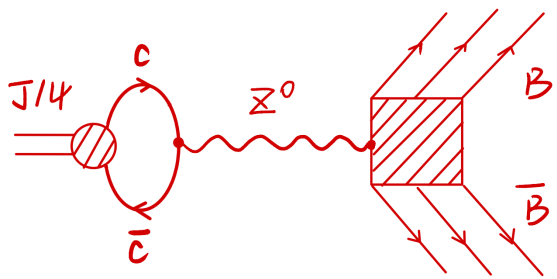
Detailed dynamics in $J/\psi$ decay to hyperon pair, have been studied:

$$\mathcal{A} = \epsilon_\mu(\lambda)\bar{u}(\lambda_1)\left(\boldsymbol{F_V}\gamma^\mu + \frac{i}{2M_\Lambda}\sigma^{\mu\nu}q_\nu\boldsymbol{H_\sigma} + \gamma^\mu\gamma^5\boldsymbol{F_A} + \sigma^{\mu\nu}\gamma^5 q_\nu\boldsymbol{H_T}\right)v(\lambda_2)$$



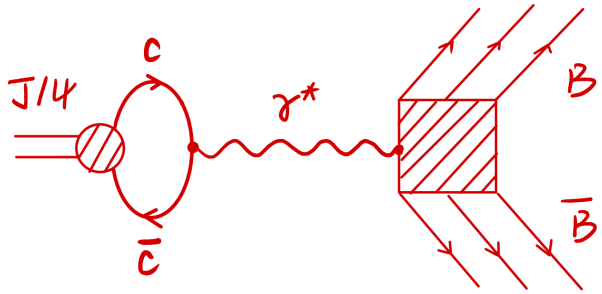

Dominant contribution
arXiv:hep-ph/0412158

Psionic form factor
$\boldsymbol{F_V}$ and $\boldsymbol{H_\sigma}$
can also be represented as $\boldsymbol{G_1}$ and $\boldsymbol{G_2}$




$P$ violation term

Complex form factor, $F_A \neq 0$ indicate $P$ violation



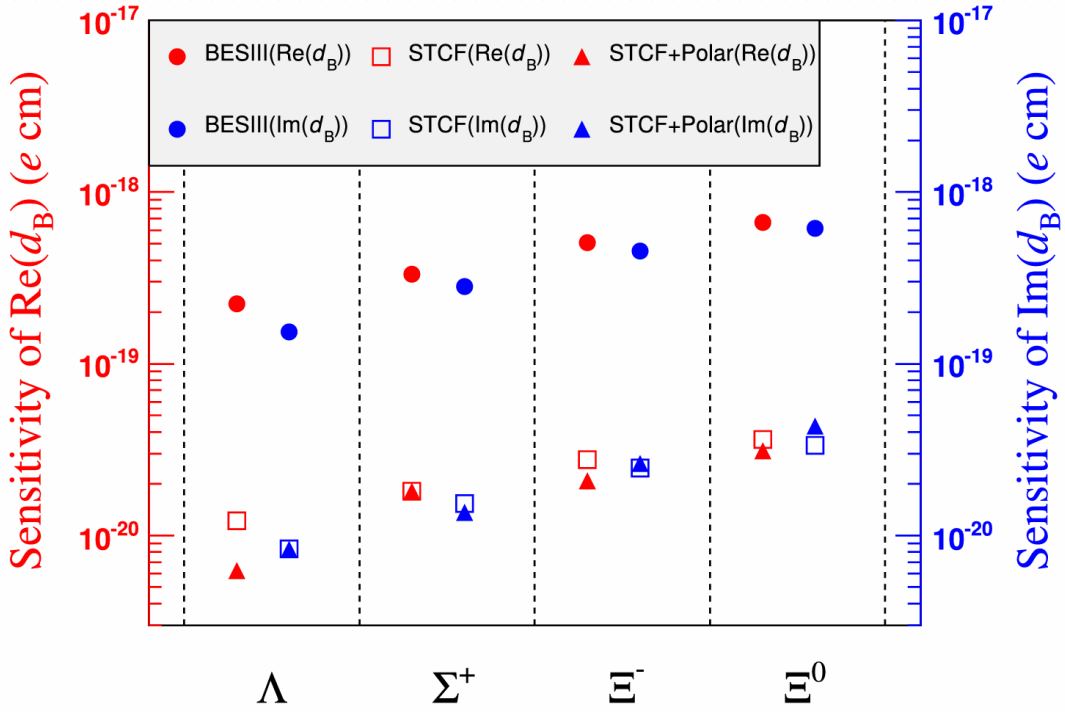

$\boldsymbol{H_T}$ is included in this term

$$H_T(q^2) = \frac{2e}{3m_{J\psi}^2}g_V d_B(q^2)$$

Assuming $d_B(q^2) \equiv d_B(0)$

$d_B(q^2)$: electric dipole form factor
$d_B(0)$ : electric dipole moment
Physics Letters B 551 (2003) 16–26

# Sensitivities of hyperon EDM at BESIII




(a) Sensitivity for $Re(d_B)$ and $Im(d_B)$

J. Fu, H.B. Li, J. Wang, F. Yu, and J. Zhang,
Phys Rev. D.108.L091301 (2023)

SM: $\sim 10^{-26}\, e$ cm

BESIII: milestone for hyperon EDM measurement

$\Lambda$ $10^{-19} e$ cm ( FermiLab $10^{-16}$ $e$ cm)

first achievement for $\Sigma^+$,$\Xi^-$ and $\Xi^0$ at level of $10^{-19} e$ cm

a litmus test for new physics

STCF: improved by more than one order of magnitude

# Λ EDM measurement at BESIII

arXiv:2506.19180
*Science* 393 (2026) 6815, 1027-1030

- 3M $J/\psi \to \Lambda\bar{\Lambda}$ decays reconstructed with purity > 99%, similar statistics as Fermilab in 1980s
- Preserve CP symmetry and a 3-order-of-magnitude improvement:

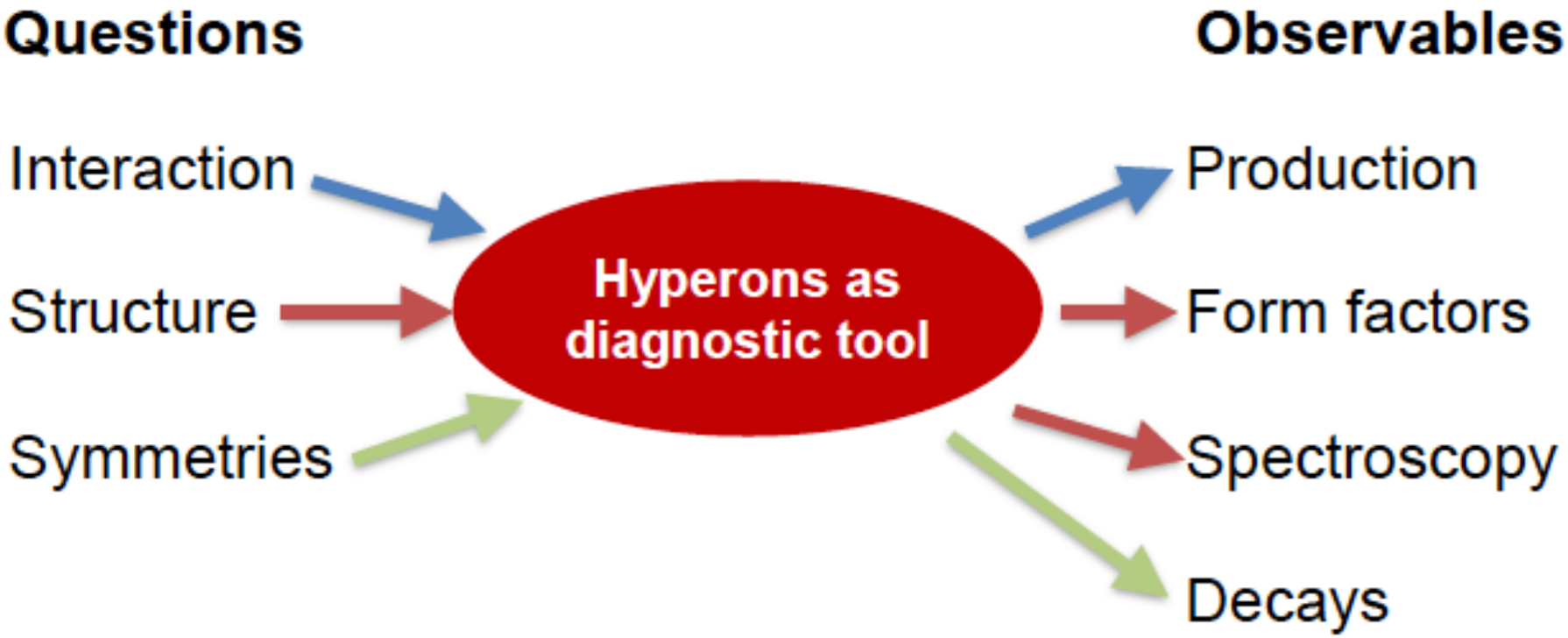
$$Re(d_\Lambda) = (-3.1 \pm 3.2 \pm 0.5) \times 10^{-19}\ e\ \text{cm},$$
$$Im(d_\Lambda) = (2.9 \pm 2.6 \pm 0.6) \times 10^{-19}\ e\ \text{cm}.$$

$$-8.6 \times 10^{-19} < Re(d_\Lambda) < 3.3 \times 10^{-19}\ e\ \text{cm},$$
$$-2.5 \times 10^{-19} < Im(d_\Lambda) < 7.2 \times 10^{-19}\ e\ \text{cm},$$
$$|d_\Lambda| < 6.5 \times 10^{-19}\ e\ \text{cm}.$$

| Parameter | This measurement |
|---|---|
| $\alpha_\Lambda$ | $0.7524 \pm 0.0036 \pm 0.0008$ |
| $\alpha_{\bar{\Lambda}}$ | $-0.7571 \pm 0.0036 \pm 0.0008$ |
| $Re(G_2)$ | $(9.71 \pm 0.06 \pm 0.24) \times 10^{-4}$ |
| $Im(G_2)$ | $(9.14 \pm 0.04 \pm 0.23) \times 10^{-4}$ |
| $P_L$ | $(-1.8 \pm 1.2 \pm 0.8) \times 10^{-3}$ |
| $Re(F_A)$ | $(-2.4 \pm 1.6 \pm 3.1) \times 10^{-6}$ |
| $Im(F_A)$ | $(-7.9 \pm 3.7 \pm 2.5) \times 10^{-6}$ |
| $Re(H_T)$ | $(-1.4 \pm 1.4 \pm 0.2) \times 10^{-6}$ GeV$^{-1}$ |
| $Im(H_T)$ | $(1.3 \pm 1.2 \pm 0.4) \times 10^{-6}$ GeV$^{-1}$ |
| $\alpha_{J/\psi}$ | $0.4748 \pm 0.0022 \pm 0.0017$ |
| $\Delta\phi$ | $0.7552 \pm 0.0042 \pm 0.0013$ |
| $A_{CP}$ | $(-3.1 \pm 4.6 \pm 1.1) \times 10^{-3}$ |
| $\sin^2\theta_W^{\text{eff}}$ | $-0.15 \pm 0.12 \pm 0.26$ |
| $Re(d_\Lambda)$ | $(-3.1 \pm 3.2 \pm 0.5) \times 10^{-19}\ e$ cm |
| $Im(d_\Lambda)$ | $(2.9 \pm 2.6 \pm 0.6) \times 10^{-19}\ e$ cm |

# Summary

BESIII provides huge amount quantum-correlated hyperon pairs!




BESIII has pioneered an innovative paradigm by utilizing spin-entangled hyperon-antihyperon pairs.

Thanks for your attentions!

谢谢!

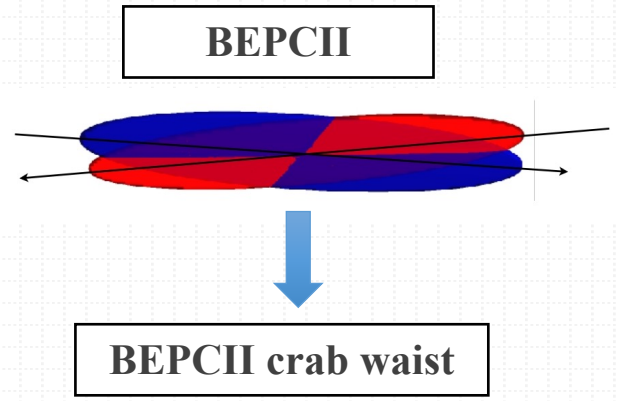
# Backup

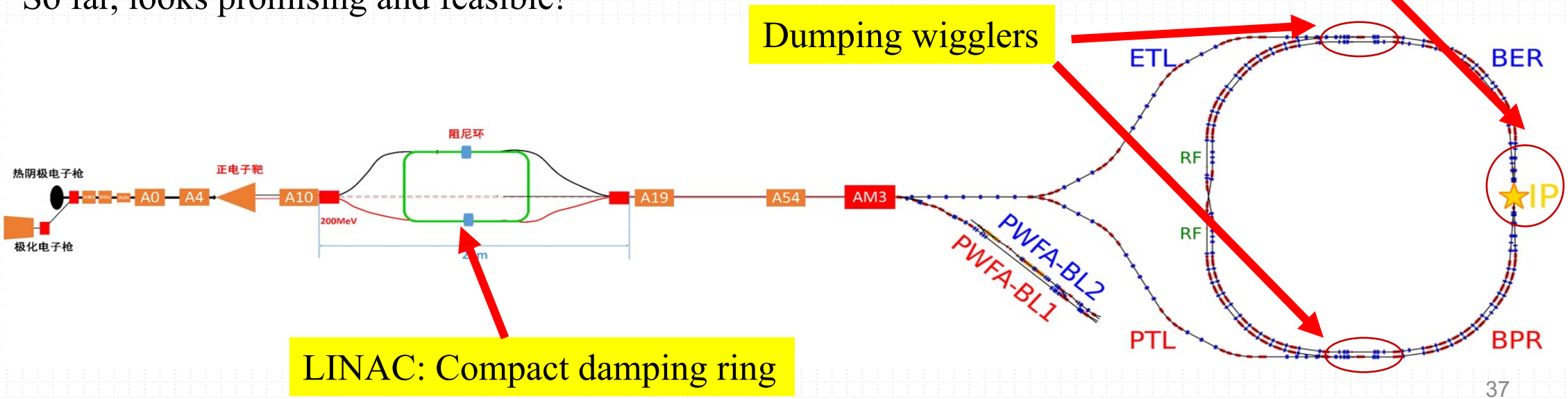
# Planned BEPCII-UP with Crab Waist

Design study supported by IHEP innovation funding:

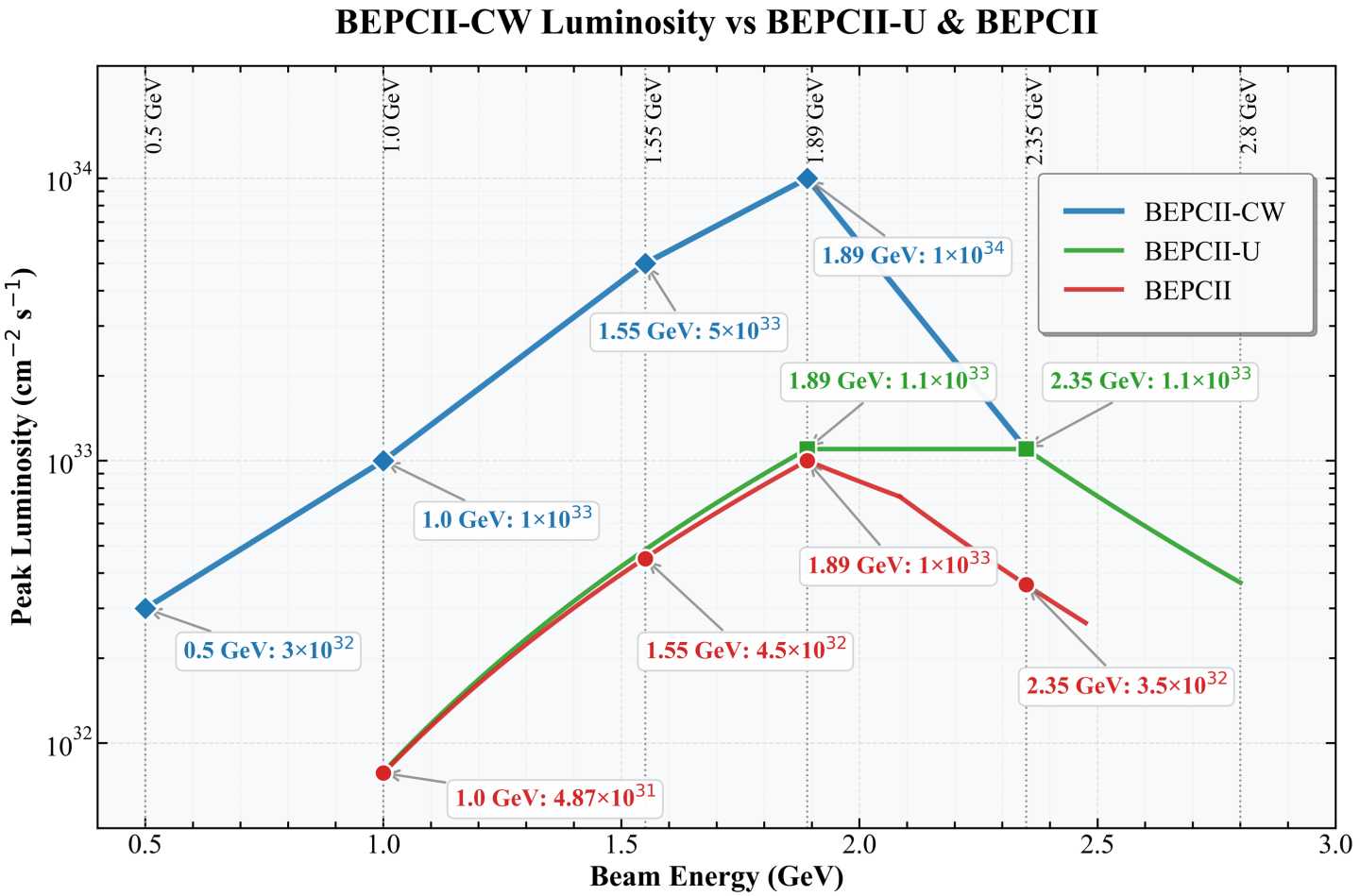
- ✓ add crab waist cavities to the ring
- ✓ modify interaction region
- ✓ super-conducting wigglers near injection points
- ✓ new damping ring for linac

So far, looks promising and feasible!



# BEPCII-UP performance outlook




- Luminosity increased by ×10 @beam energy 1.89GeV,.
- Operation with beam energy from 0.5 – 1.0 GeV
- Possibility: beam energy → 0.3 GeV, around $\rho - \omega$ peaks with visible luminosity

# Prospects at STCF

**BESIII**

- $e^+e^-$ collider
- $E_{\rm cms} \in (2.0, 4.95)$ GeV
- $\mathcal{L}_{\rm peak} = 10^{33}$ cm$^{-2}$s$^{-1}$
- $N_{J/\psi} = 10^{10}$
- Data collection from 2009

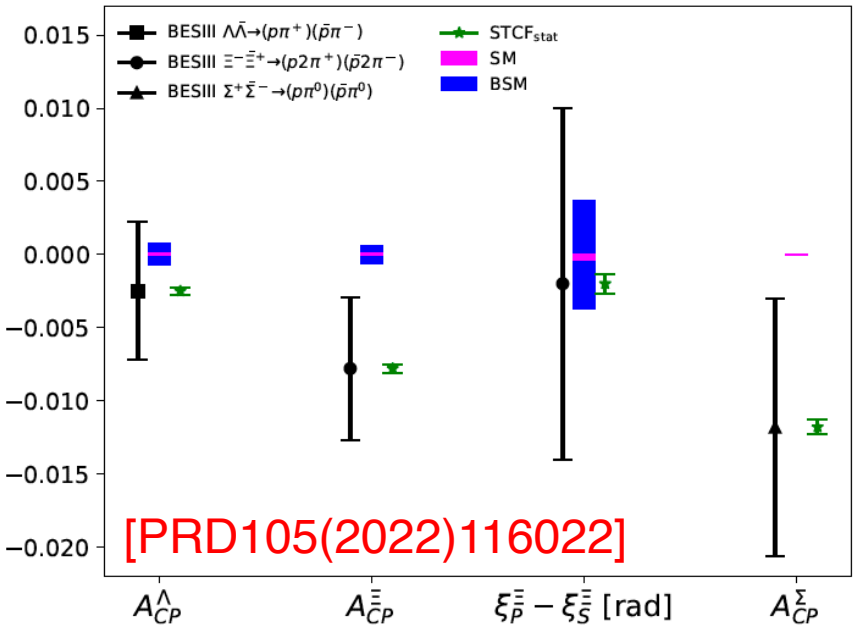
**STCF**

- $e^+e^-$ collider
- $E_{\rm cms} \in (2.0, 7.0)$ GeV
- $\mathcal{L}_{\rm peak} = 0.5{\cdot}10^{35}$ cm$^{-2}$s$^{-1}$ @ 4 GeV
- $N_{J/\psi} \sim 3.4 \cdot 10^{12}$
- Data collection after 2030+

[FrontPhys19(2024)14701] [arXiv:2502.08907]

| | $\sigma(A_{CP}^{\Lambda})$ | $\sigma(A_{CP}^{\bar{\Xi}})$ | $\sigma(\Delta\phi_{CP}^{\Xi})$ | |
|---|---|---|---|---|
| BESIII | $4.3 \cdot 10^{-3}$ | $4.8 \cdot 10^{-3}$ | $5.1 \cdot 10^{-3}$ | [PRL136(2026)201802] |
| STCF | $2.3 \cdot 10^{-4}$ | $2.6 \cdot 10^{-4}$ | $2.8 \cdot 10^{-4}$ | projection |

Possible to have longitudinally polarized electron beam




New Physics:
Tandean,Valencia PRD67 (2003) 056001
Tandean Phys.Rev.D69 (2004) 076008
X.G. He et al. Sci.Bull. 67 (2022) 1840-1843

# Direct CP violation in $K^0$ decays

(I) $K^0 \to \pi^+\pi^-$ (II) $K^0 \to \pi^0\pi^0$

Two weak transitions needed
$|\Delta I| = \frac{1}{2}$ and $|\Delta I| = \frac{3}{2}$ (5%)

$K^0 \to \pi^+\pi^-$ $\quad \mathcal{A}_I = A_0 \exp(i\xi_0 + i\delta_0) + A_2 \exp(i\xi_2 + i\delta_2)$

$\bar{K}^0 \to \pi^+\pi^-$ $\quad \bar{\mathcal{A}}_I = A_0 \exp(-i\xi_0 + i\delta_0) + A_2 \exp(-i\xi_2 + i\delta_2)$

$(\pi\pi)_{I=0,2}$

$$\mathrm{Re}(\epsilon') := \frac{1}{2}\frac{|\mathcal{A}_I|^2 - |\bar{\mathcal{A}}_I|^2}{|\mathcal{A}_I|^2 + |\bar{\mathcal{A}}_I|^2} \approx (\xi_0 - \xi_2)\sin(\delta_0 - \delta_2)\frac{A_2}{A_0}$$

Exp. avg PDG

$$\mathrm{Re}(\epsilon'/\epsilon) = (16.6 \pm 2.3) \cdot 10^{-4}$$

$$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$$

$$3.7(5) \times 10^{-6} \approx (\xi_0 - \xi_2)\sin 47.7° \frac{1}{22}$$

$$(\xi_0 - \xi_2) \approx 10^{-4}\ \mathrm{rad}$$

# Semi-leptonic decay

- Momenta and masses: $Y_1(p_1, M_1) \to Y_2(p_2, M_2) + l^-(p_l, m_l) + \bar{\nu}_l(p_{\bar{\nu}_l}, 0)$
- FF for weak current-induced baryonic $1/2^+ \to 1/2^+$ transitions [EPJ C59 (2009) 27]:

$$\langle Y_2(p_2)|J_\mu^{V+A}|Y_1(p_1)\rangle = \bar{u}(p_2)\left[\gamma_\mu(f_1(q^2) - g_1(q^2)\gamma_5) - \frac{i\sigma_{\mu\nu}q^\nu}{M_1}(f_2(q^2) - g_2(q^2)\gamma_5)\right.$$

$$\left. + \frac{q^\mu}{M_1}(f_3(q^2) - g_3(q^2)\gamma_5)\right] u(p_1)$$

where $q_\mu = (p_1 - p_2)_\mu$

- 6 FFs define 3 vector and 3 axial vector helicity amplitudes:
  $H_{\lambda_2,\lambda_W} = H^V_{\lambda_2,\lambda_W} + H^A_{\lambda_2,\lambda_W} \leftarrow \{H^{V,A}_{\frac{1}{2}1}, H^{V,A}_{\frac{1}{2}0}, H^{V,A}_{\frac{1}{2}t}\}$ with $H^{V,A}_{-\lambda_2,-\lambda_W} = \pm H^{V,A}_{\lambda_2,\lambda_W}$
- For $Y_1 \to Y_2 e^- \bar{\nu}_e$ at $\mathcal{O}(\frac{m_e^2}{2q^2}) \to 0 \Longrightarrow f_3, g_3 \to 0$
- Main parameters:

$$g_{av}(0) = \frac{g_1(0)}{f_1(0)}, \quad g_w(0) = \frac{f_2(0)}{f_1(0)}, \quad g_{av2}(0) = \frac{g_2(0)}{f_1(0)}$$

# Search for CP violation in hyperon decays

## 1) A CP-violating phase:

**Ordinary phases in QM**

matter: $\delta$ — antimatter: $\delta$ (same sign)

**CP violating phases**

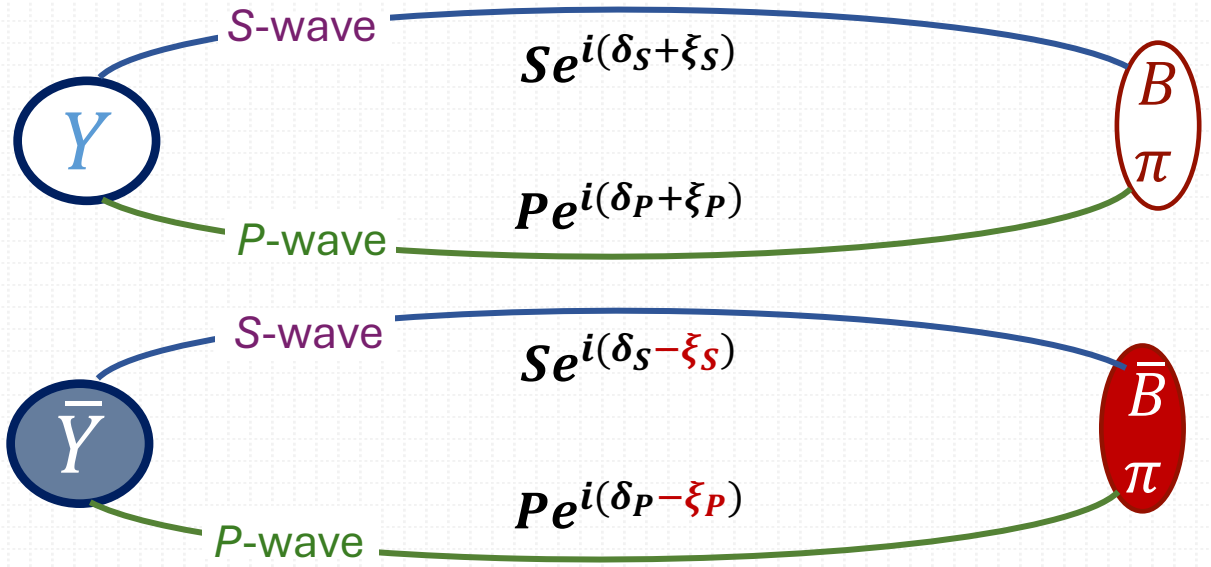
matter: $\xi$ — antimatter: $-\xi$ (opposite sign)

If only have one path:

$$\left|Ae^{i(\delta+\xi)}\right|^2 = A^2$$

The CPV phase vanishes in the probability density.

## 2) Two or more interfering paths to the same final state




Spin-1/2 hyperon

Spin-1/2 baryon

Suitable for CPV searches!

# Search for CPV in $\Xi^0 \to \Lambda\pi^0$ with $e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0$

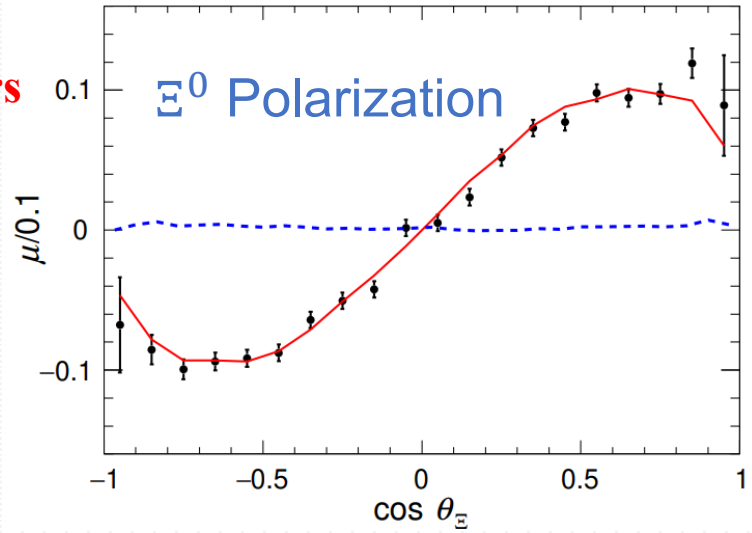
10 billion **J/$\psi$**

$e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0$ $\quad$ $\Xi^0 \to \Lambda\pi^0$

| Parameter | This work | Previous result |
|---|---|---|
| $\alpha_{J/\psi}$ | $0.514 \pm 0.006 \pm 0.015$ | $0.66 \pm 0.06$ [34] |
| $\Delta\Phi$(rad) | $1.168 \pm 0.019 \pm 0.018$ | - |
| $\alpha_\Xi$ | $-0.3750 \pm 0.0034 \pm 0.0016$ | $-0.358 \pm 0.044$ [18] |
| $\bar{\alpha}_\Xi$ | $0.3790 \pm 0.0034 \pm 0.0021$ | $0.363 \pm 0.043$ [18] |
| $\phi_\Xi$(rad) | $0.0051 \pm 0.0096 \pm 0.0018$ | $0.03 \pm 0.12$ [18] |
| $\bar{\phi}_\Xi$(rad) | $-0.0053 \pm 0.0097 \pm 0.0019$ | $-0.19 \pm 0.13$ [18] |
| $\alpha_\Lambda$ | $0.7551 \pm 0.0052 \pm 0.0023$ | $0.7519 \pm 0.0043$ [13] |
| $\bar{\alpha}_\Lambda$ | $-0.7448 \pm 0.0052 \pm 0.0017$ | $-0.7559 \pm 0.0047$ [13] |
| $\xi_P - \xi_S$(rad) | $(0.0 \pm 1.7 \pm 0.2) \times 10^{-2}$ | - |
| $\delta_P - \delta_S$(rad) | $(-1.3 \pm 1.7 \pm 0.4) \times 10^{-2}$ | - |
| $A_{CP}^\Xi$ | $(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$ | $(-0.7 \pm 8.5) \times 10^{-2}$ [18] |
| $\Delta\phi_{CP}^\Xi$(rad) | $(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$ | $(-7.9 \pm 8.3) \times 10^{-2}$ [18] |
| $A_{CP}^\Lambda$ | $(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$ | $(-2.5 \pm 4.8) \times 10^{-3}$ [13] |
| $\langle\alpha_\Xi\rangle$ | $-0.3770 \pm 0.0024 \pm 0.0014$ | - |
| $\langle\phi_\Xi\rangle$(rad) | $0.0052 \pm 0.0069 \pm 0.0016$ | - |
| $\langle\alpha_\Lambda\rangle$ | $0.7499 \pm 0.0029 \pm 0.0013$ | $0.7542 \pm 0.0026$ [13] |

**Phys. Rev. D 108, L031106 (2023) Editors' suggestion**

**320 K $\Xi^0 - \bar{\Xi}^0$ pairs with 98% purity**



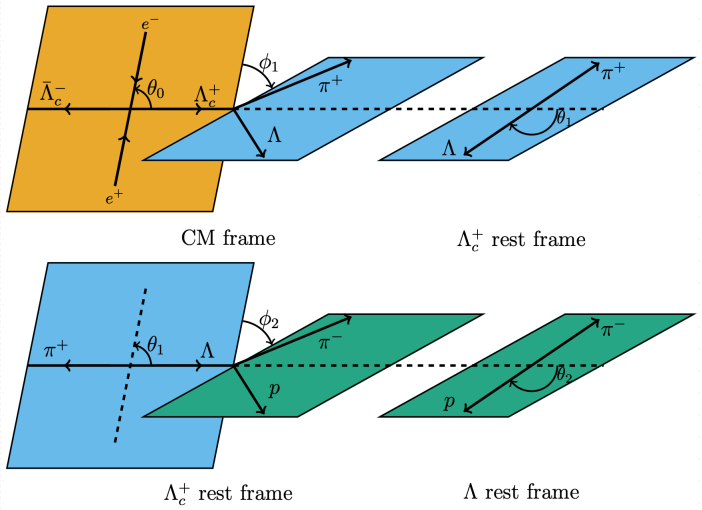

**The precision of the asymmetry parameter: $10^{-3}$**

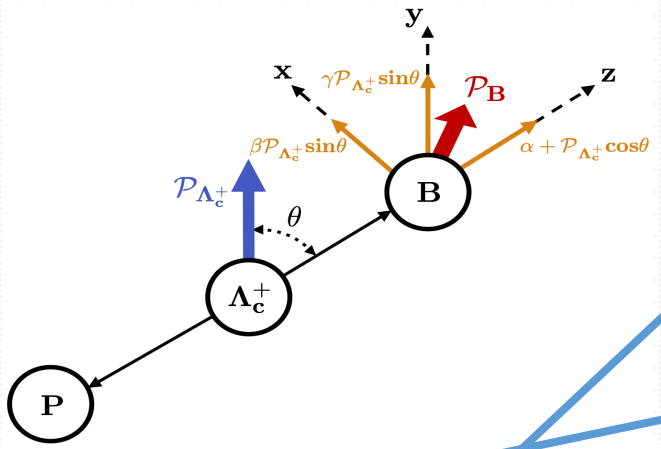
**Measurement of the weak (CPV) phase difference in $\Xi^0$ decays, most precise results in weakly baryon decays: $|\xi_P - \xi_S| < 1.4°$ (@ 90% C.L.)**

**Three CP tests**

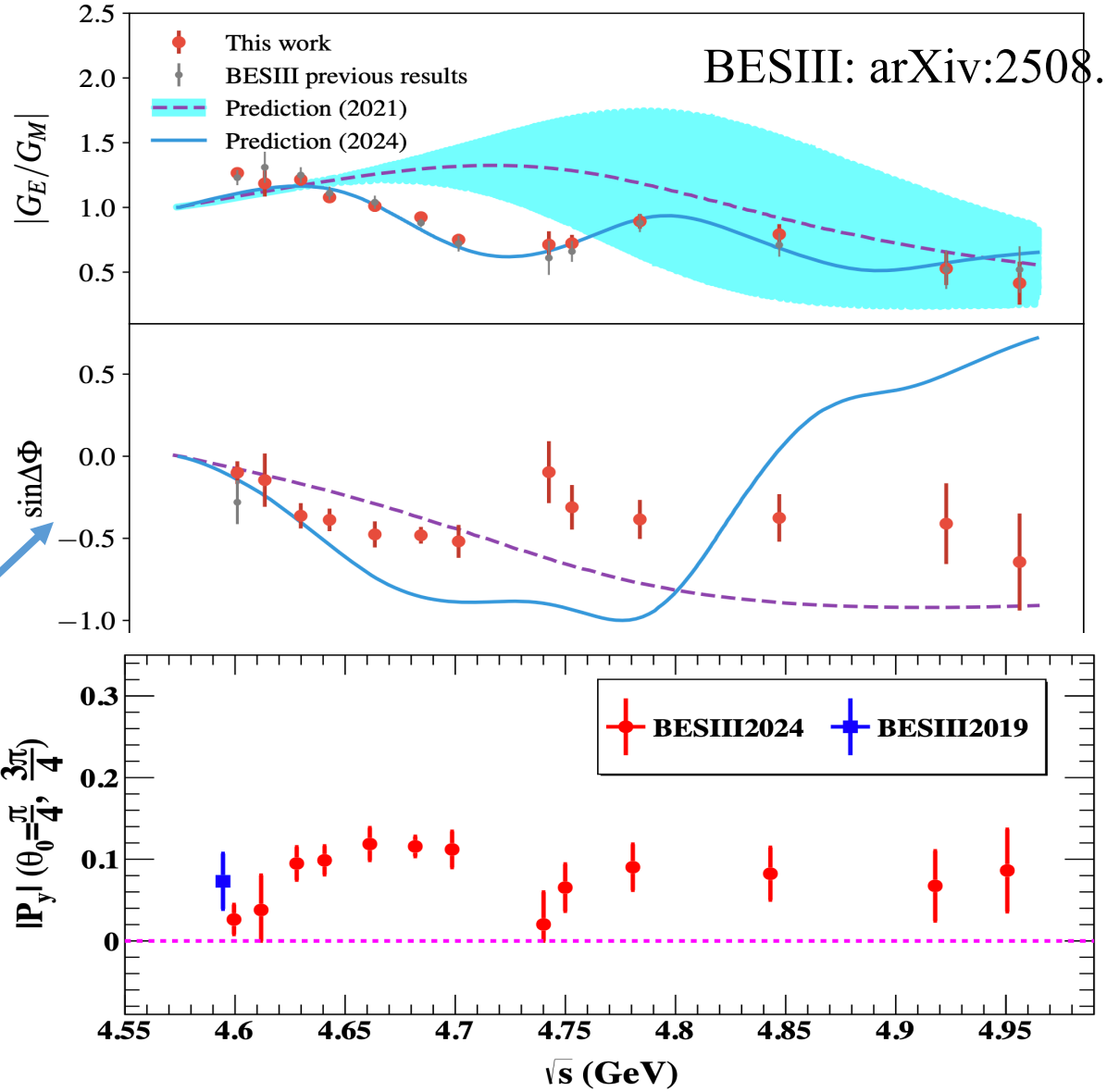
**The precision of $\langle\alpha_\Lambda\rangle$ obtained from 320K $\Xi^0$ is comparable to that obtained from the measurement of 3.2 million $\Lambda$ decays!**

# Energy-dependent polarization in $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$




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




What's the production dynamics of charmed baryon?

# Most precise Λ hyperon EDM measurement

- EDM extracted via **full angular analysis**:

$$\mathrm{Re}(d_\Lambda) = (-3.1 \pm 3.2 \pm 0.5)\times10^{-19}\, e\cdot\mathrm{cm}$$
$$\mathrm{Im}(d_\Lambda) = (2.9 \pm 2.6 \pm 0.6)\times10^{-19}\, e\cdot\mathrm{cm}$$

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

BESIII: arXiv:2506.19180

which corresponds to an upper bound of:

$$|d_\Lambda| < 6.5\times10^{-19}\ e\cdot cm\ \ (95\%\ CL)$$

- Improves sensitivity by more than **2 orders of magnitude** over previous best.

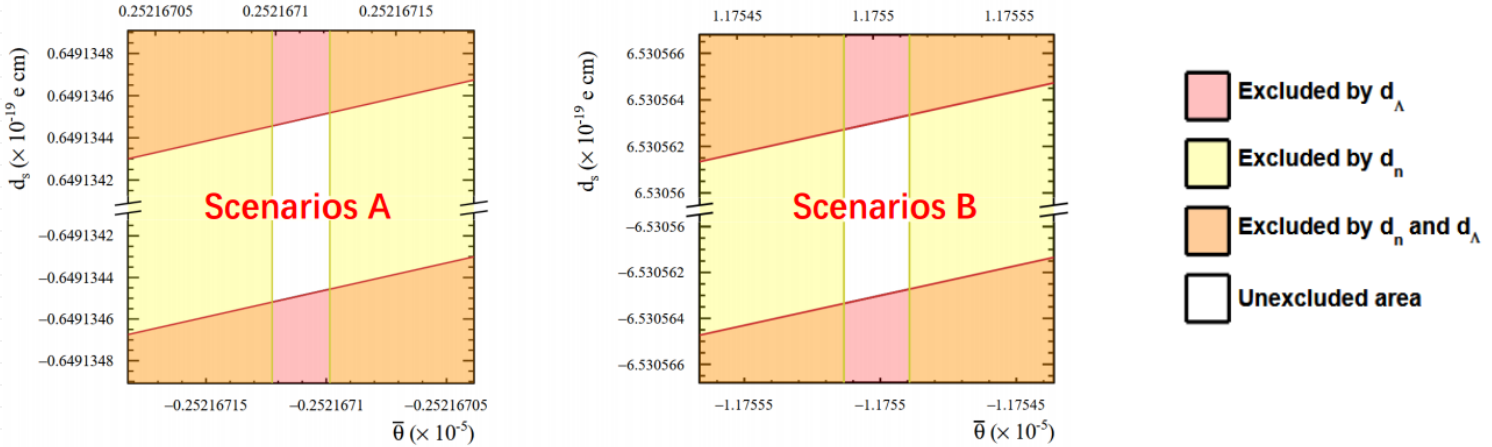
Prior direct Λ EDM limit (Fermilab, 1981): $|d_\Lambda| < 1.5\times10^{-16} e\cdot cm$.

- The Λ EDM is sensitive to the **QCD vacuum angle ($\bar{\theta}$)** and the **strange quark EDM ($d_s$).**
- **Effective EDM relation** from theory**:**

$$d_\Lambda = (-2.6 \pm 0.4)\times10^{-16}\bar{\theta}\ e\ \mathrm{cm} + d_s$$
$$d_n = -(1.5 \pm 0.7)\times10^{-16}\bar{\theta}\ e\ \mathrm{cm} - (0.20 \pm 0.01)d_u + (0.78 \pm 0.03)d_d + (0.0027 \pm 0.0016)d_s$$

- Combining Λ and neutron EDM constraints allows tighter exclusion of BSM scenarios.

A. **With SU(3) flavor symmetry**: $d_u = d_d = d_s$
B. **Without SU(3) symmetry**: $d_s \gg d_u, d_d$



# Complementarity of Λ hyperon and neutron EDMs

K. C. Chen, X. G. He, J. P. Ma, X. B. Tong, Phys. Rev. Lett. 136 (2026) 5, 051902

$\tilde{d}$: chromo-electric dipole moments

$$d_\Lambda = 5.29 \times 10^{-4} d_s + 4.61 \times 10^{-5}(d_u + d_d) + 6.21 \times 10^{-5} e\tilde{d}_s + 1.98 \times 10^{-5} e\tilde{d}_d - 2.14 \times 10^{-5} e\tilde{d}_u$$

$$d_n = -(0.20 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.0016) d_s - (0.55 \pm 0.28) e\tilde{d}_u - (1.1 \pm 0.55) e\tilde{d}_d$$

The QCD theta-term is neglected

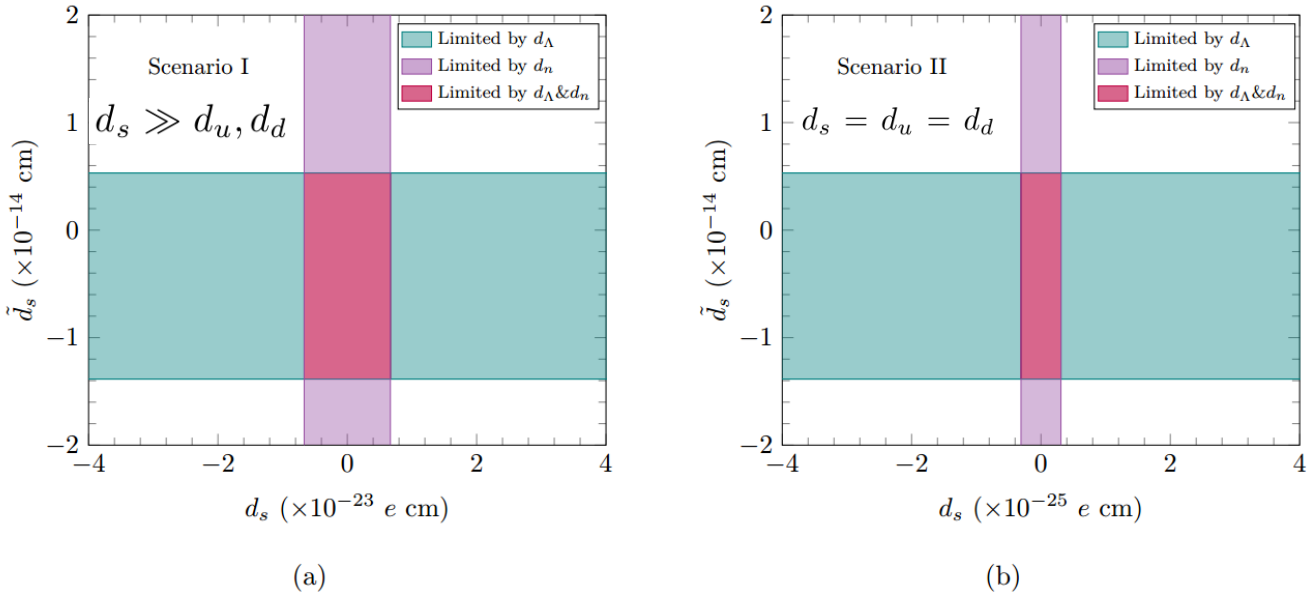



Figure 2: Constraints on the $s$-quark EDM $d_s$ and CEDM $\tilde{d}_s$ from the measurements on the Λ and $n$ EDMs.

**Limitations of the Neutron EDM:**

- Sensitive mainly to the EDMs of up and down quarks.
- Insensitive to the chromo-EDM of the strange quark ($\tilde{d}_s$)

**Unique Advantage of the Λ Hyperon EDM:**

- Particularly sensitive to the strange quark chromo-EDM

**Complementary Information:**

- Λ EDM provides information on the strange quark chromo-EDM that cannot be accessed via the neutron EDM

# Test of $\Delta I = 1/2$ rule in hyperon decays

- In the weak interaction, the isospin is not a conserved quantity, however, there is an experimentally well-established empirical rule -- $\Delta I = 1/2$ rule.

- The $\Delta I = 1/2$ rule allows only those decay transitions in which the change in the total isospin is 1/2.

- Originally, this rule is found in the kaon decays $K \to \pi\pi$, which give the ratio between the $\Delta I = 3/2$ amplitude and the $\Delta I = 1/2$ amplitude: $\frac{Re(A2)}{Re(A0)} = 0.0445 \pm 0.0001 \approx 1/22.47$. In hyperon decays, there are no observations of the existence of the $\Delta I = 3/2$ component before the BESIII measurements.

V. Cirigliano, G. Ecker, H. Neufeld, A. Pich, and J. Portoles, Rev. Mod. Phys. 84, 399 (2012).

## Dynamics of the Standard Model, section XII–6

DOI: 10.1017/9781009291033

$$W(\theta) = 1 + \alpha \mathbf{P}_B \cdot \hat{\mathbf{p}}_{B'}, \qquad \alpha = \frac{2\mathrm{Re}\,(A^*\,\bar{B})}{|A|^2 + |\bar{B}|^2}, \tag{6.4}$$

and the polarization $\langle \mathbf{P}_{B'} \rangle$ of the final-state baryon,

$$\langle \mathbf{P}_{B'} \rangle = \frac{(\alpha + \mathbf{P}_B \cdot \hat{\mathbf{p}}_{B'})\,\hat{\mathbf{p}}_{B'} + \beta\,(\mathbf{P}_B \times \hat{\mathbf{p}}_{B'}) + \gamma\,[\hat{\mathbf{p}}_{B'} \times (\mathbf{P}_B \times \hat{\mathbf{p}}_{B'})]}{W(\theta)},$$

$$\beta = \frac{2\mathrm{Im}(A^*\,\bar{B})}{|A|^2 + |\bar{B}|^2}, \qquad \gamma = \frac{|A|^2 - |\bar{B}|^2}{|A|^2 + |\bar{B}|^2} = \pm\sqrt{1 - \alpha^2 - \beta^2}, \tag{6.5}$$

where $\mathbf{P}_B$ is the polarization of $B$ and $\hat{\mathbf{p}}_{B'}$ is a unit vector in the direction of motion of $B'$. Experimental studies of these distributions lead to the amplitudes listed in Table XII–5.

The nonleptonic amplitudes may be decomposed into isospin components in a notation where superscripts refer to $\Delta I = 1/2,\ 3/2$,

$$\begin{aligned}
A_{\Lambda\to p\pi^-} &= \sqrt{2}\,A_\Lambda^{(1)} - A_\Lambda^{(3)}, & A_{\Sigma^-\to n\pi^-} &= A_\Sigma^{(1)} + A_\Sigma^{(3)},\\
A_{\Lambda\to n\pi^0} &= -A_\Lambda^{(1)} - \sqrt{2}\,A_\Lambda^{(3)}, & A_{\Sigma^+\to n\pi^+} &= \frac{1}{3}A_\Sigma^{(1)} - \frac{2}{3}A_\Sigma^{(3)} + X_\Sigma,\\
A_{\Xi^0\to\Lambda\pi^0} &= -A_\Xi^{(1)} - \sqrt{2}\,A_\Xi^{(3)}, & \sqrt{2}\,A_{\Sigma^+\to p\pi^0} &= -\frac{2}{3}A_\Sigma^{(1)} + \frac{4}{3}A_\Sigma^{(3)} + X_\Sigma,\\
A_{\Xi^-\to\Lambda\pi^-} &= \sqrt{2}\,A_\Xi^{(1)} - A_\Xi^{(3)}, &&
\end{aligned} \tag{6.6}$$

and $X_\Sigma$ is of mixed symmetry. Similar relations hold for the $B$ amplitudes. From

A stands for S-wave amplitude
B stands for P-wave amplitude

If only $\Delta I = 1/2$ component exists:

$$A_{\Lambda\to p\pi^-} = -\sqrt{2}A_{\Lambda\to n\pi^0},$$
$$B_{\Lambda\to p\pi^-} = -\sqrt{2}B_{\Lambda\to n\pi^0},$$

then $\alpha_{\Lambda\to p\pi^-} = \alpha_{\Lambda\to n\pi^0}$