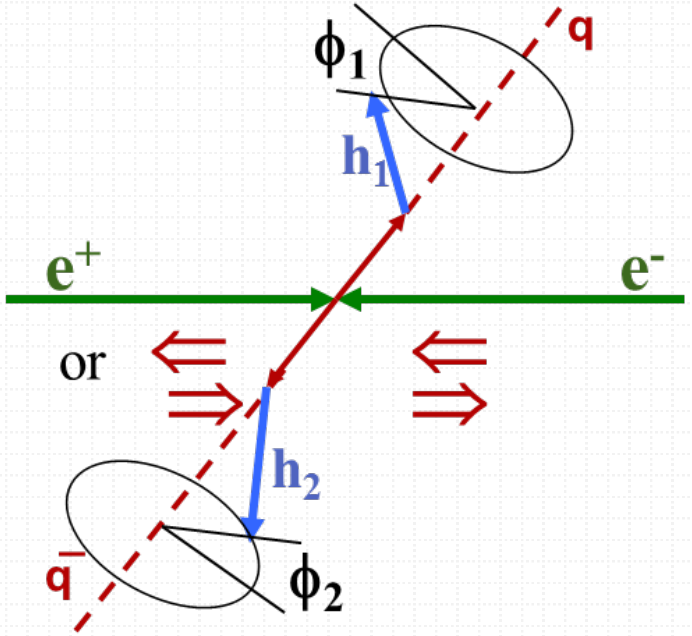
Paradigm-changing studies of spin entangled hyperons and antihyperons at BESIII



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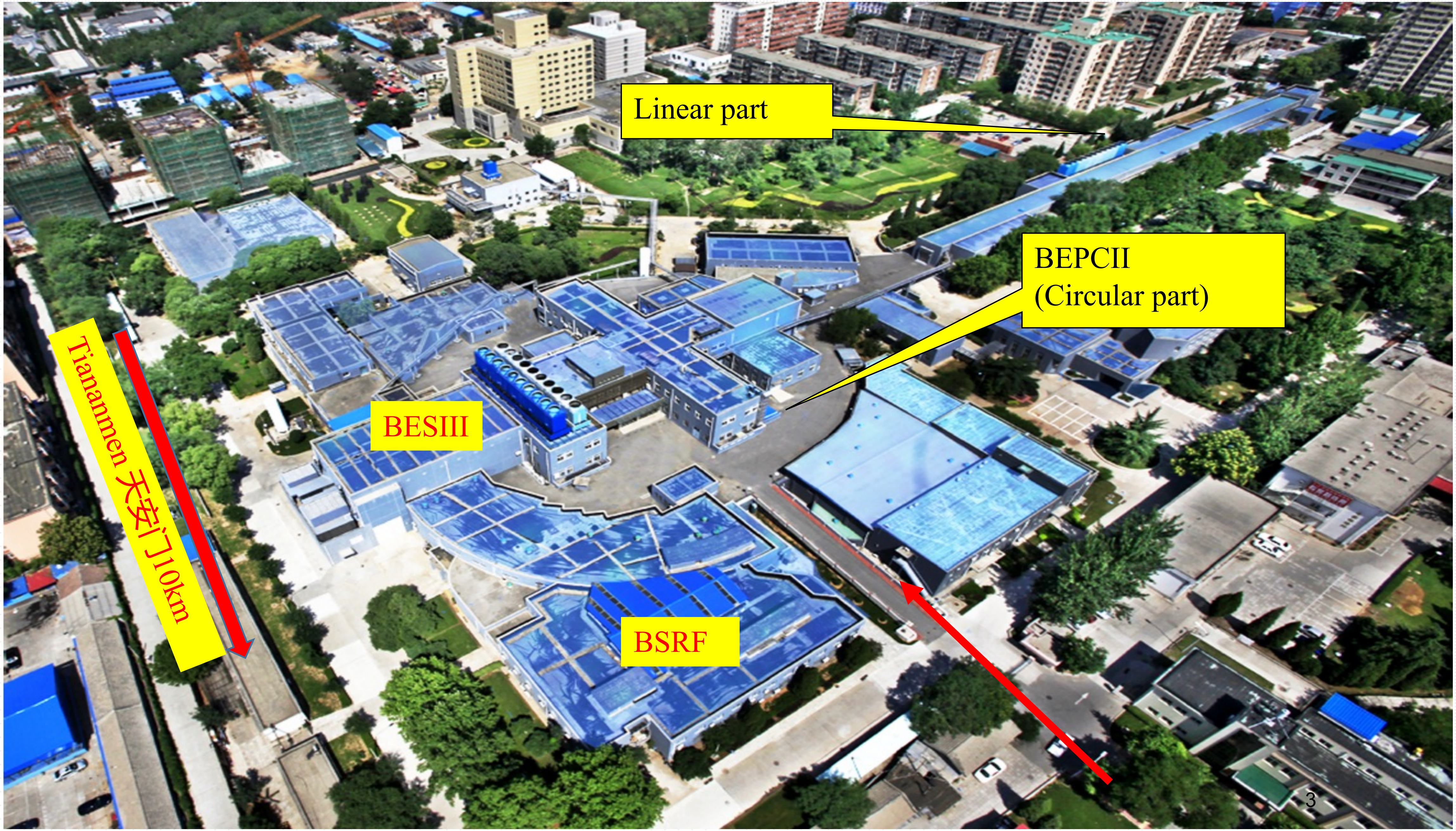
第一届强相互作用自旋物理会议
26-31 July, 2026, 青岛

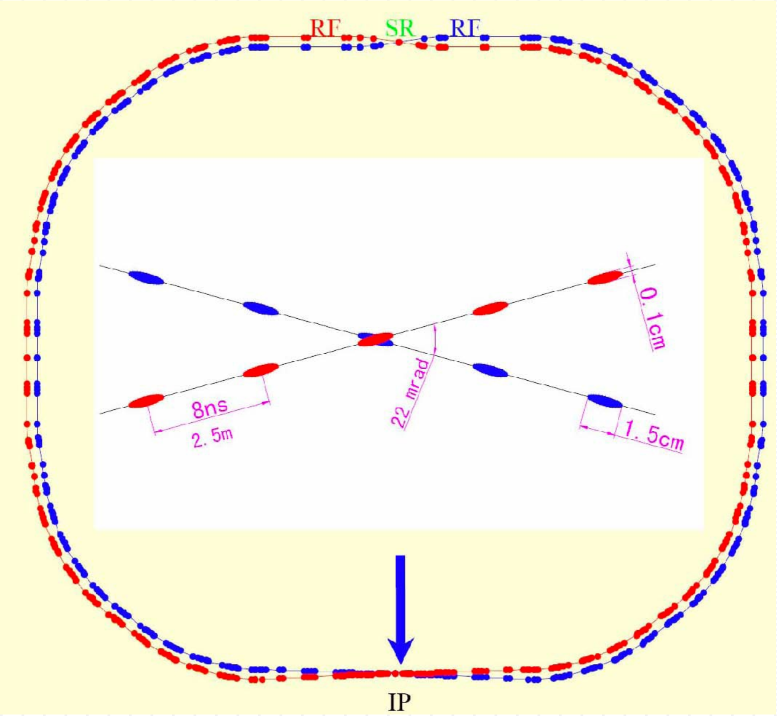
Outline

- ✓ Introduction
- ✓ Hyperon physics
- ✓ Summary

Beijing Electron-Positron Collider II (BEPCII)



BEPCII storage rings: a τ-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: . $1.1 \times 10^{33}\ cm^{-2} s^{-1}$

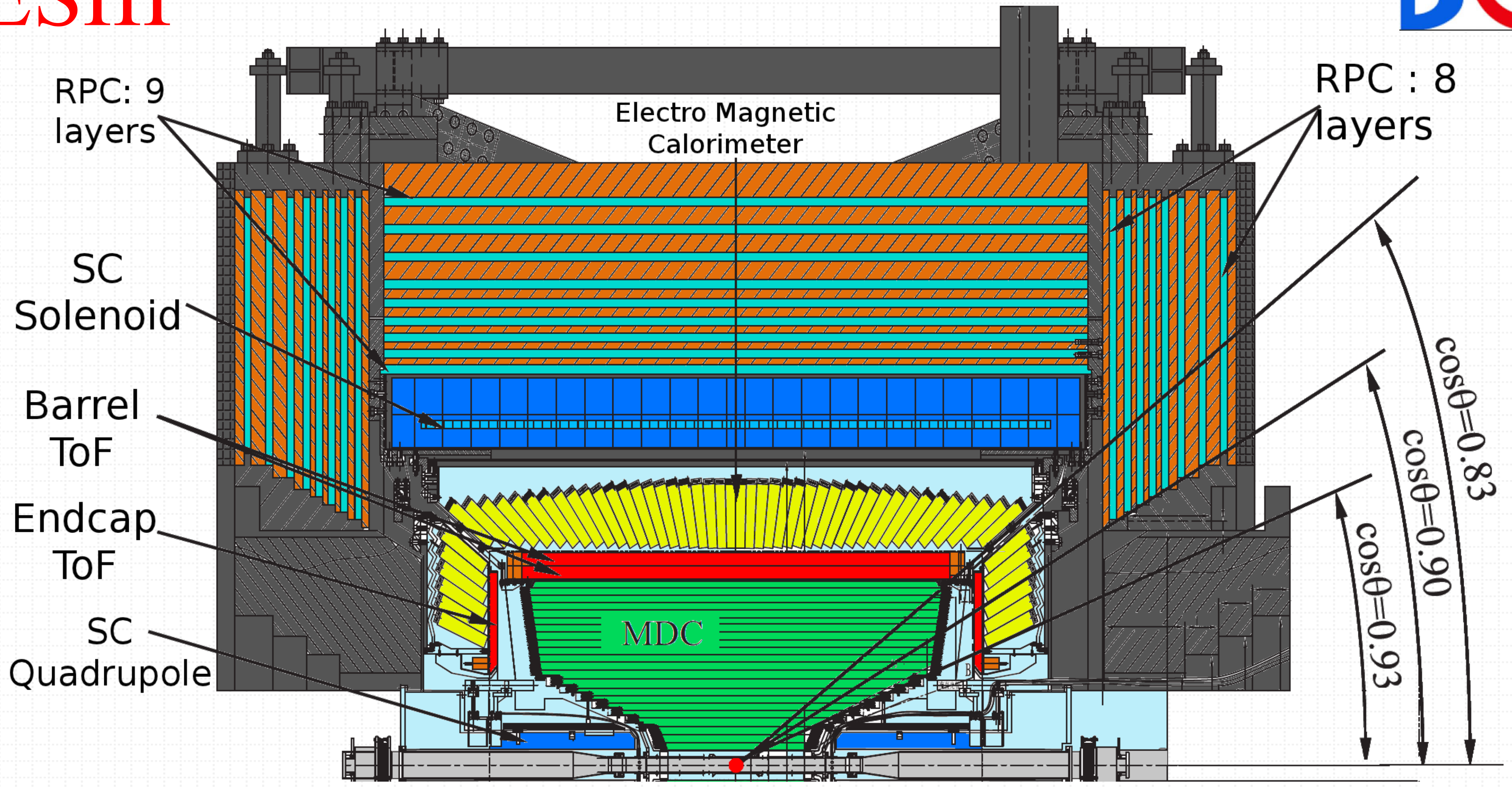
Beam energy measurement:

Laser Compton backscattering

$\Delta E / E \approx 5 \times 10^{-5}$

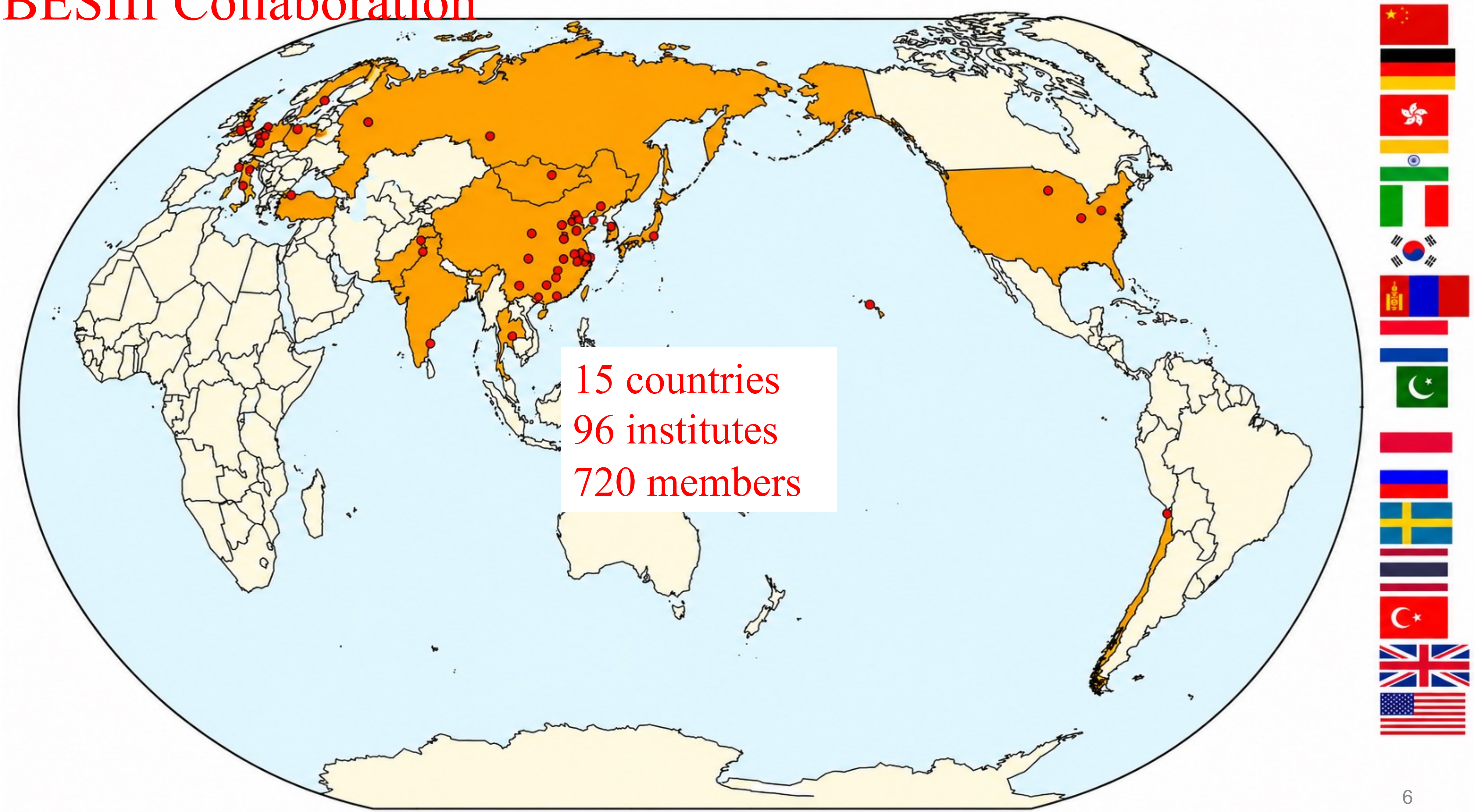
(50 keV at $\tau^+ \tau^-$threshold)

BESIII



Extremely reliable operation of detector and readout electronics

BESIII Collaboration



15 countries
96 institutes
720 members

BEPCII upgrade in 2024

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

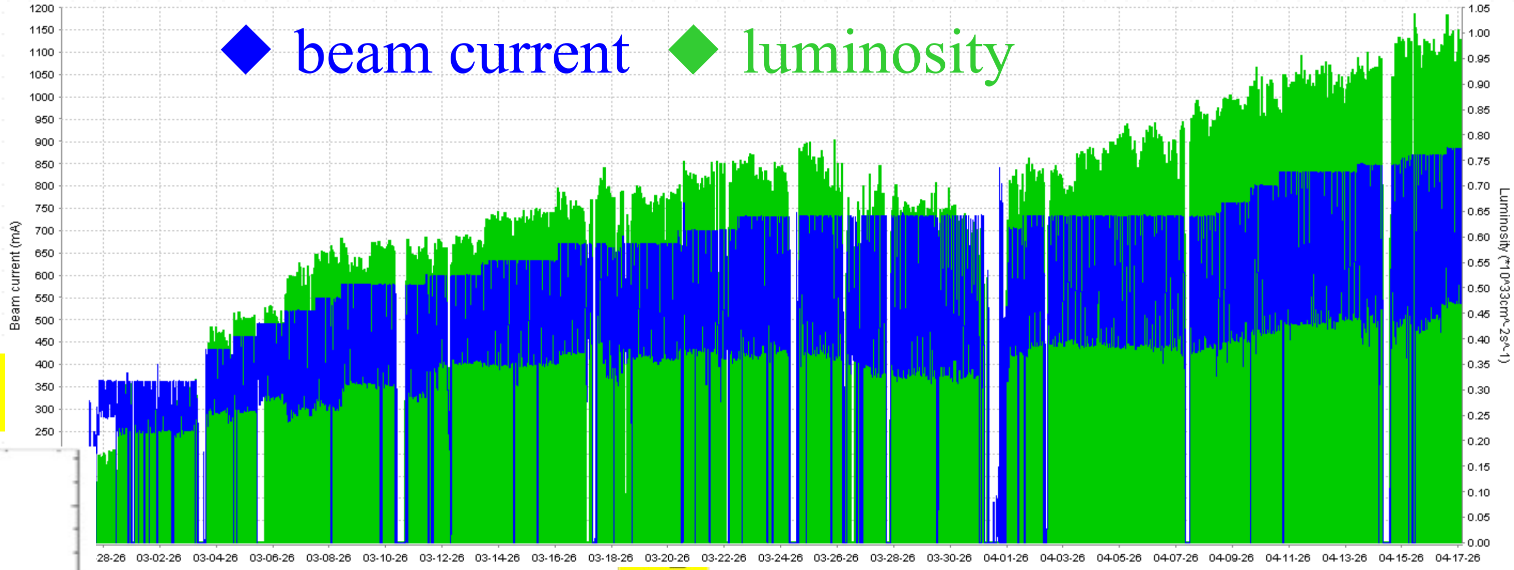
@Eb=2.35 GeV （Pre-upgrade: 0.**35× 10^{33}cm^{-2}s^{-1}**)

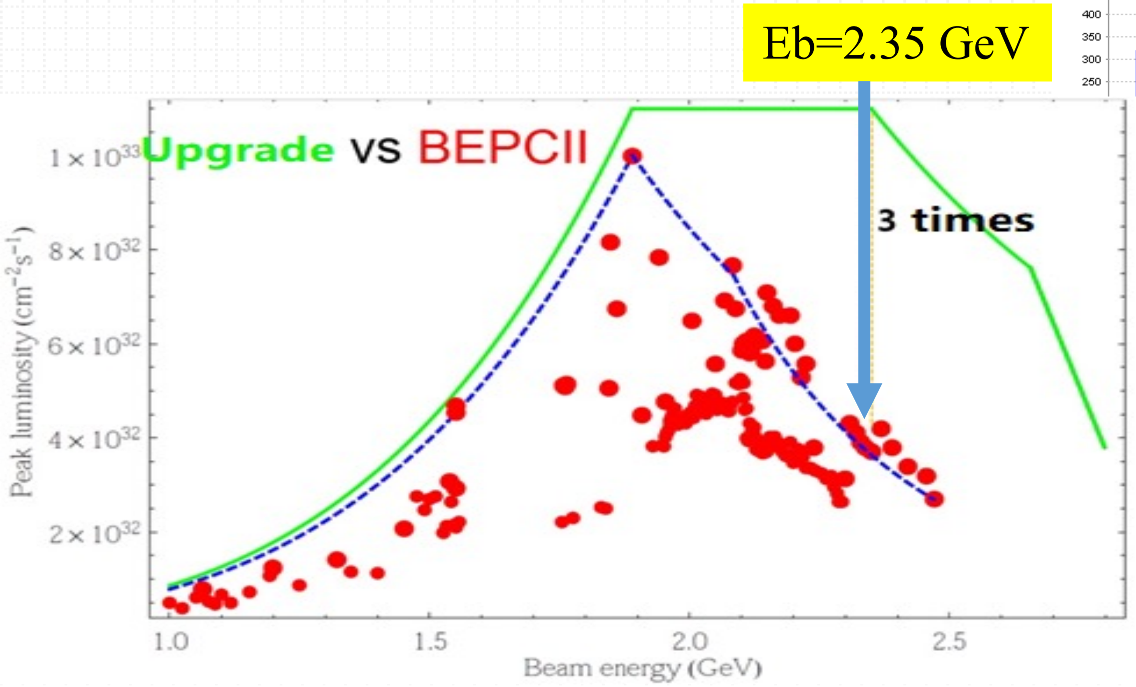
BEPCII upgrade (installation: 2024. 7- 2024. 12)

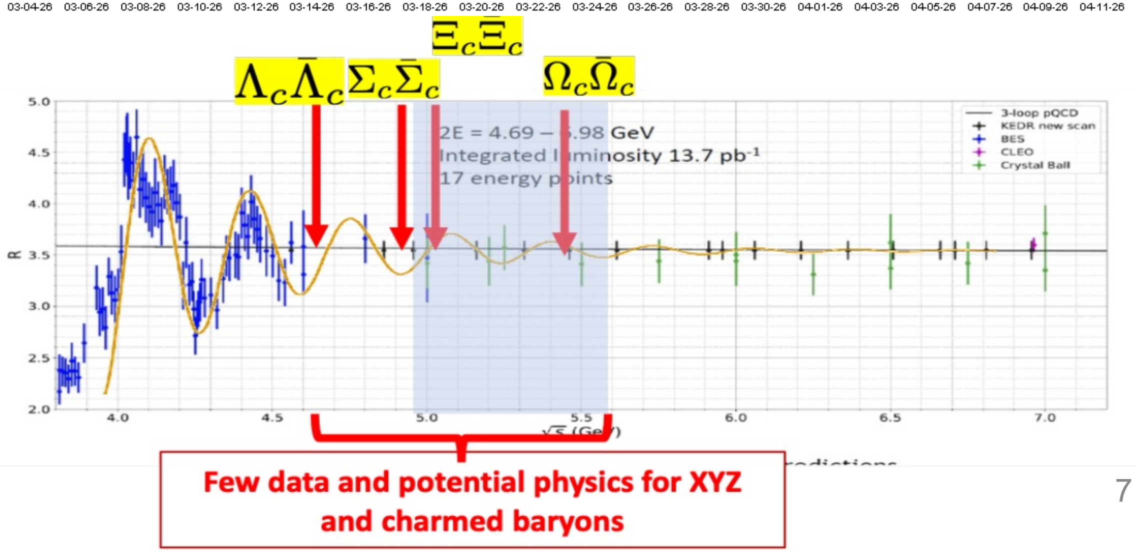
Highest beam energy: 2.8 GeV

Luminosity: 1.1×10^{33} cm^{-2}s^{-1} （4.0 ~ 5.0 GeV）

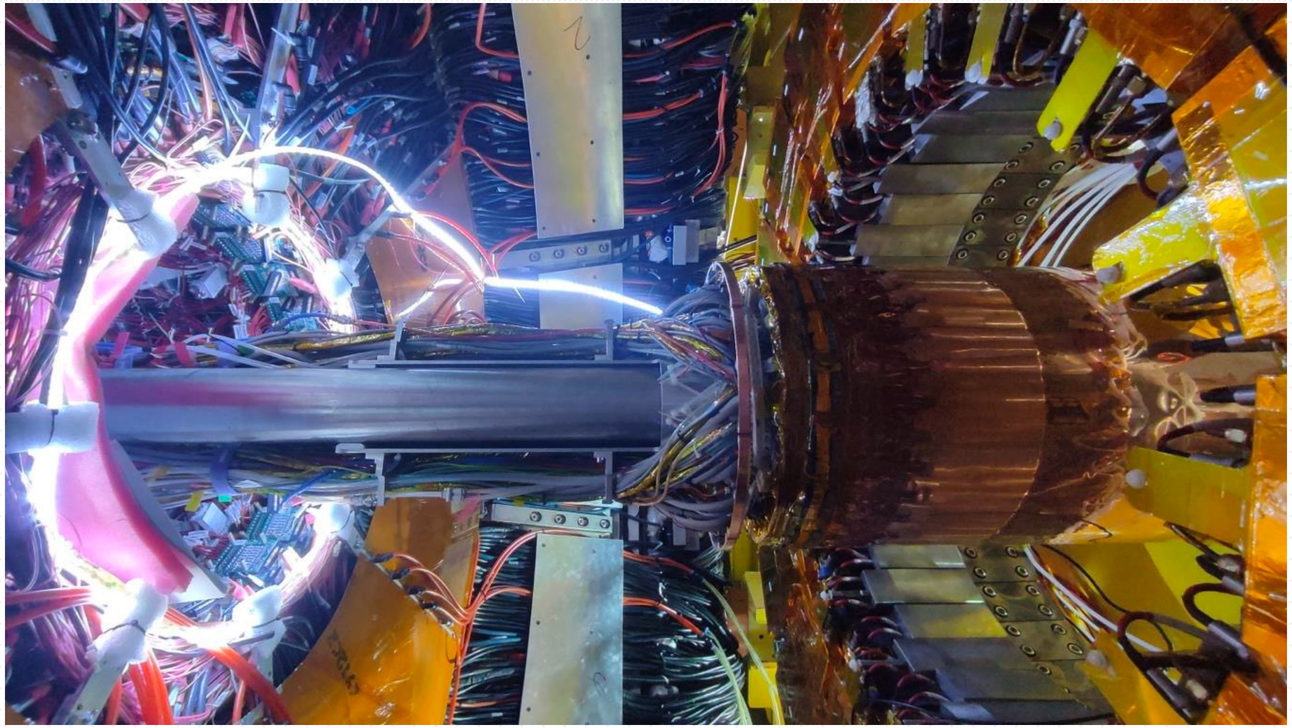
(0.4-0.7) $\times10^{33}$ cm^{-2}s^{-1} (5.0 ~ 5.6GeV）







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

Planned BEPCII-UP with Crab Waist

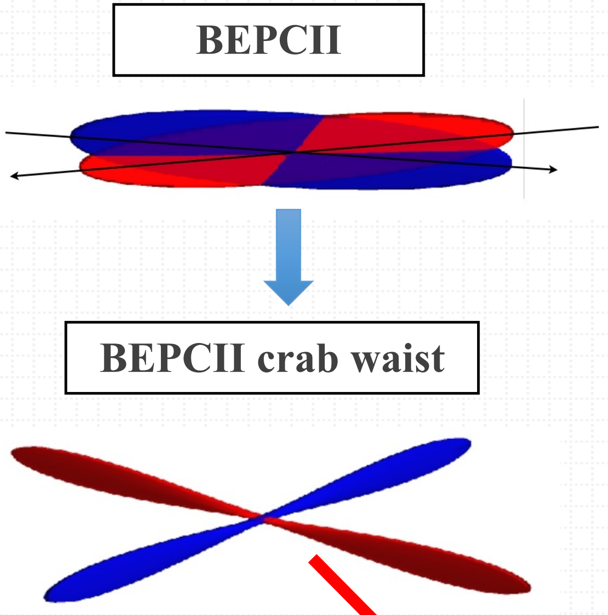
Design study supported by IHEP innovation funding:

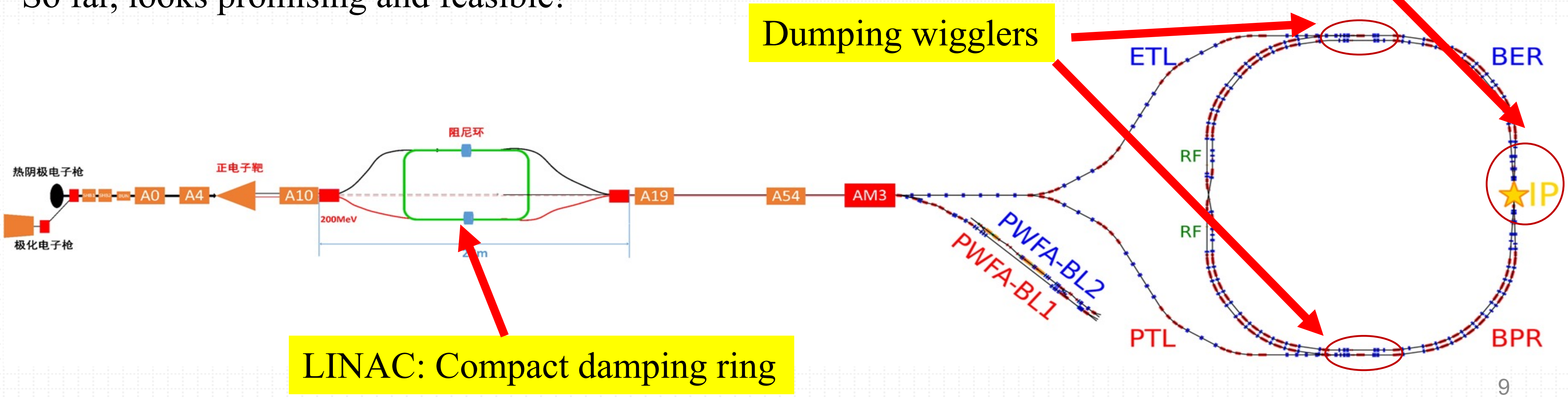
- ✓ add crab waist cavities to the ring
- ✓ modify interaction region
- ✓ super-conducting wigglers near injection points
- ✓ new damping ring for linac

So far, looks promising and feasible!

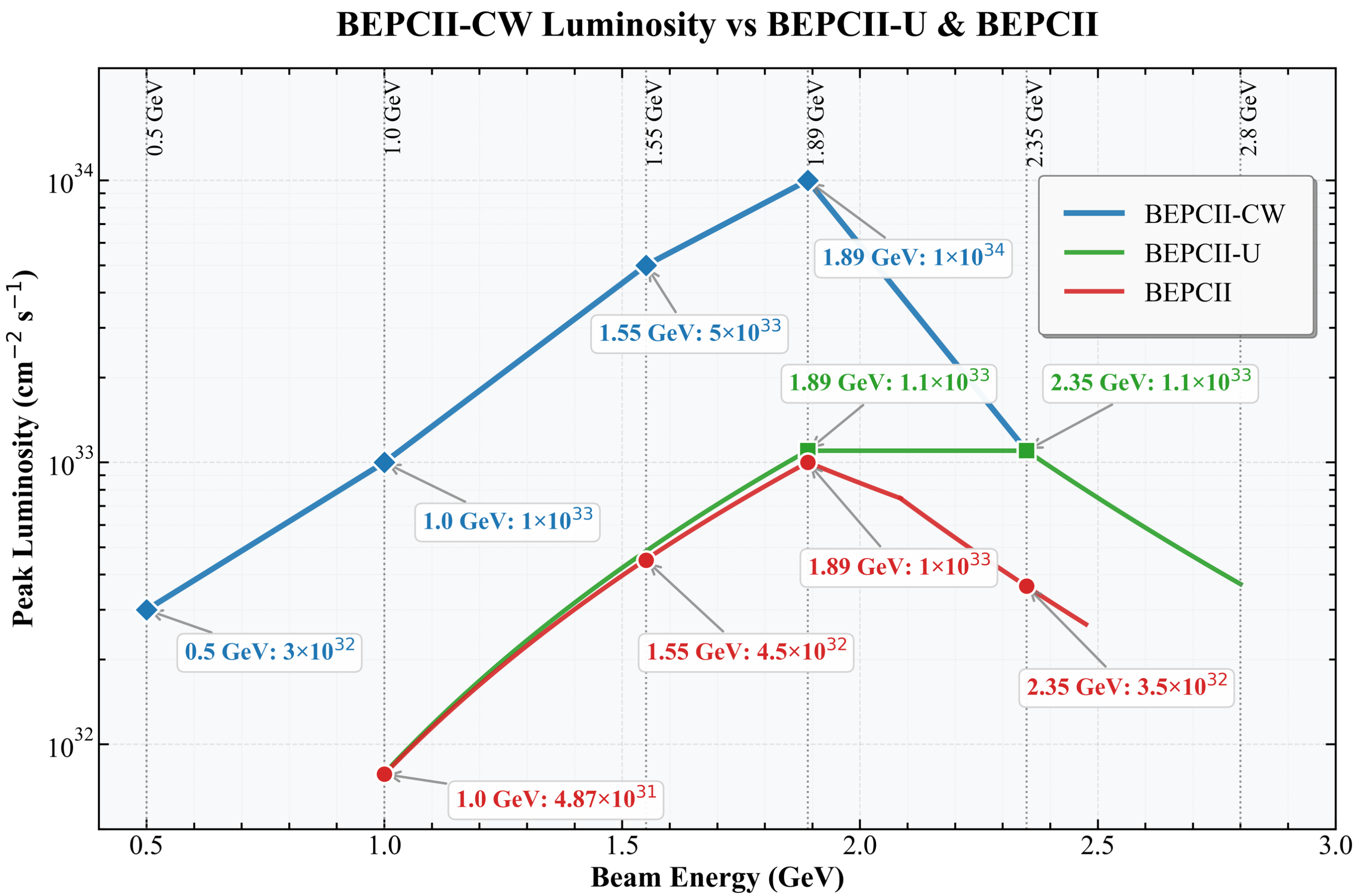
11 mrad

18 mrad





BEPCII-UP performance outlook

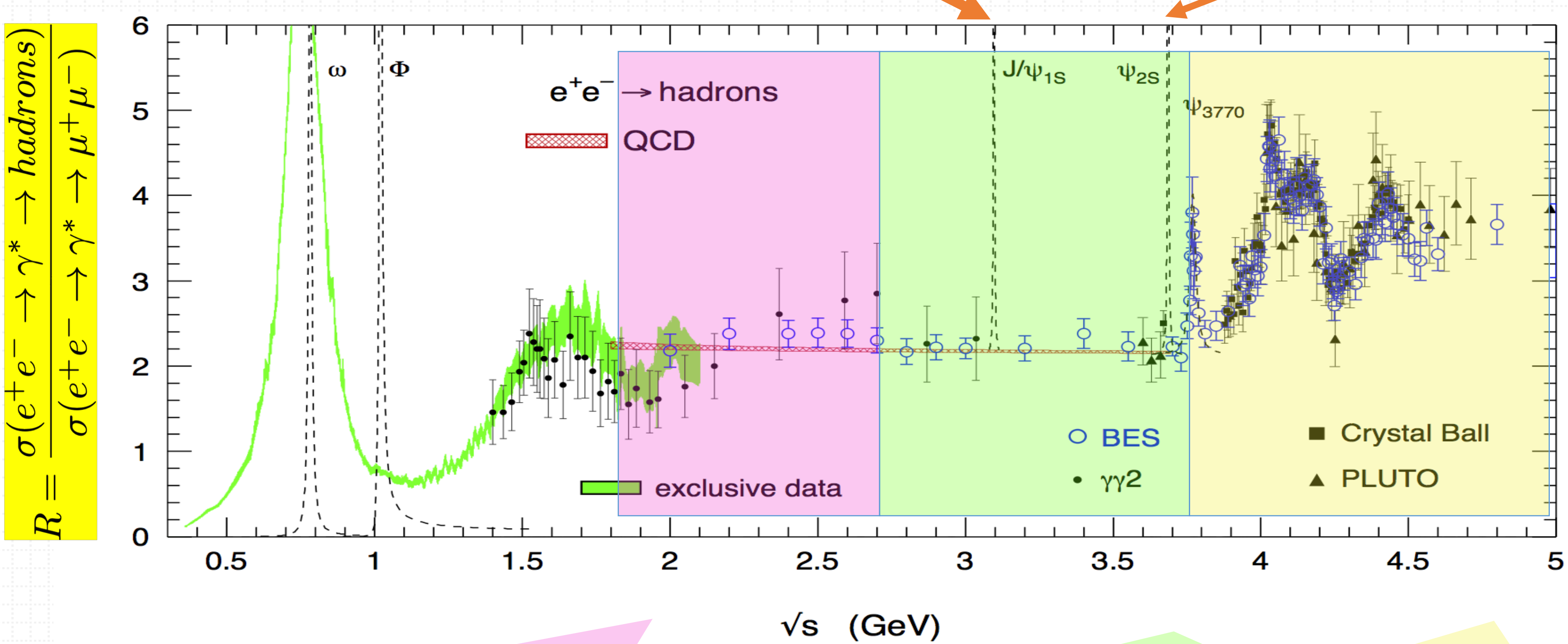


- Luminosity increased by ×10 @beam energy 1.89GeV,.
- Operation with beam energy from 0.5 – 1.0 GeV
- Possibility: beam energy → 0.3 GeV, around $\rho - \omega$ peaks with visible luminosity

Rich Physics at τ-charm Energy Region

$\sigma(e^+e^- \to J/\psi) = 3400nb$

$\sigma(e^+e^- \to \psi(3686)) = 600nb$



- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with τ lepton

- XYZ particles
- Charm mesons
- Charm baryons

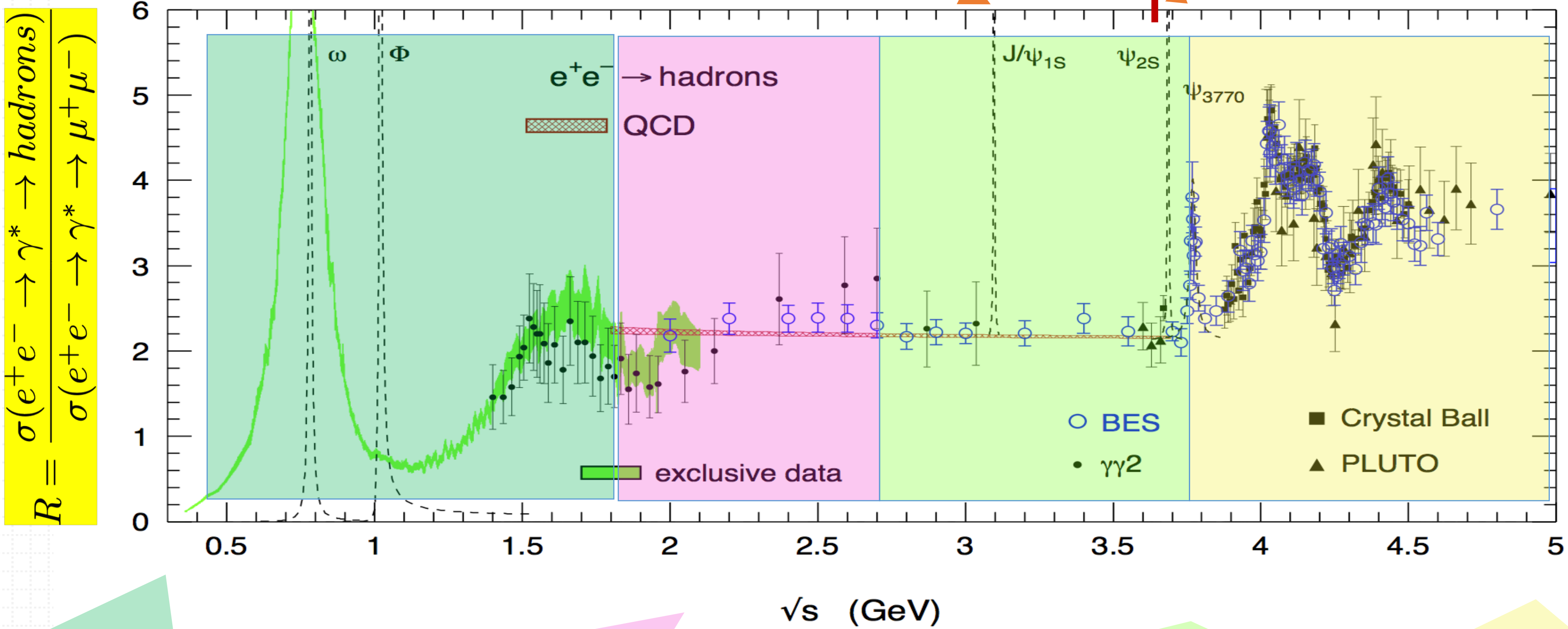
Rich Physics at τ-charm Energy Region

BEPCII-UP

BEPCII-U

$\sigma(e^+e^- \to J/\psi) = 3400nb$

$\sigma(e^+e^- \to \psi(3686)) = 600nb$



- R values <2.0GeV
- Strangeonium physics
- Nucleon form factors
- Hadron vacuum polarization

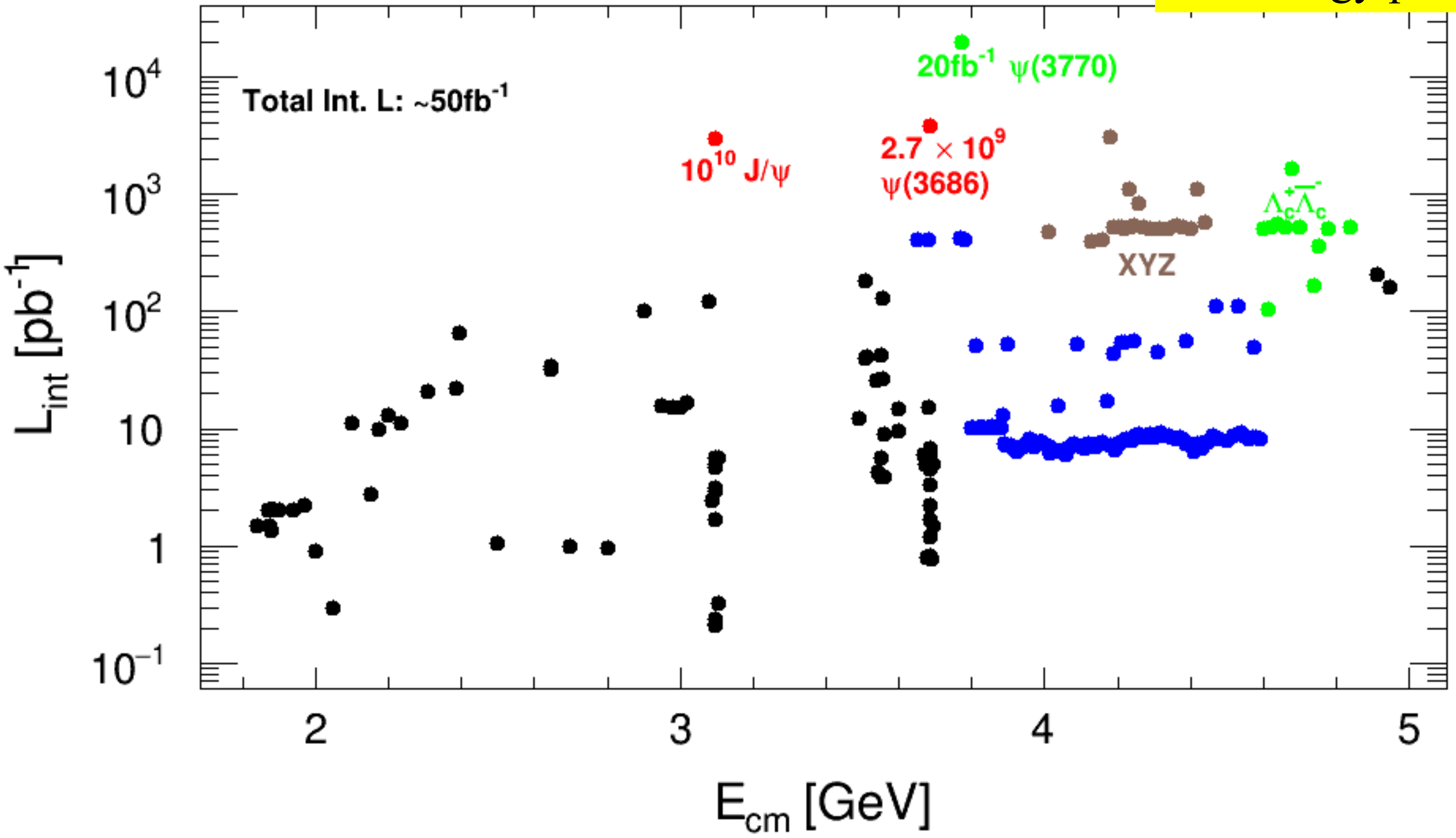
- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with τ lepton

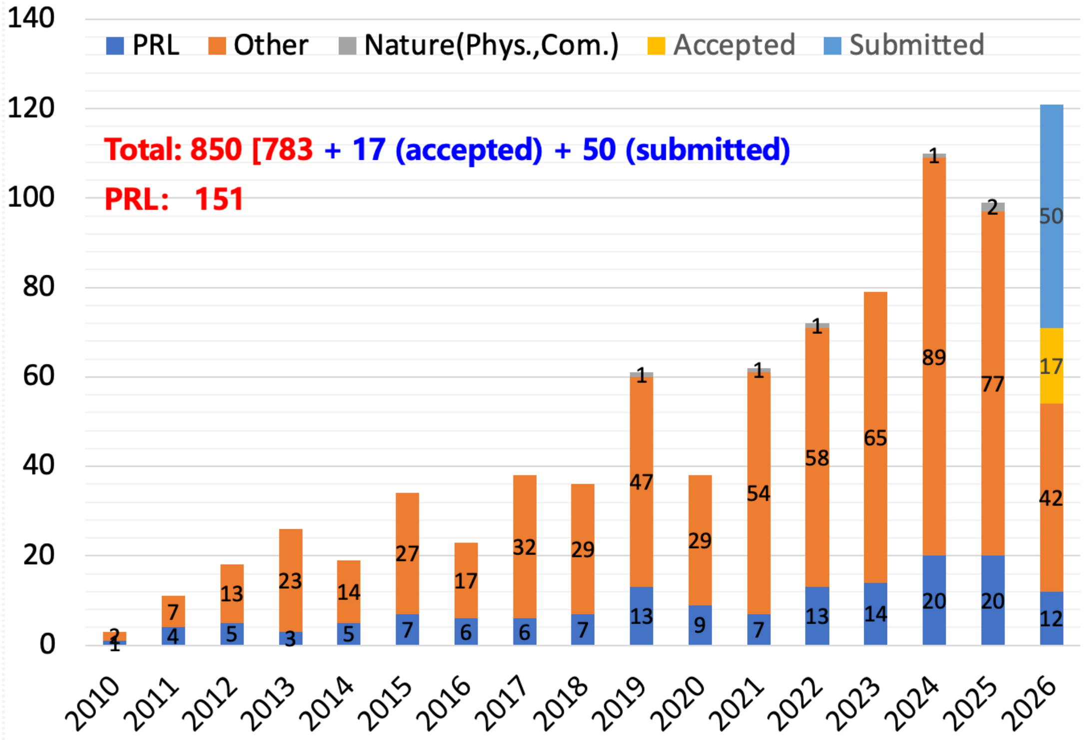
- XYZ particles
- Charm mesons
- Charm baryons

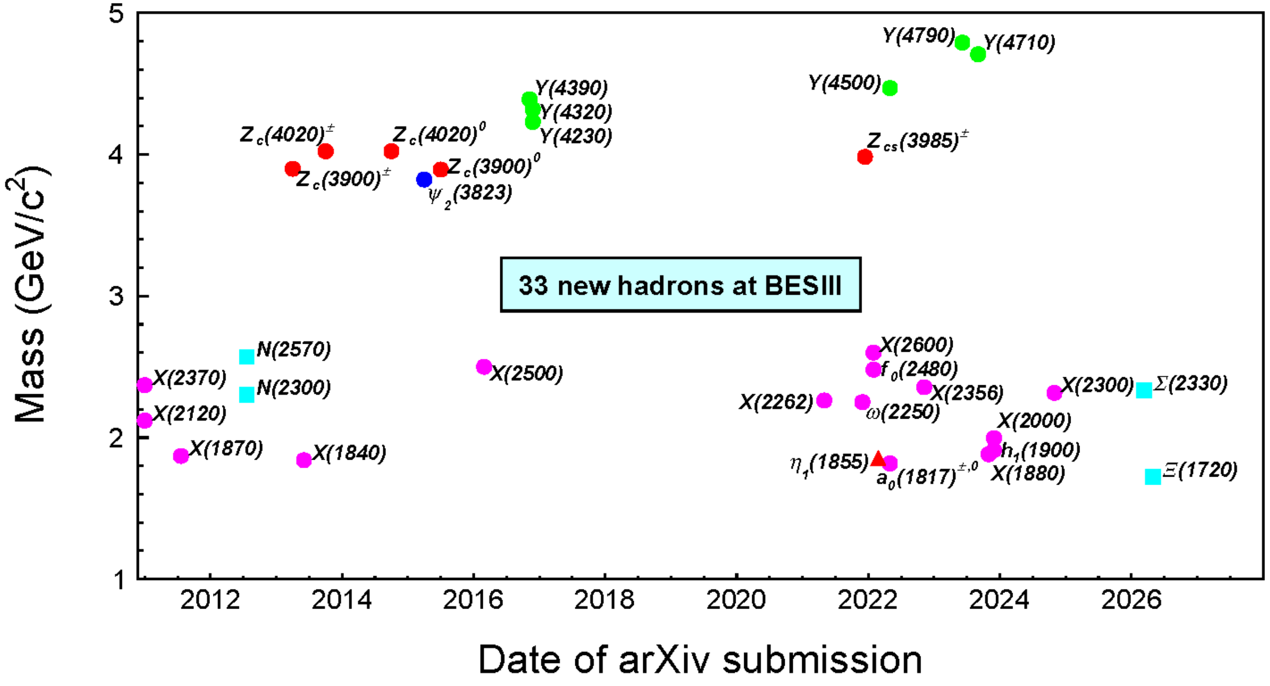
16 years data-taking at BESIII

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 21 Mar 2025, there is no observation of CPV in the baryon system.**

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

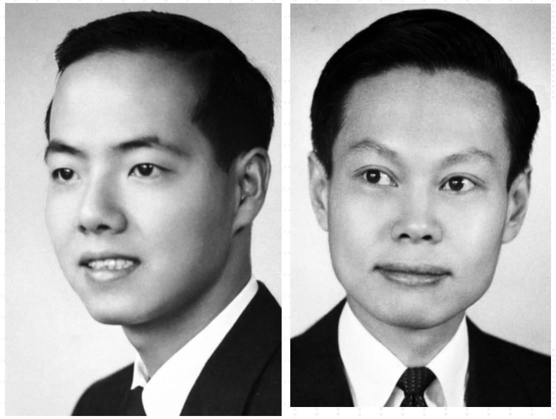
K meson CPV	B meson CPV	D meson CPV	Λ_b baryon	Hyperon/charmed baryon?
1964	2001	2019	2025	

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 π:

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

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

The measurable decay parameters:

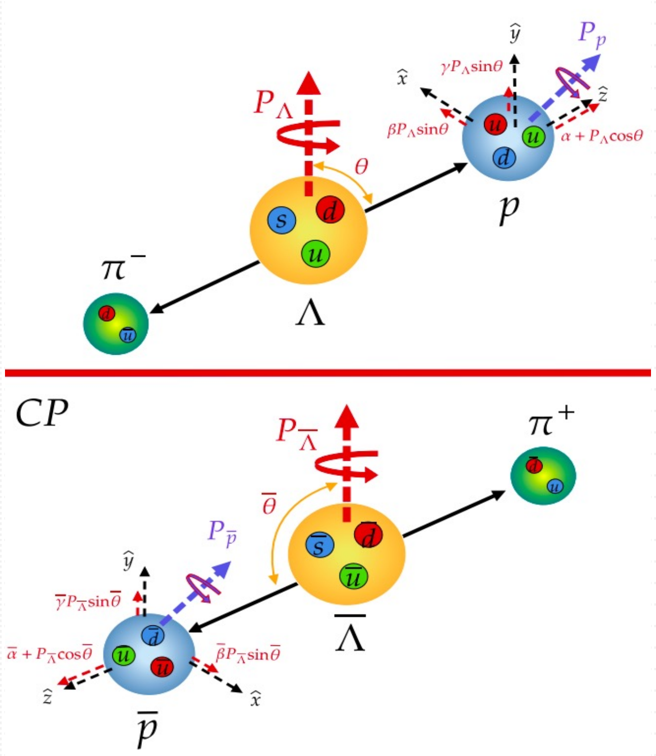
$$\alpha_Y = \frac{2\,\mathrm{Re}\left(S^* P\right)}{|S|^2+|P|^2},\quad \beta_Y = \frac{2\,\mathrm{Im}\left(S^* P\right)}{|S|^2+|P|^2},\quad \gamma_Y = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

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

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

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

SM Predictions

strong phase weak phase

Not sensitive to *CPV* → **Decay width difference** $\Delta_{CP} = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}} \approx \sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}}\sin(\delta_P-\delta_S)\sin(\xi_P-\xi_S)$ -5.4×10^{-7}

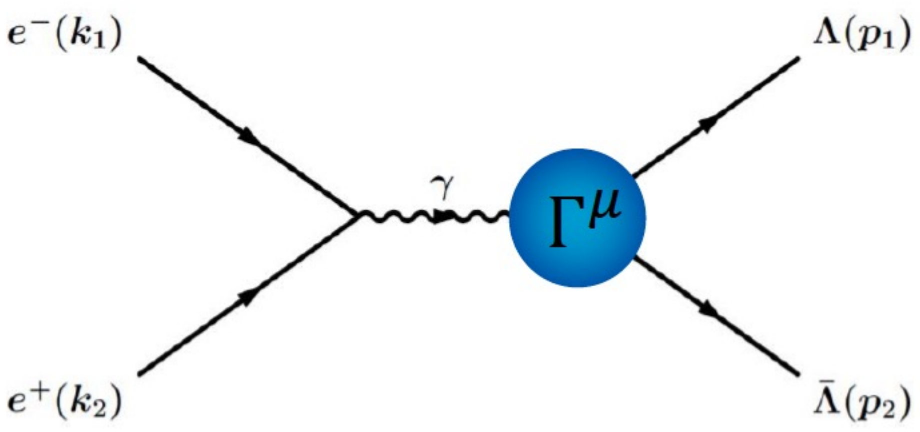
Easy to measure → **Decay parameter difference** $A_{CP} = \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} \approx -\tan(\delta_P-\delta_S)\,tan(\xi_P-\xi_S)$ -0.5×10^{-4}

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

Ξ^-, Ξ^0, Ω^- 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:

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

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

If $\Delta\Phi \neq 0$, Λ and $\bar{\Lambda}$ 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

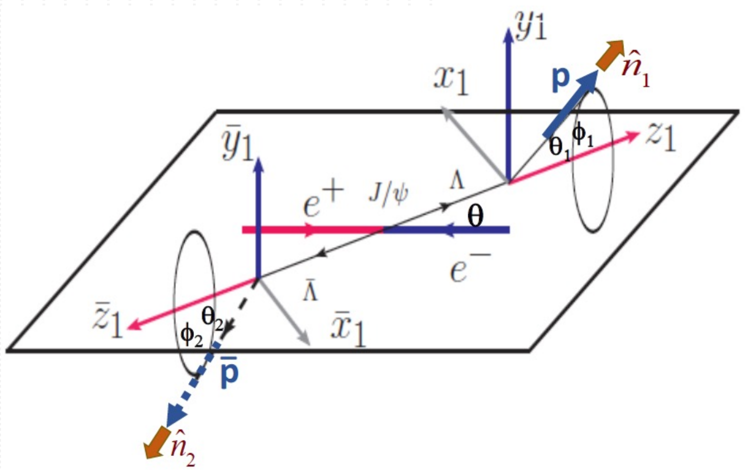
Spin correlated part

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

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

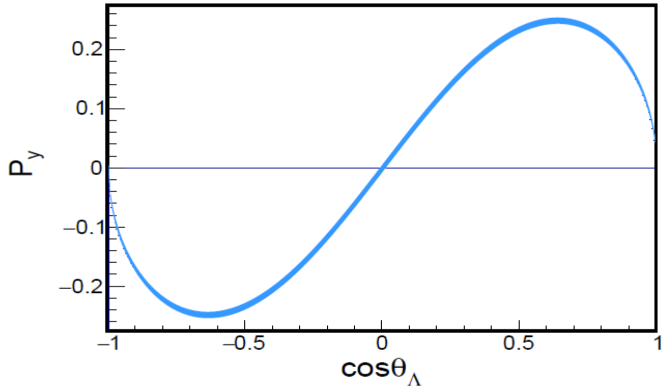
$$+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\ \sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_- n_{1,y}+\alpha_+ n_{2,y}\right),$$

Spin Polarized part



Spin correlated term and polarization term can be used to determine α_- and α_+ simultaneously and precisely.

Λ



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

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:

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

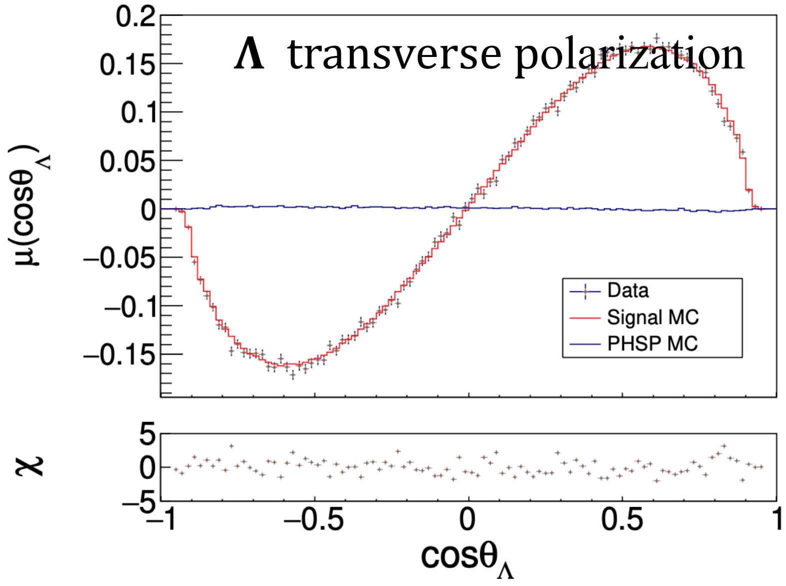
$$\alpha_- = \ \ 0.7519(36)(24)$$

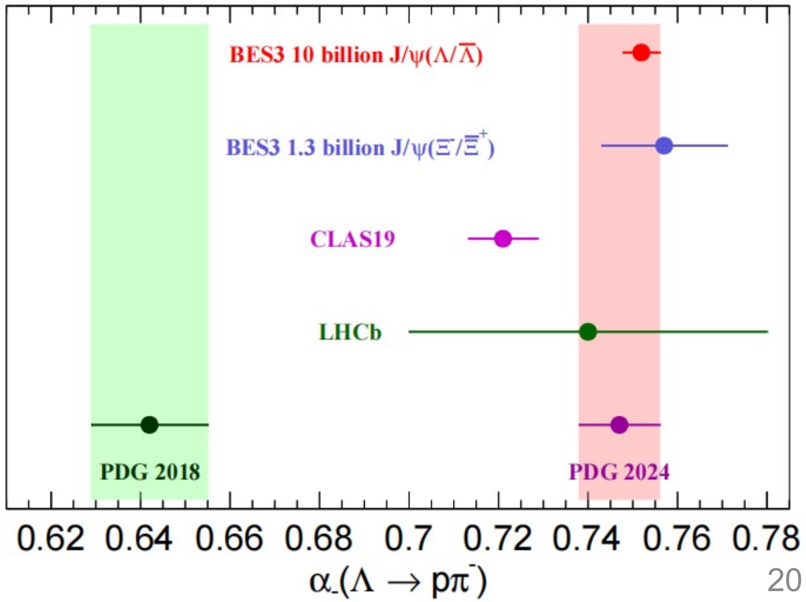
$$\alpha_+ = -0.7559(36)(30)$$

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

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

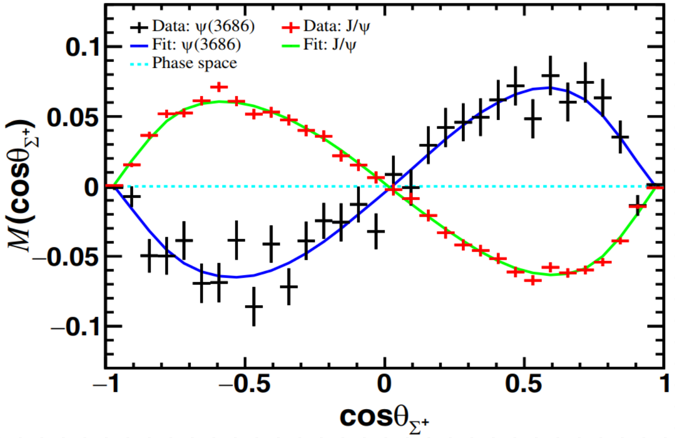
$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = (-2.5 \pm 4.6 \pm 1.1)\times 10^{-3}$$



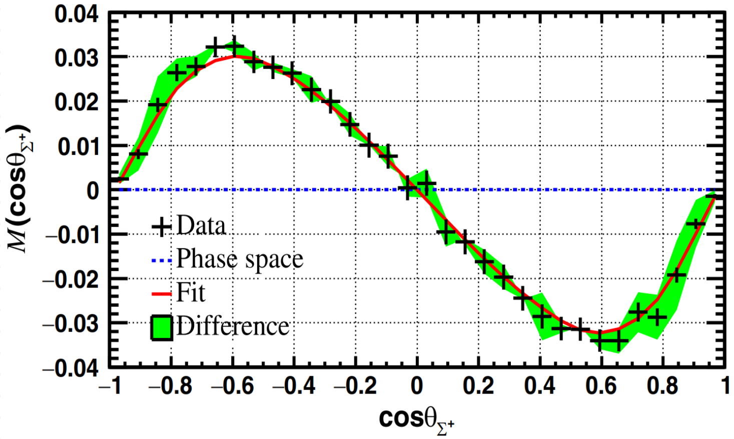


Search for CPV in Σ^+ decay (10 billion J/ψ)

[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/ψ 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

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

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

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

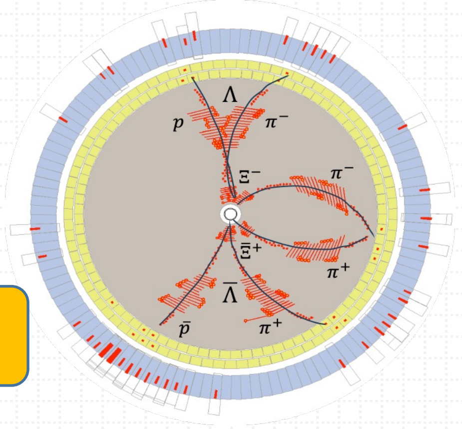
The most precise CP test in Σ sector:

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

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

[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)

spin-aligned

quantum entangled

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

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

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

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

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

Hyperon Production

Hyperon decays

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

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

CPV tests in hyperon decays

$\Xi^- \to \Lambda\pi^-$	$\bar{\Xi}^+ \to \bar{\Lambda}\pi^+$
$S = \lvert S\rvert \exp(\boxed{i\xi_S} + i\delta_S)$	$\bar{S} = \lvert S\rvert \exp(\boxed{-i\xi_S} + i\delta_S)$
$P = \lvert P\rvert \exp(\boxed{i\xi_P} + i\delta_P)$	$\bar{P} = -\lvert P\rvert \exp(\boxed{-i\xi_P} + i\delta_P)$

CP-odd phases

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

$$A_{\mathrm{CP}} = -\tan(\delta_P - \delta_S)\tan(\xi_P - \xi_S)$$

$$B_{\mathrm{CP}} = \tan(\xi_P - \xi_S)\ ,$$

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

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

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

The most precise decay parameters:

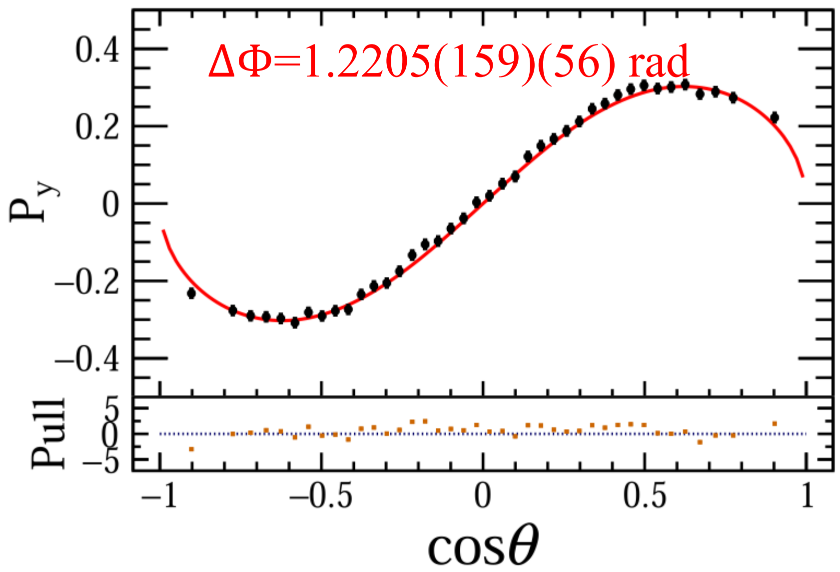
$$\alpha_\Xi = -0.3813(26)(5)$$
$$\bar{\alpha}_\Xi = 0.3873(26)(6)$$
$$\Phi_\Xi = -0.0008(72)(10) \text{ rad}$$
$$\bar{\Phi}_\Xi = 0.0020(72)(6) \text{ rad}$$
$$\alpha_\Lambda = 0.7434(39)(15)$$
$$\bar{\alpha}_\Lambda = -0.7478(38)(15)$$

Three CPV tests:

$$A_{CP}^{\Xi} := \frac{\alpha_\Xi+\bar{\alpha}_\Xi}{\alpha_\Xi-\bar{\alpha}_\Xi} = (-7.8 \pm 4.8 \pm 0.8)\times10^{-3}$$

$$A_{CP}^{\Lambda} := \frac{\alpha_\Lambda+\bar{\alpha}_\Lambda}{\alpha_\Lambda-\bar{\alpha}_\Lambda} = (-2.9 \pm 4.3 \pm 0.7)\times10^{-3}$$

$$\Delta\Phi_{CP}^{\Xi} := \frac{\Phi_\Xi+\bar{\Phi}_\Xi}{2} = (0.6 \pm 5.1 \pm 0.2)\times10^{-3} \text{ rad}$$



The weak CP and strong phases are extracted :

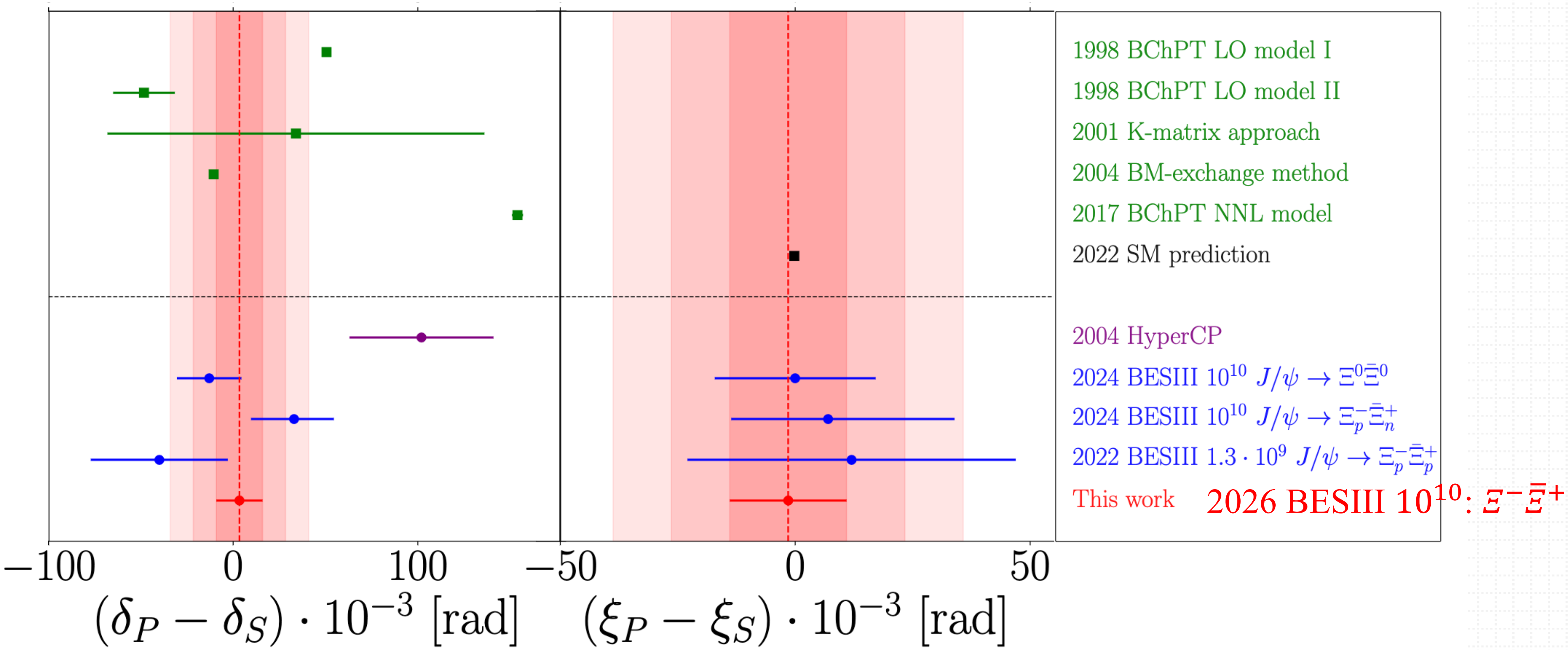
$$(\boldsymbol{\xi_P - \xi_S}) = (-0.2 \pm 1.2 \pm 0.1)\times10^{-2} \text{ rad}$$
$$(\boldsymbol{\delta_P - \delta_S}) = (0.3 \pm 1.2 \pm 0.2)\times10^{-2} \text{ rad}$$

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

$$A_{CP}^{\Xi 0} = (-5.4 \pm 6.5 \pm 3.1)\times10^{-3}$$
$$A_{CP}^{\Lambda} = (6.9 \pm 5.8 \pm 1.8)\times10^{-3}$$
$$\Delta\Phi_{CP}^{\Xi 0} = (-0.1 \pm 6.9 \pm 0.9)\times10^{-3} \text{ rad}$$

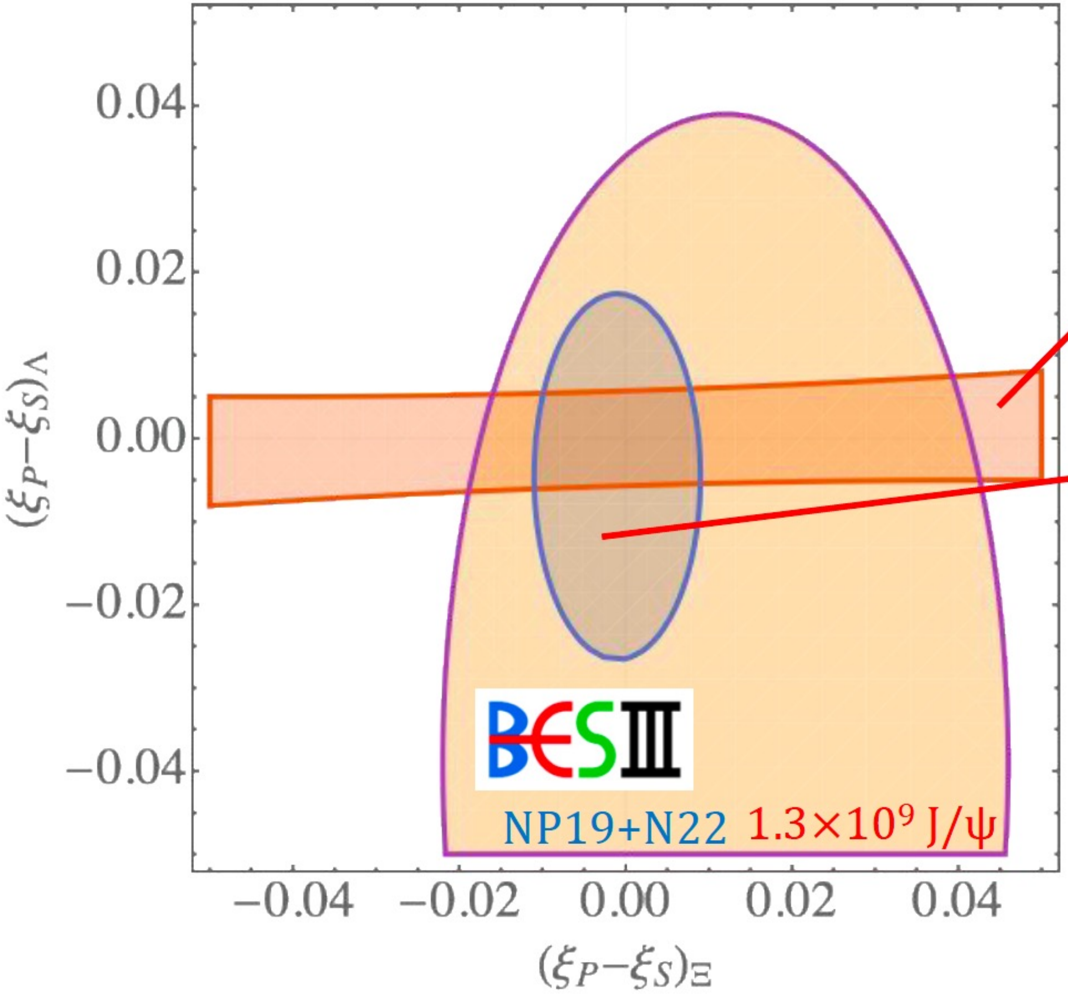
CP tests in hyperon decays with 10 billion J/ψ

PRL 129 (2022) 131801 : 32×10^5 $\Lambda\bar{\Lambda}$ pairs (0.1% bkg)
PRD 108 (2023) L031106: 3.3×10^5 $\Xi^0\bar{\Xi}^0$pairs (2% bkg)
PRL 136 (2026) 201802: 5.8×10^5 $\Xi^-\bar{\Xi}^+$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 $3.2\times10^{6}\ \Lambda\bar{\Lambda}$

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

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

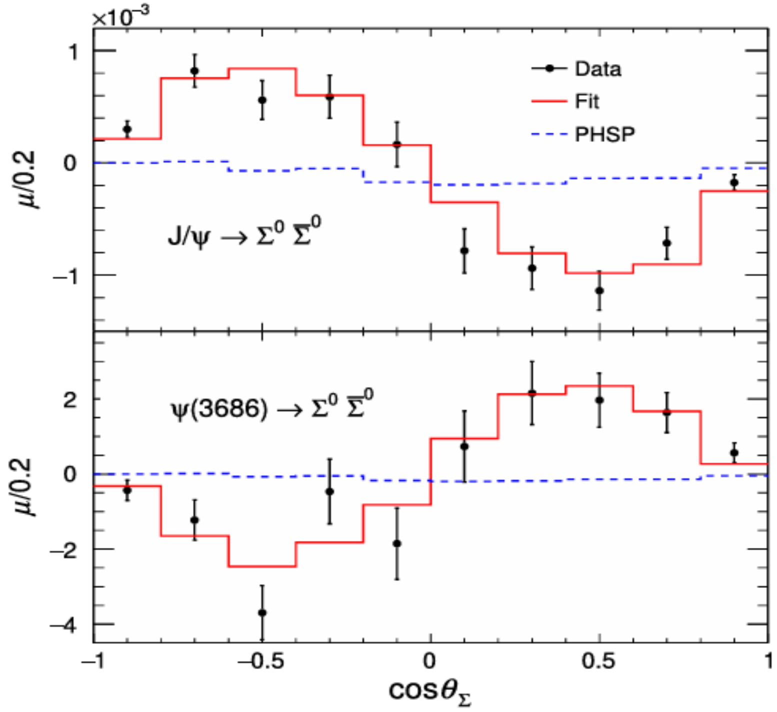
Nature 606 (2022) 64-69, 1.3 billion J/ψ : 73 K $\Xi^-\bar{\Xi}^+$ pairs
PRL 136,201802 , 10 billion J/ψ : 580 K $\Xi^-\bar{\Xi}^+$ pairs

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/ψ and 2.7 B $\psi(3686)$



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

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

Opposite directions of the Σ^0 polarization,
Similar behavior is observed in Σ^+, but not in Λ or Ξ.

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

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

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

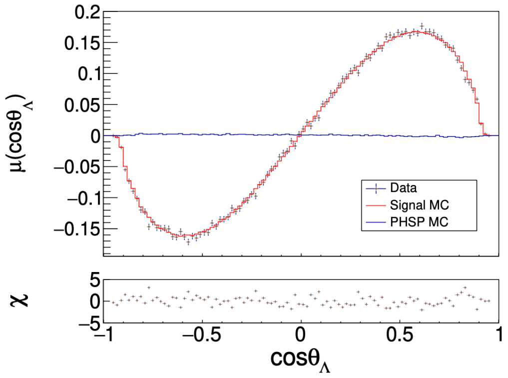
$$A_{CP}^{\Sigma^0} := \alpha_{\Sigma^0} + \bar{\alpha}_{\Sigma^0} = (-0.4 \pm 2.9 \pm 1.3)\times 10^{-3}$$

Spin polarizations of different hyperons

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

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

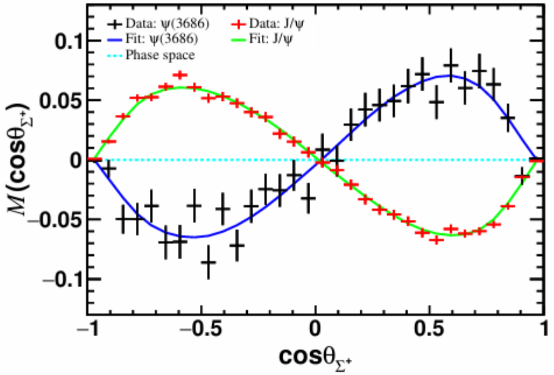
PRL129, 131801(2022)



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

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

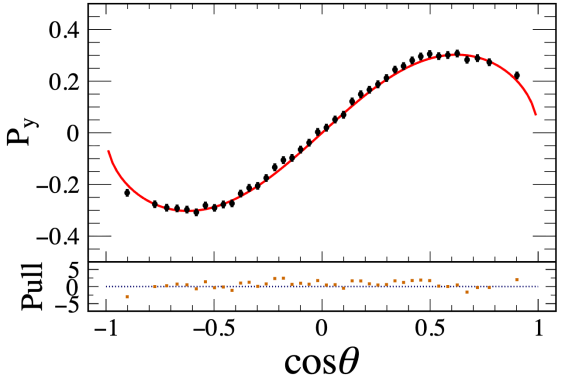
PRL135, 141804 (2025)



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

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

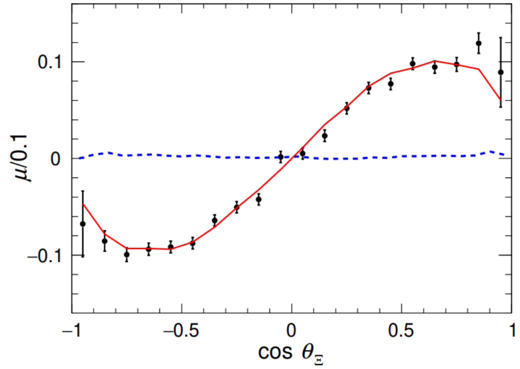
Phys. Rev. Lett. 136, 201802 (2026)



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

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

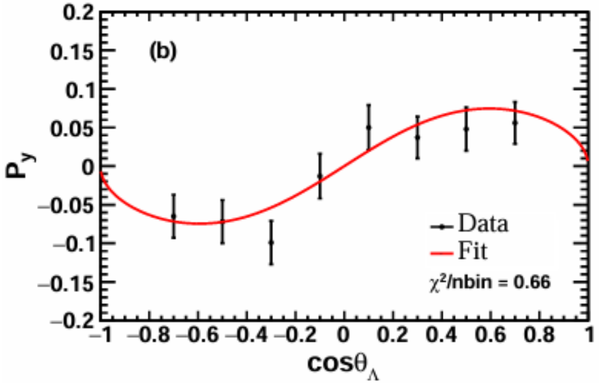
Phys. Rev. D 108, L031106 (2023)



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

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

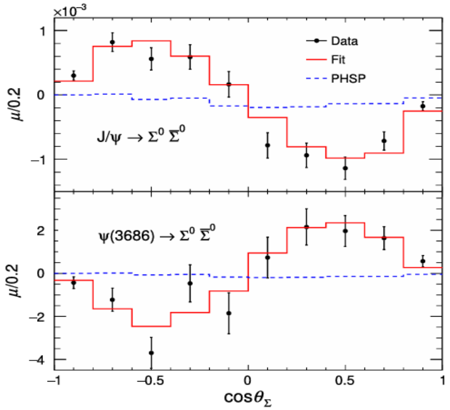
arXiv:2509.15276



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

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

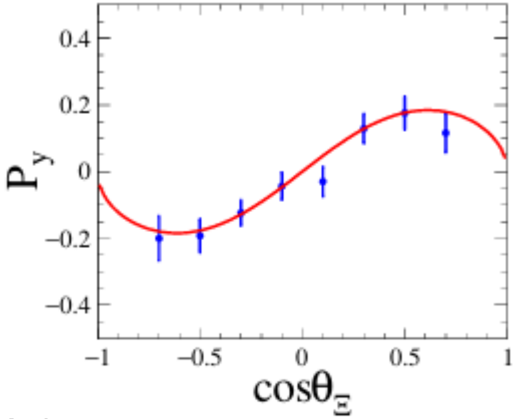
Phys. Rev. Lett. 133 (2024) 10, 101902



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

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

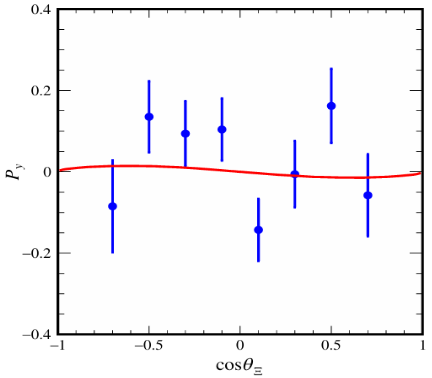
Phys. Rev. D 106, L091101 (2022)



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

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

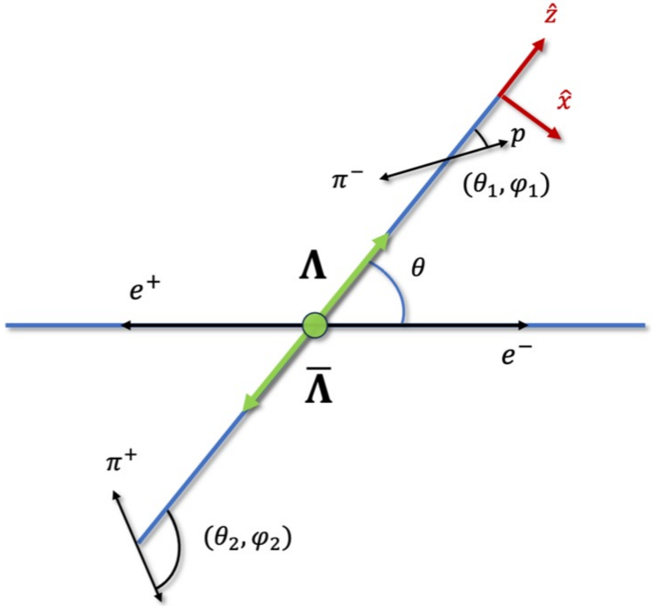
Phys. Rev. D 108, L011101 (2023)

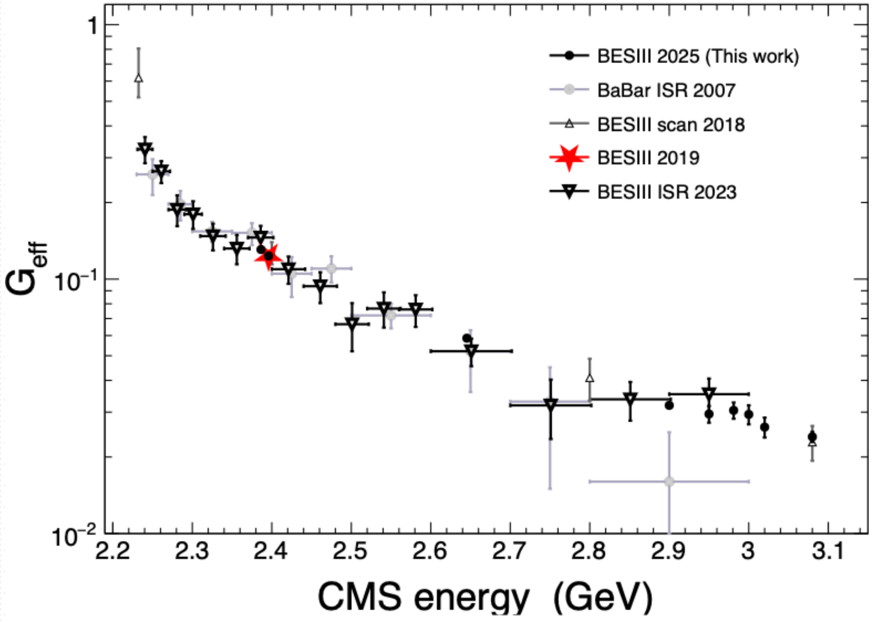


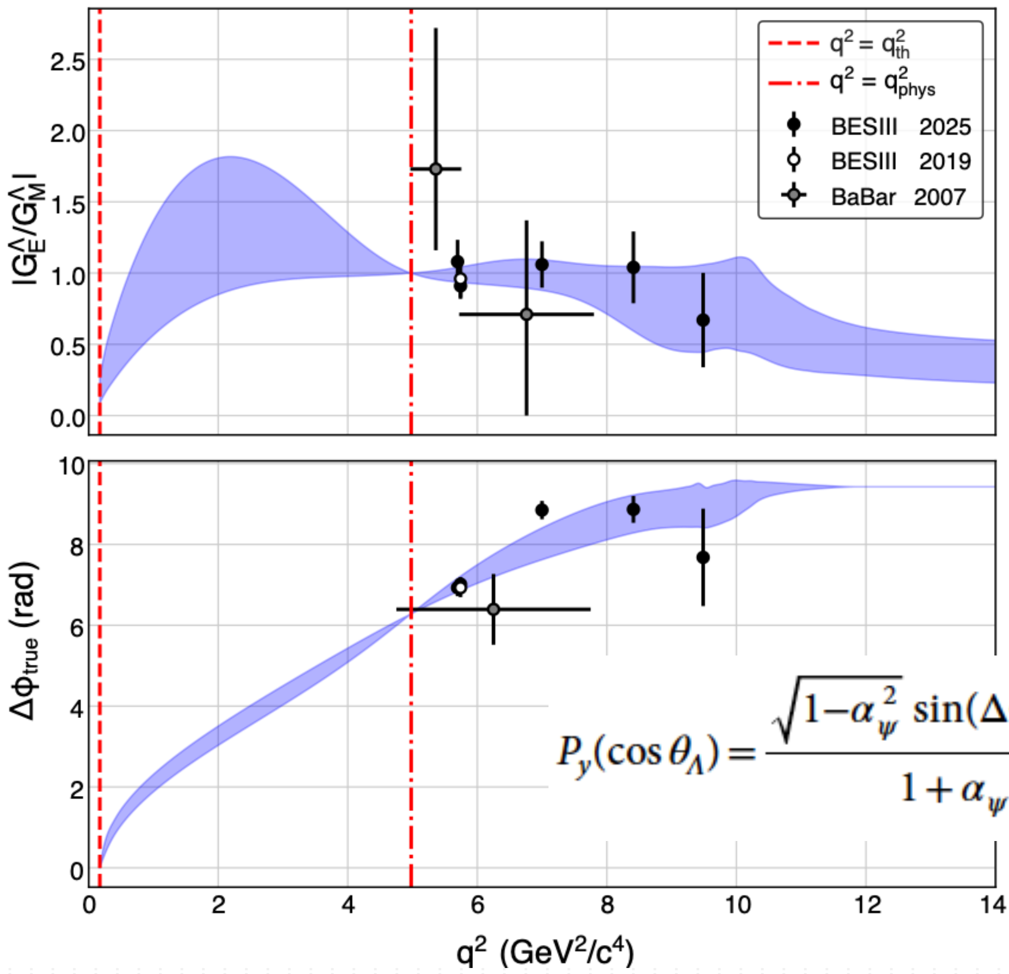
$\Delta\Phi = (-0.050 \pm 0.150 \pm 0.020)$ rad

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

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





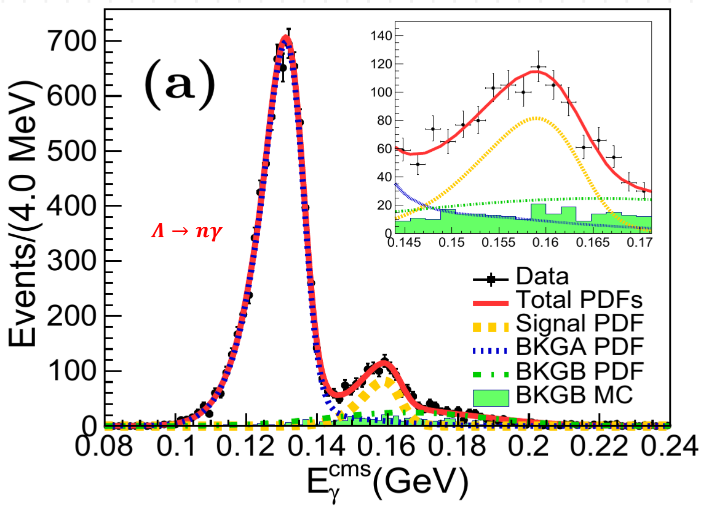


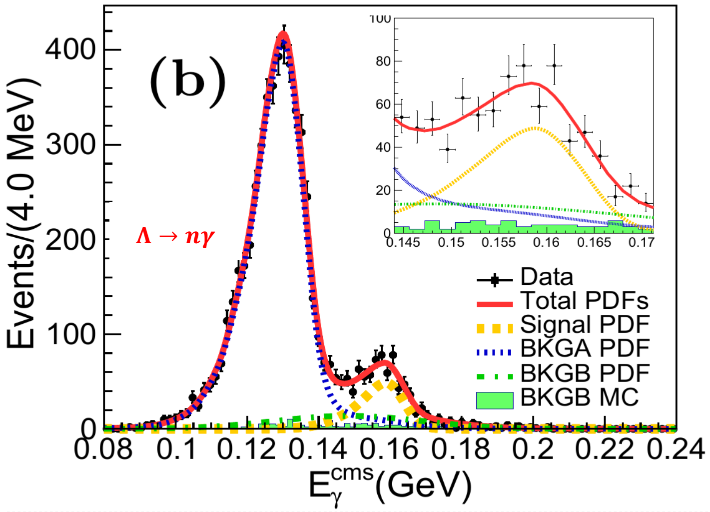
$$P_y(\cos\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda \sin\theta_\Lambda}{1+\alpha_\psi \cos^2\theta_\Lambda}$$

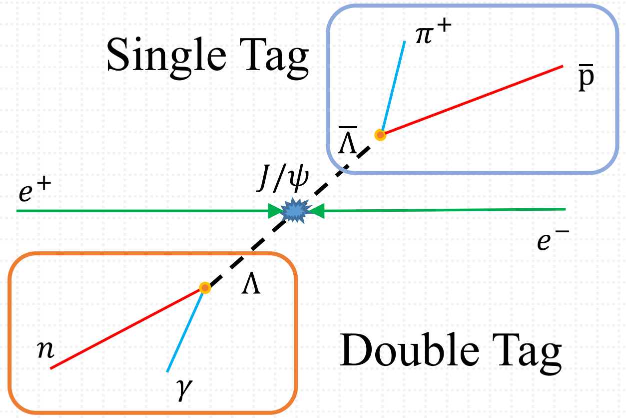
The modulus of the ratio between the electric and magnetic form factor, remains fairly constant across the considered energy range, the relative phase changes by more than 90^o between 2.40 and 2.65 GeV.

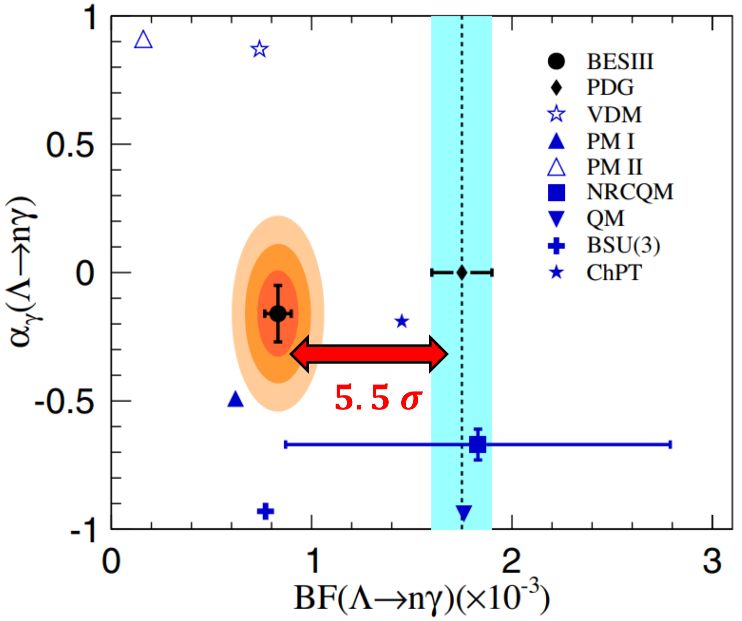
Radiative decay: $\Lambda \to n\gamma$ in $J/\psi \to \Lambda\bar{\Lambda}$

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









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

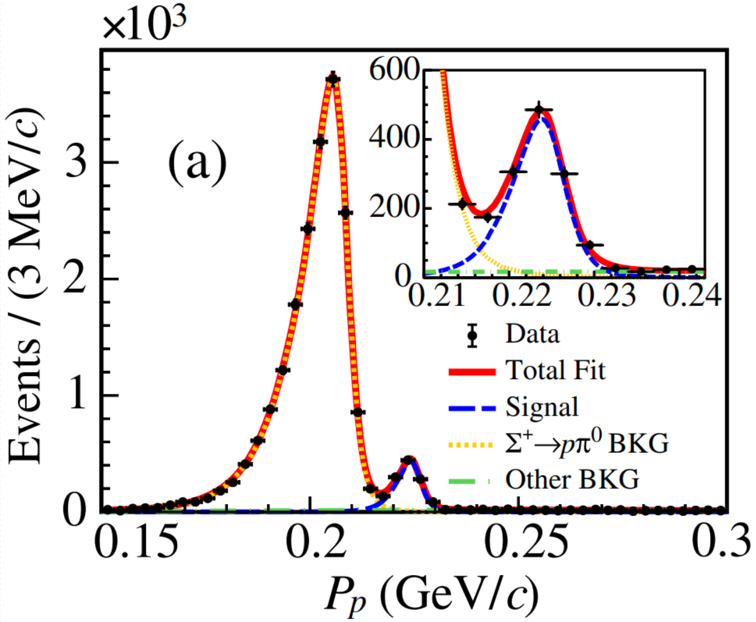
$$\mathcal{B}(\boldsymbol{\Lambda} \to \gamma n) = (0.832 \pm 0.038 \pm 0.054)\times 10^{-3}$$

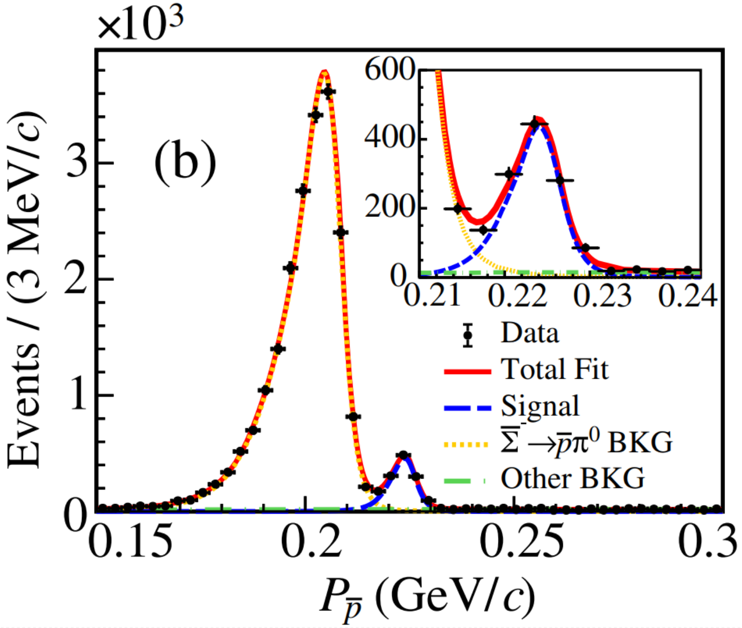
$$\alpha_\gamma = -0.16 \pm 0.10 \pm 0.05$$

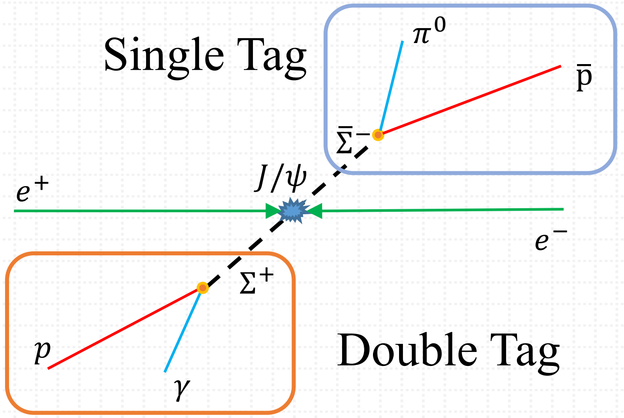
BF of $\Lambda \to n\gamma$, with improved precision, is smaller than PDG value by 5.5σ

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

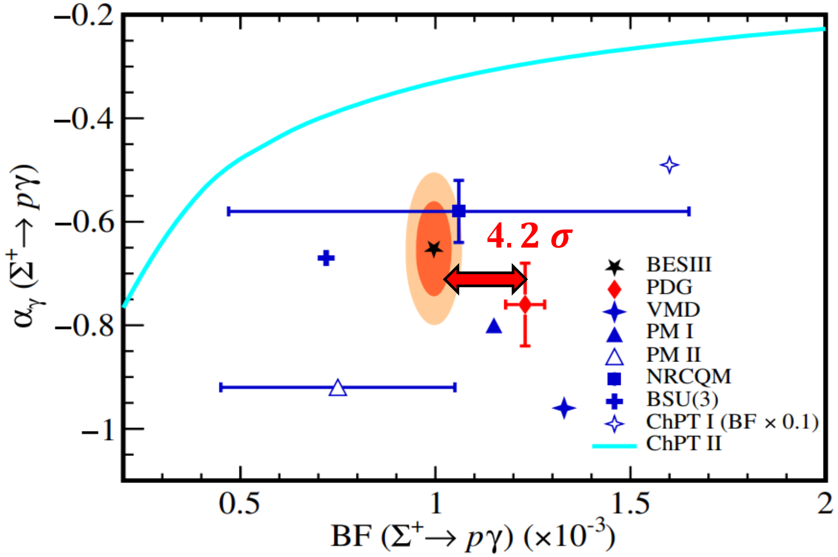
Phys. Rev. Lett. 130, 211901(2023)







The decay rate deviates from previous value by 4.2σ



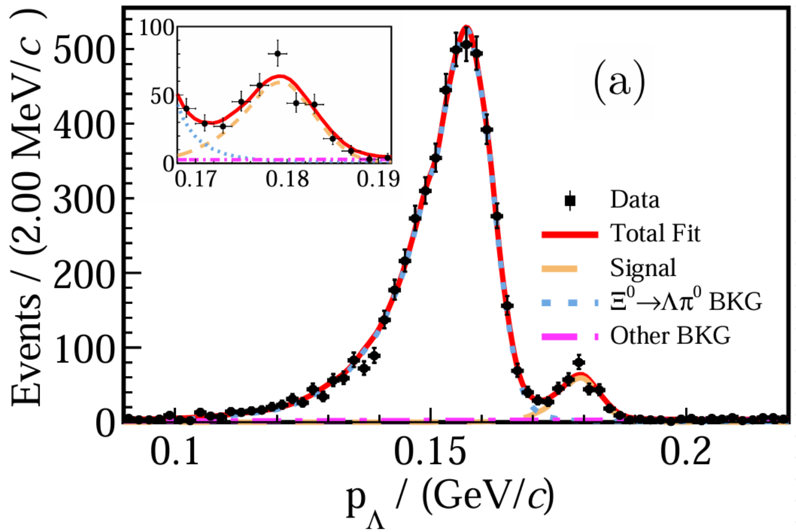
The most precise branching fraction and decay parameter of $\Sigma^+ \to p\gamma$:

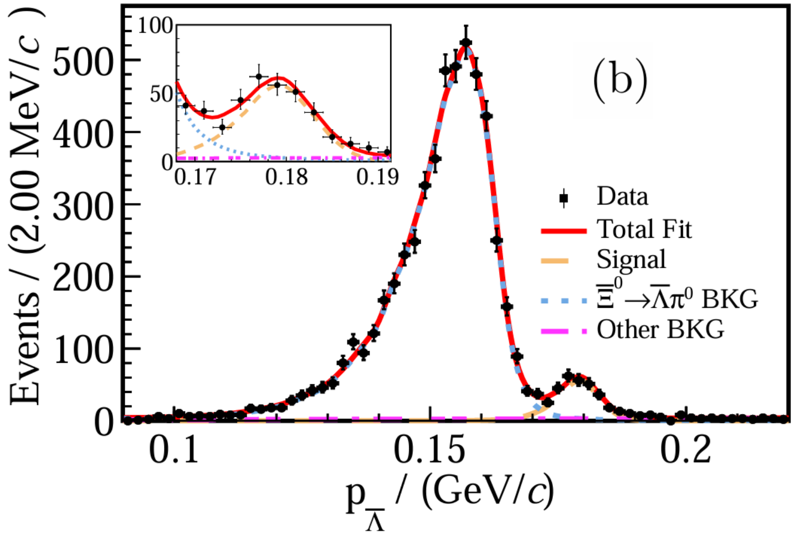
- $\mathcal{B}(\Sigma^+ \to p\gamma) = (0.996 \pm 0.021 \pm 0.018) \times 10^{-3}$
- $\alpha_\gamma = -0.652 \pm 0.056 \pm 0.020$

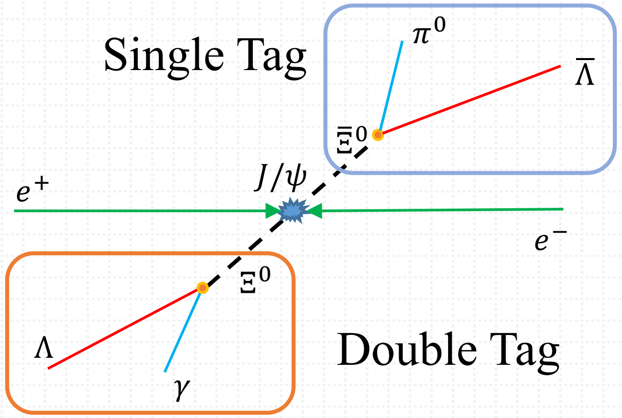
The CP asymmetry is calculated to be:

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

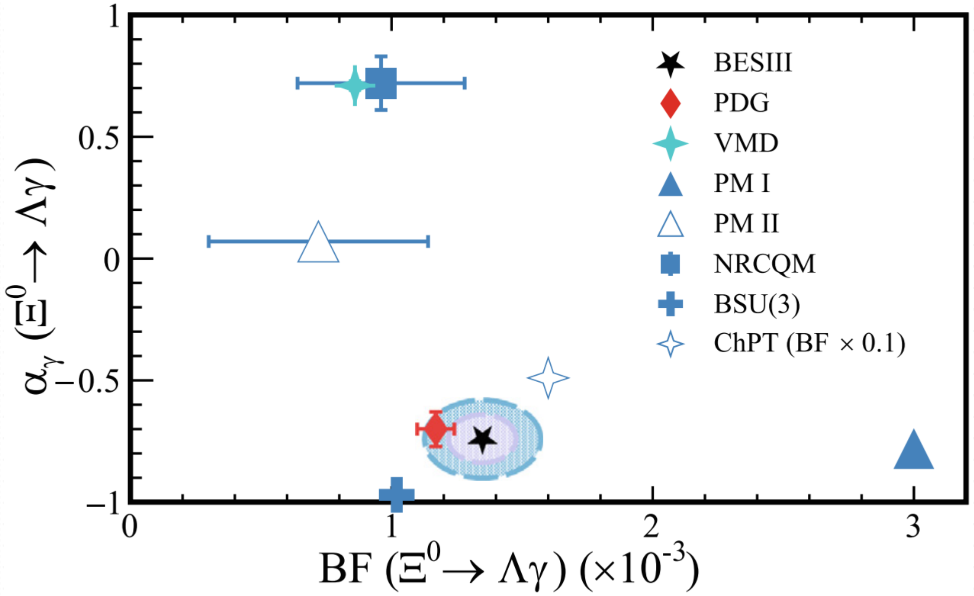
Radiative decay: $\Xi^0 \to \Lambda\gamma$ in $J/\psi \to \Xi^0\bar{\Xi}^0$







Sci. Bull. 70 (2025) 454-459

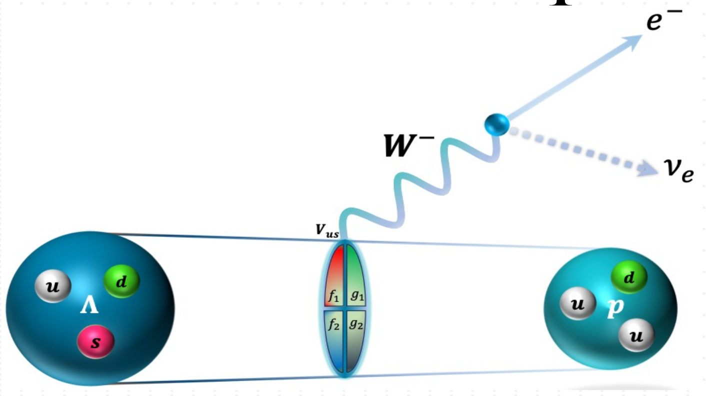


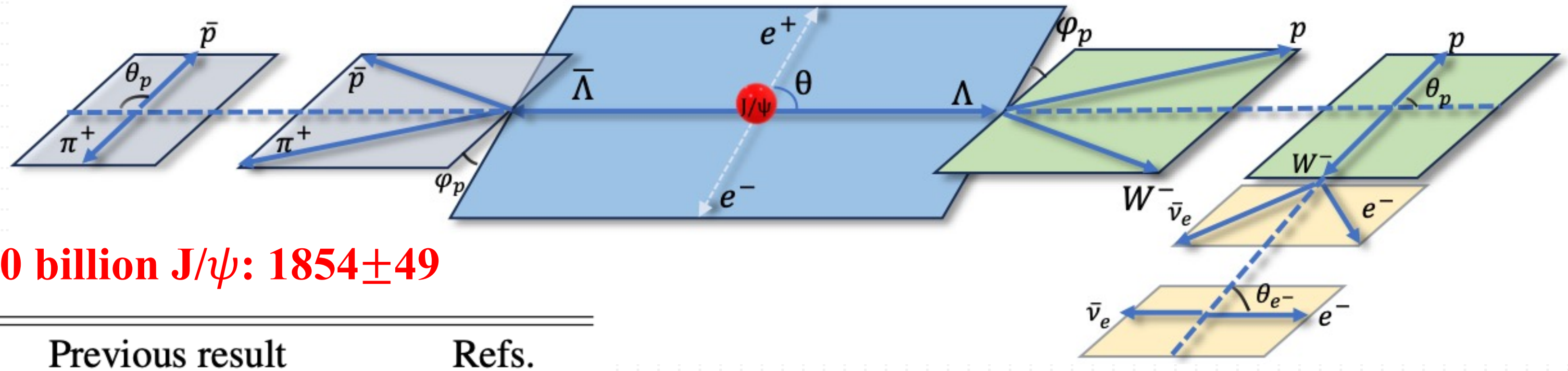
Channels	$\Xi^0 \to \Lambda\gamma$	$\bar{\Xi}^0 \to \bar{\Lambda}\gamma$
BF(10^{-3})	$1.348 \pm 0.090 \pm 0.054$	$1.326 \pm 0.098 \pm 0.066$
Combined BF(10^{-3})	$1.347 \pm 0.066 \pm 0.054$	
$\alpha_\gamma(\bar{\alpha}_\gamma)$	$-0.652 \pm 0.092 \pm 0.016$	$0.830 \pm 0.080 \pm 0.044$
Combined α_γ	$-0.741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

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

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

BESIII: arXiv:2509.09266





10 billion J/ψ: 1854±49

Observable	This work	Previous result	Refs.
$\mathcal{B}(\Lambda \to p e^- \bar{\nu}_e)$	$(8.16 \pm 0.22 \pm 0.15) \times 10^{-4}$	$(8.34 \pm 0.14) \times 10^{-4}$	[PDG2024]
g_{av}^-	$0.742^{+0.075}_{-0.057} \pm 0.009$	0.718 ± 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 ± 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 ± 0.0094	0.2224 ± 0.0034	[9, 34]
$\lvert V_{us} \rvert_{\mathrm{LQCD}}$	0.2332 ± 0.0042		
$\lvert V_{us} \rvert \cdot \sqrt{f_1^2 + 3g_1^2}$	0.4543 ± 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: $g_w \equiv \frac{f_2}{f_1}$;

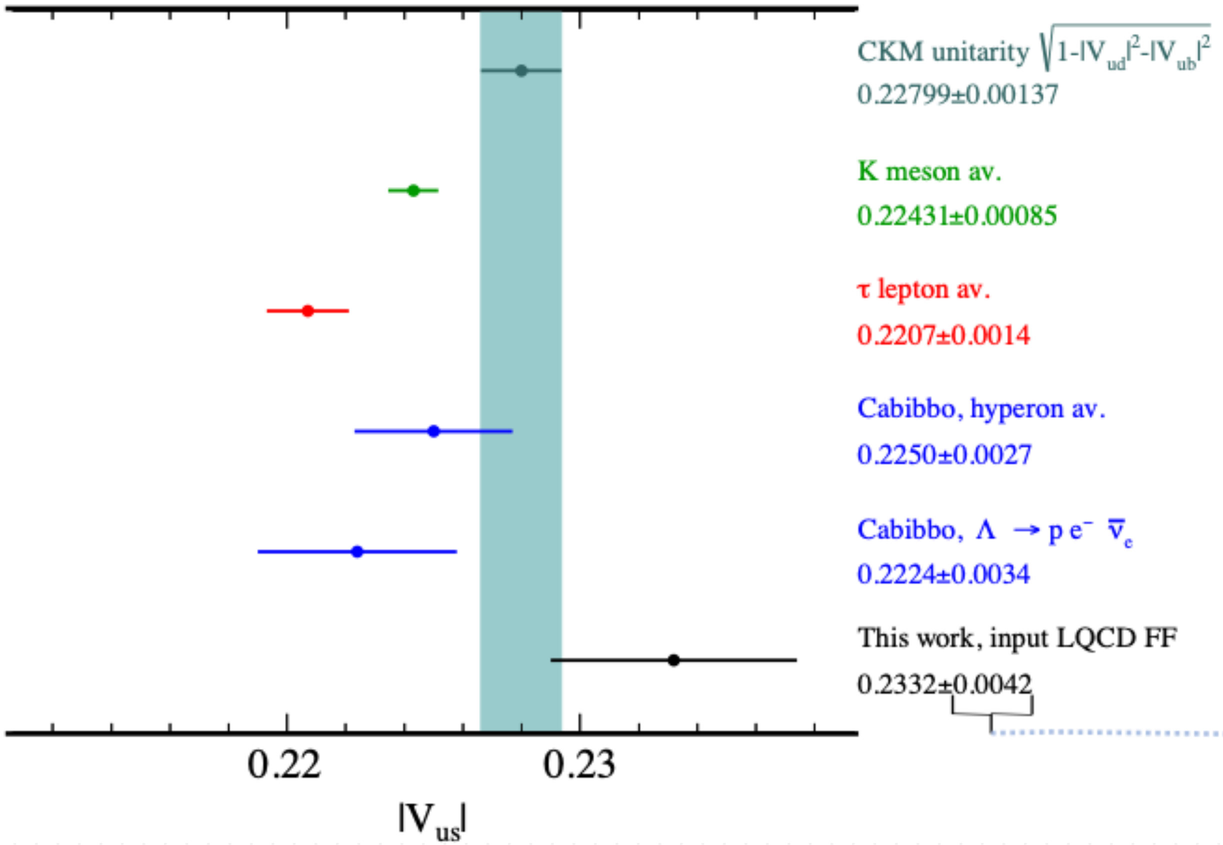
weak electricity: $g_{av2} \equiv \frac{g_2}{f_1}$

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

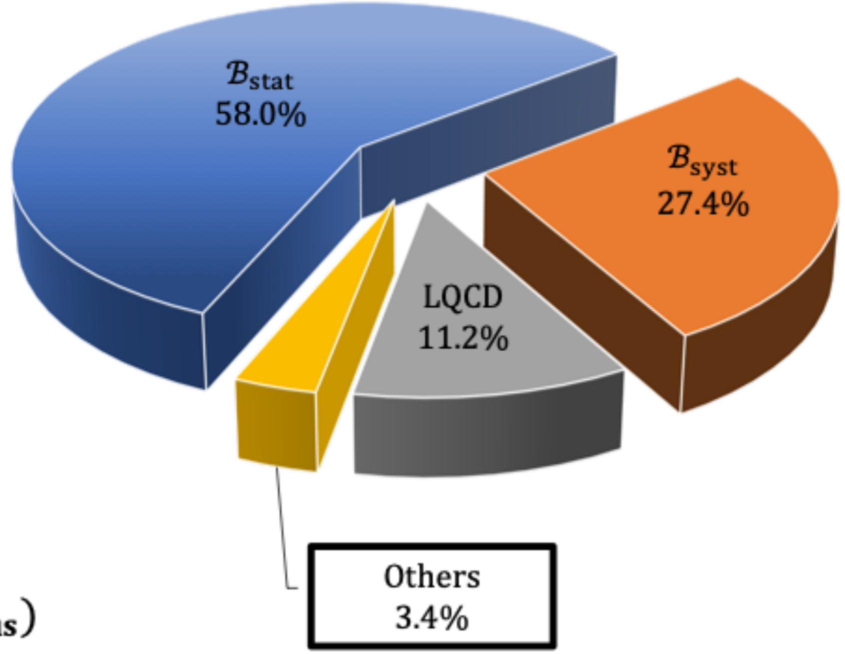
BESIII: arXiv:2509.09266

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

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

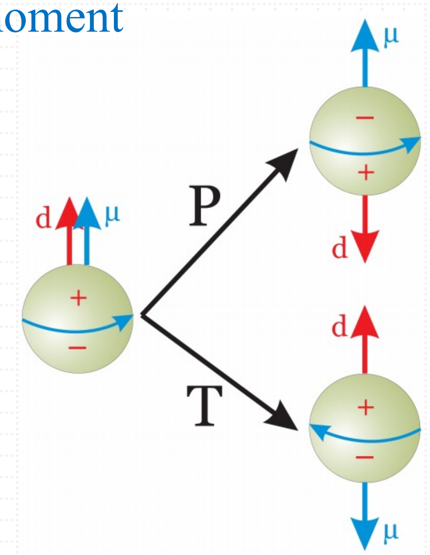


$\sigma^2(V_{us})$



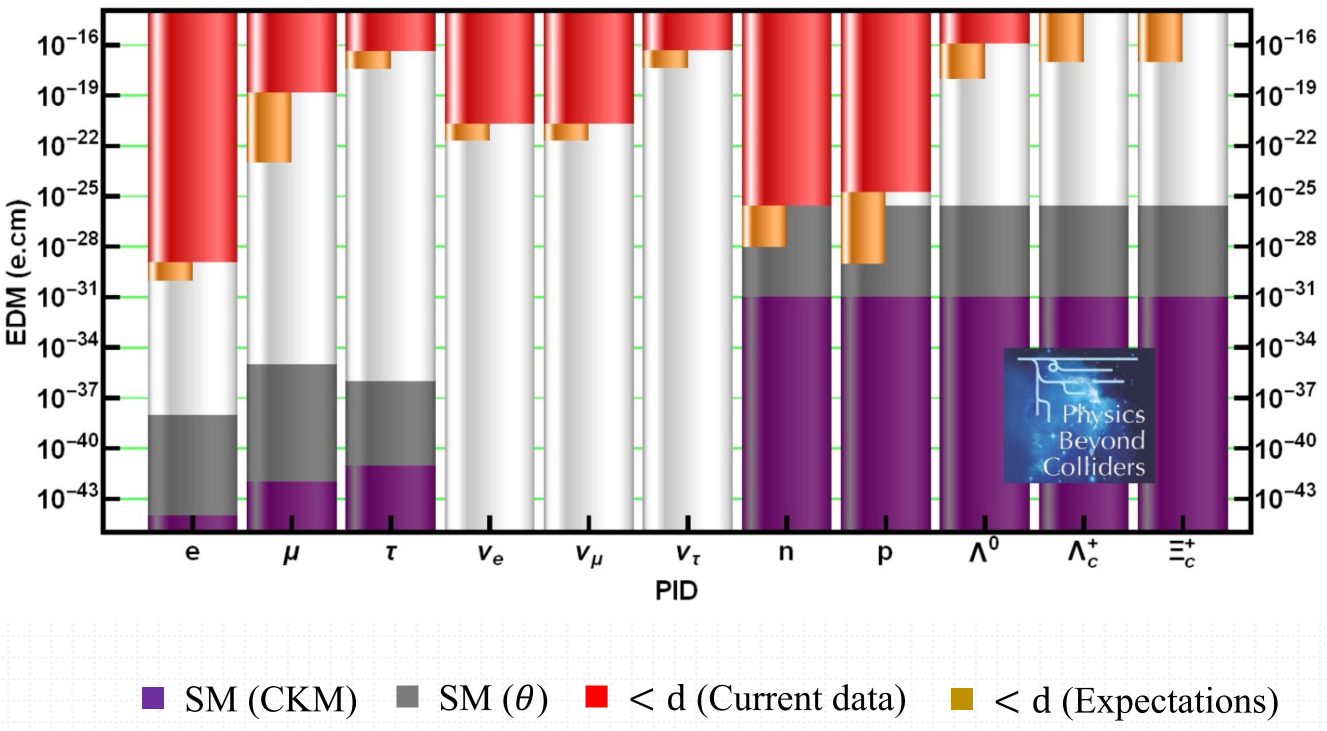
Search for hyperon EDM at BESIII

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.



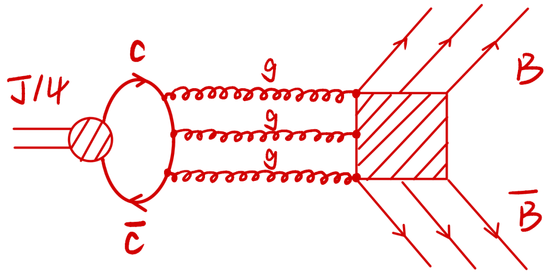
J. Phys. G 47 (2020) 1, 010501

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

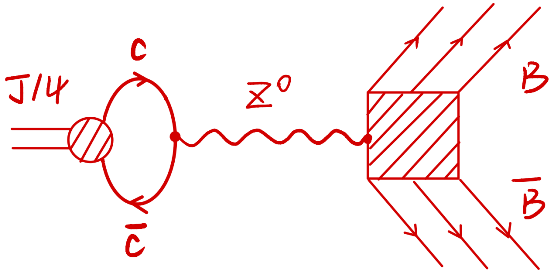
Detailed dynamics in J/ψ decay to hyperon pair, have been studied:

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



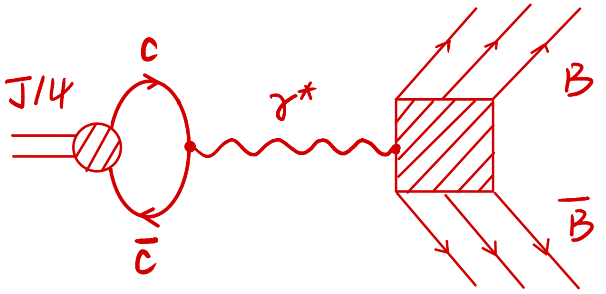
Dominant contribution
arXiv:hep-ph/0412158

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



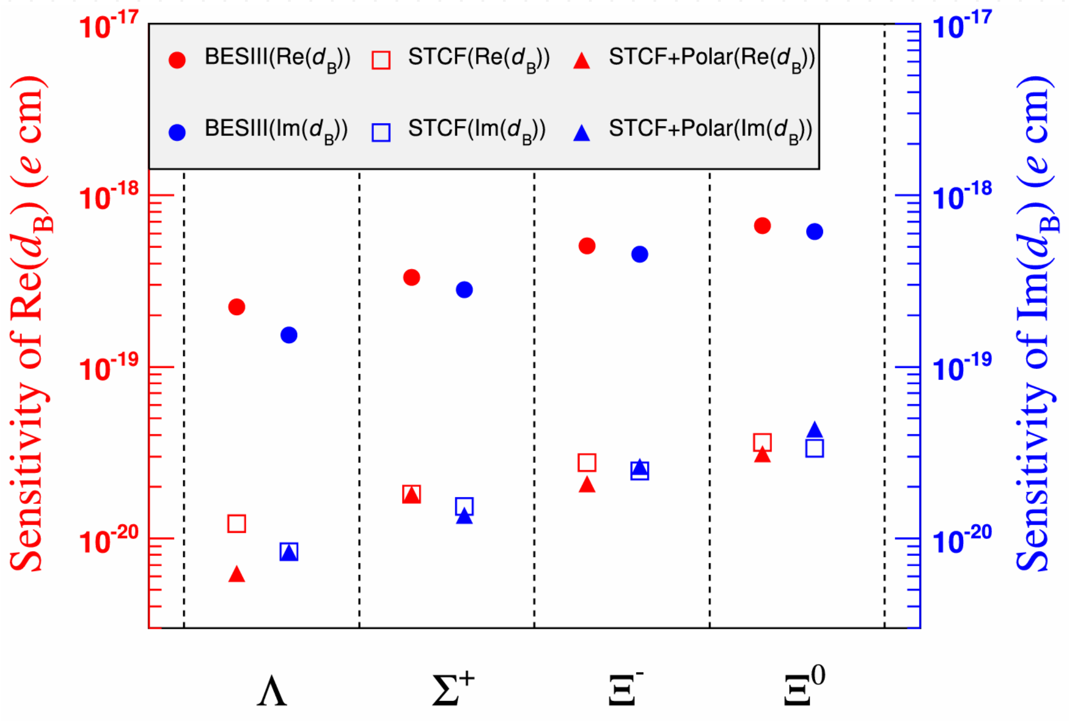
$\boldsymbol{H_T}$ is included in this term

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

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, PhysRevD.108.L091301

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

BESIII: milestone for hyperon EDM measurement

Λ 10^{-19}e cm (FermiLab 10^{-16} e cm)

first achievement for Σ^+,Ξ^- and Ξ^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

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

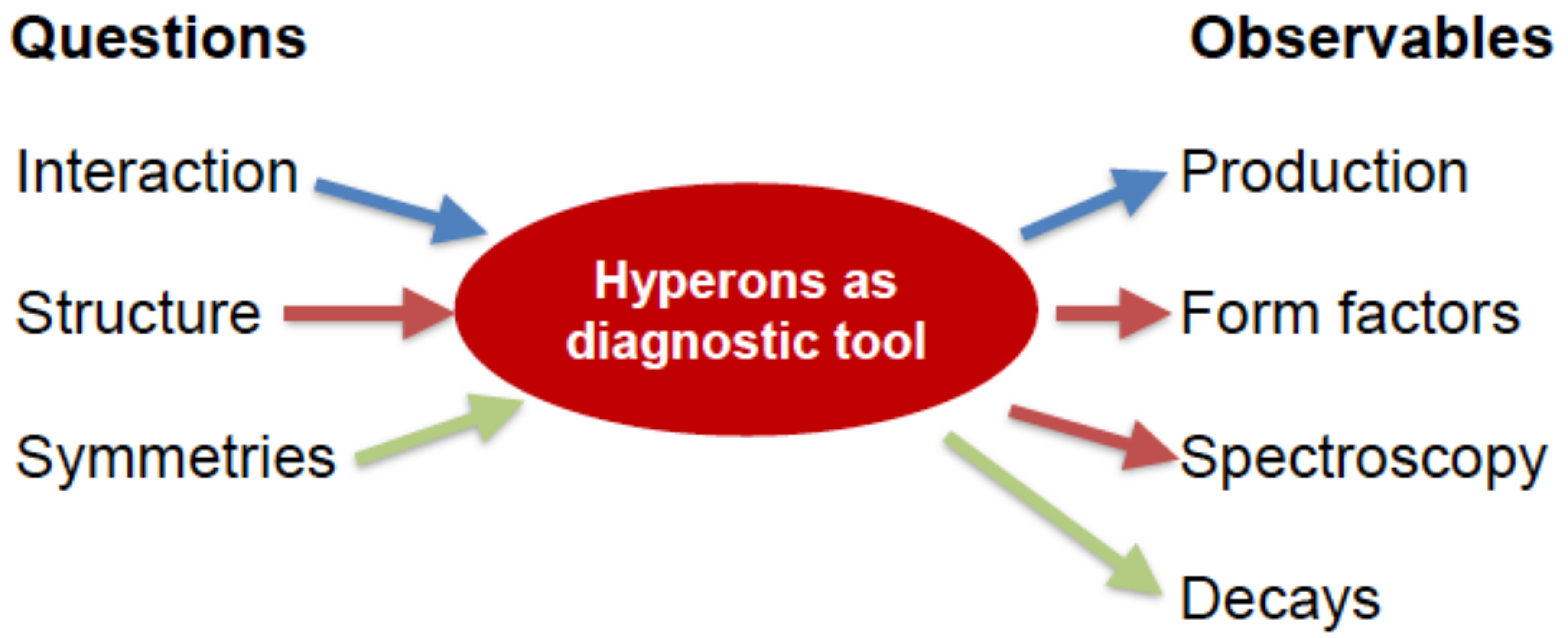
$$Re(d_\Lambda) = (-3.1 \pm 3.2 \pm 0.5) \times 10^{-19}\ e\ \text{cm},$$
$$Im(d_\Lambda) = (2.9 \pm 2.6 \pm 0.6) \times 10^{-19}\ e\ \text{cm}.$$

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

Parameter	**This measurement**
α_Λ	$0.7524 \pm 0.0036 \pm 0.0008$
$\alpha_{\bar{\Lambda}}$	$-0.7571 \pm 0.0036 \pm 0.0008$
$Re(G_2)$	$(9.71 \pm 0.06 \pm 0.24) \times 10^{-4}$
$Im(G_2)$	$(9.14 \pm 0.04 \pm 0.23) \times 10^{-4}$
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！

谢谢！

Backup

Prospects at STCF

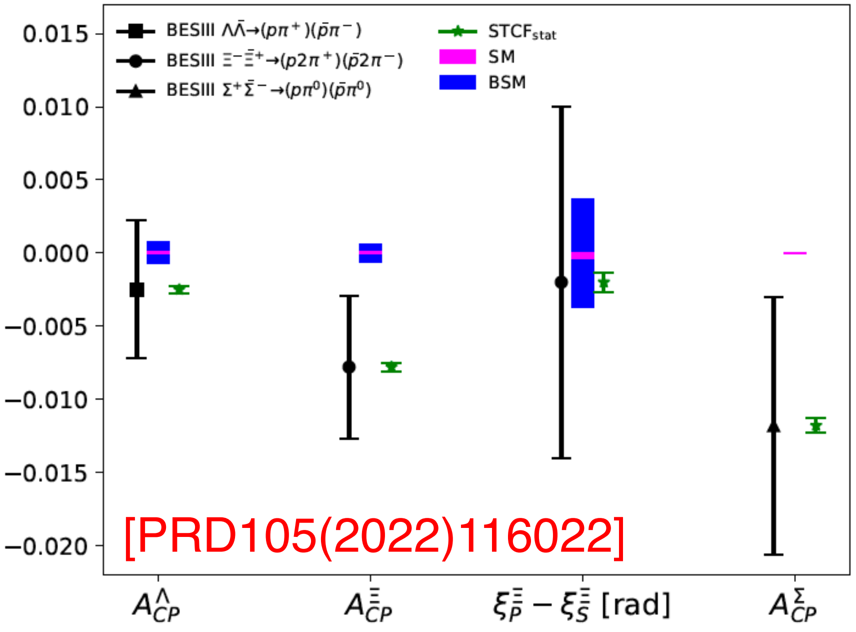
BESIII	STCF
e^+e^- collider	e^+e^- collider
$E_{\text{cms}} \in (2.0, 4.95)$ GeV	$E_{\text{cms}} \in (2.0, 7.0)$ GeV
$\mathcal{L}_{\text{peak}} = 10^{33}$ cm^{-2}s^{-1}	$\mathcal{L}_{\text{peak}} = 0.5 \cdot 10^{35}$ cm^{-2}s^{-1} @ 4 GeV
$N_{J/\psi} = 10^{10}$	$N_{J/\psi} \sim 3.4 \cdot 10^{12}$
Data collection from 2009	Data collection after 2030+

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

	$\sigma(A^{\Lambda}_{CP})$	$\sigma(A^{\Xi}_{CP})$	$\sigma(\Delta\phi^{\Xi}_{CP})$	
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%)

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

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

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

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

Exp. avg PDG

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

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

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

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

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]:

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

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

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

- 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 **antimatter**

δ δ

same sign

CP violating phases

matter **antimatter**

ξ $-\xi$

opposite sign

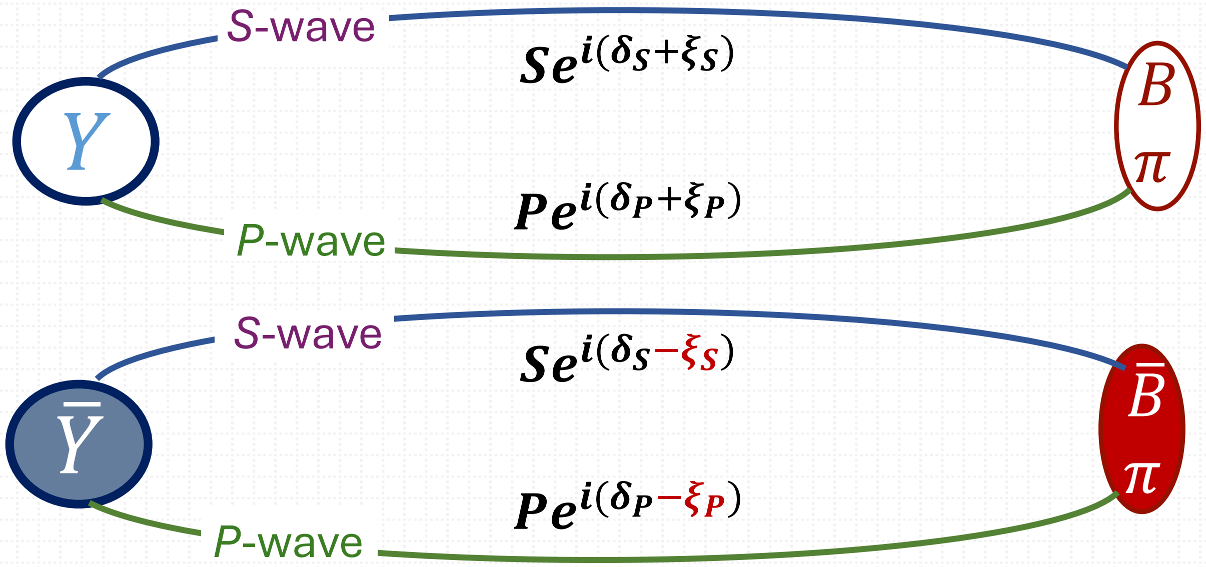
If only have one path:

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

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

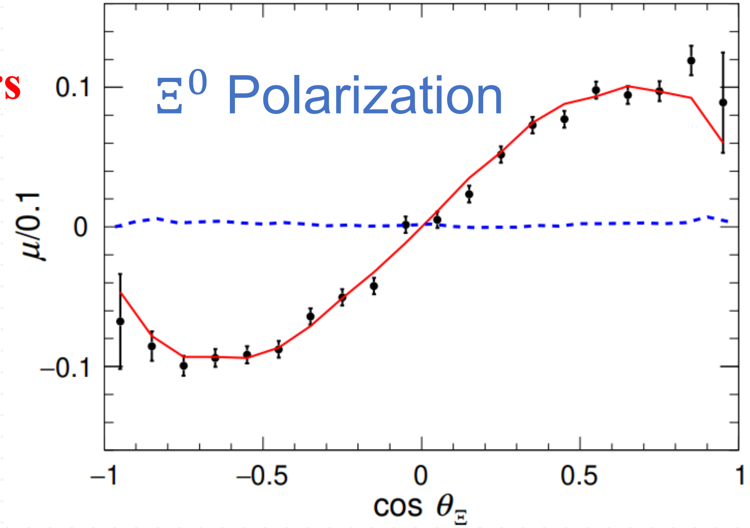
10 billion J/ψ

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

Parameter	This work	Previous result
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$	0.66 ± 0.06 [34]
$\Delta\Phi$(rad)	$1.168 \pm 0.019 \pm 0.018$	-
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$	-0.358 ± 0.044 [18]
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$	0.363 ± 0.043 [18]
ϕ_Ξ(rad)	$0.0051 \pm 0.0096 \pm 0.0018$	0.03 ± 0.12 [18]
$\bar{\phi}_\Xi$(rad)	$-0.0053 \pm 0.0097 \pm 0.0019$	-0.19 ± 0.13 [18]
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$	0.7519 ± 0.0043 [13]
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$	-0.7559 ± 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}^{Ξ}	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$	$(-0.7 \pm 8.5) \times 10^{-2}$ [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}^{Λ}	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$	$(-2.5 \pm 4.8) \times 10^{-3}$ [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 ± 0.0026 [13]

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

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



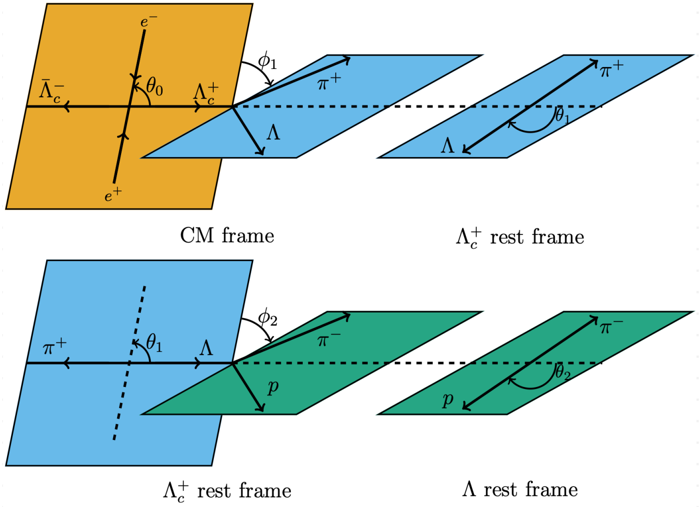
The precision of the asymmetry parameter: 10^{-3}

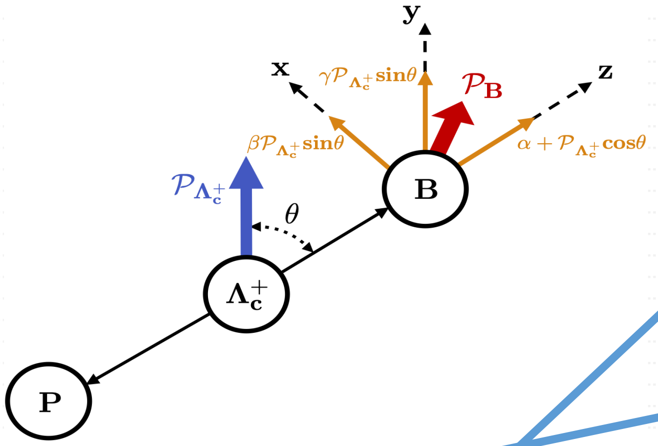
Measurement of the weak (CPV) phase difference in Ξ^0 decays, most precise results in weakly baryon decays: **$|\xi_P\text{-}\xi_S|<1.4^\circ$ (@ 90% C.L.)**

Three CP tests

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

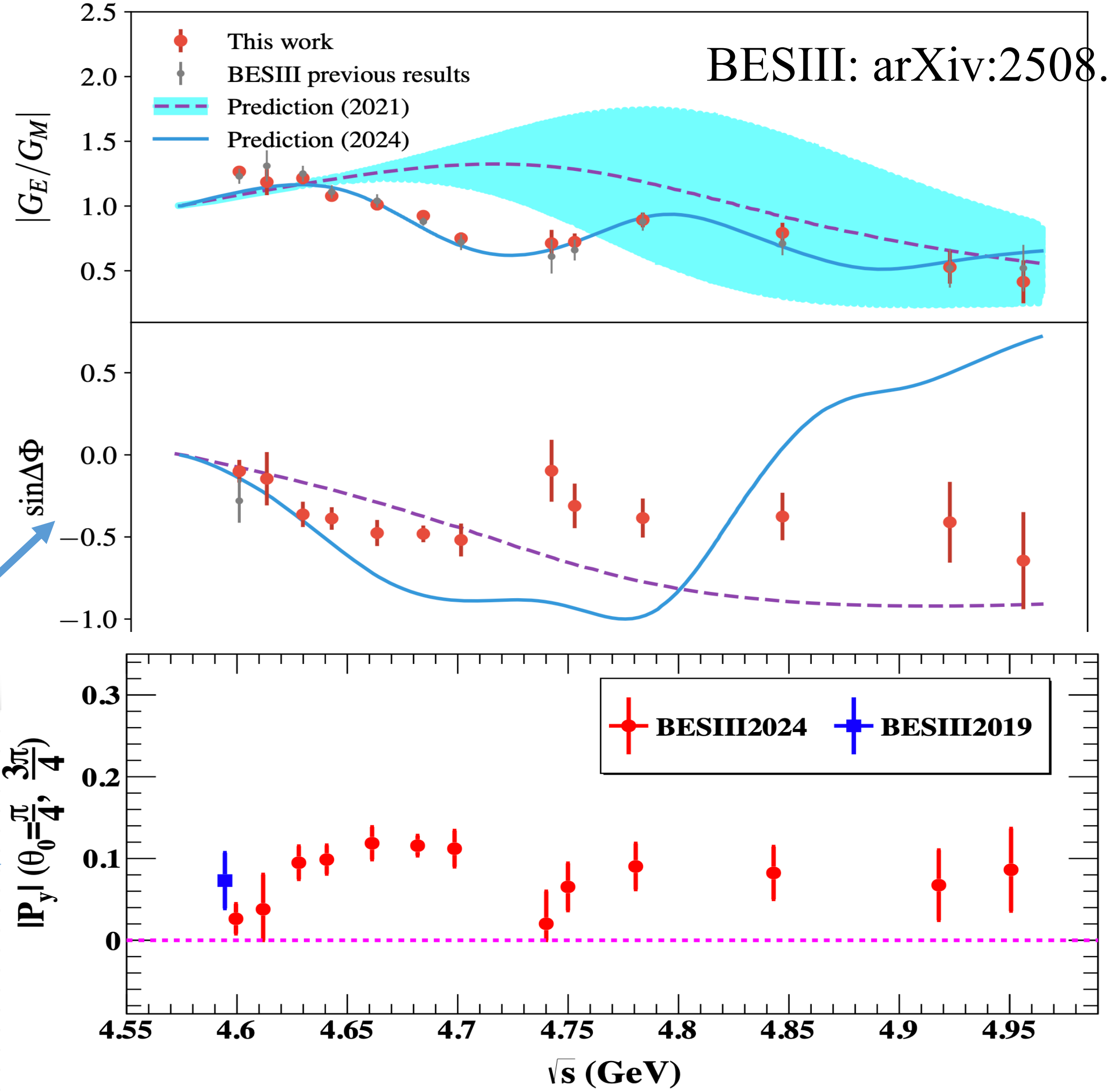
Energy-dependent polarization in $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$





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

BESIII: arXiv:2508.11400



What's the production dynamics of charmed baryon?

Most precise Λ hyperon EDM measurement

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

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

which corresponds to an upper bound of:

$$|d_\Lambda| < 6.5\times 10^{-19}\ e\cdot cm \quad (95\%\ CL)$$

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

BESIII: arXiv:2506.19180

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

Prior direct Λ EDM limit (Fermilab, 1981): $|\boldsymbol{d_\Lambda}| < \mathbf{1.5 \times 10^{-16}} \boldsymbol{e\cdot cm}$.

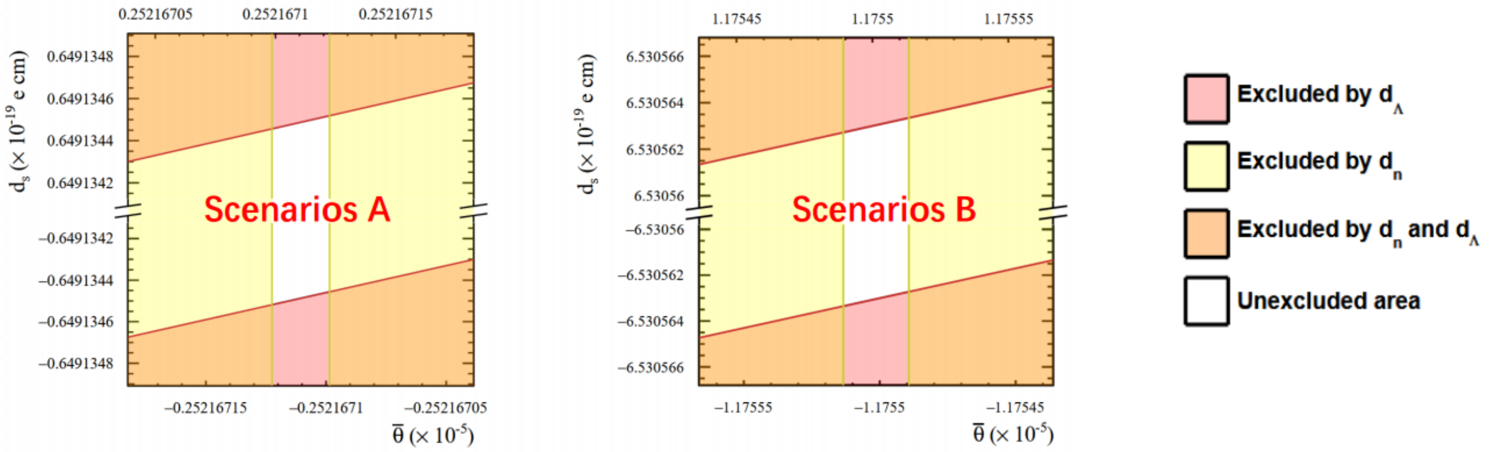
- The Λ EDM is sensitive to the **QCD vacuum angle ($\bar{\theta}$)** and the **strange quark EDM (d_s).**
- **Effective EDM relation** from theory**:**

$$d_\Lambda = (-2.6 \pm 0.4)\times 10^{-16}\bar{\theta}\ e\ \mathrm{cm} + d_s$$
$$d_n = -(1.5 \pm 0.7)\times 10^{-16}\bar{\theta}\ e\ \mathrm{cm} - (0.20 \pm 0.01)d_u + (0.78 \pm 0.03)d_d + (0.0027 \pm 0.0016)d_s$$

- 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

$$d_\Lambda = \boxed{5.29\times10^{-4} d_s} + 4.61\times10^{-5}(d_u+d_d) + \boxed{6.21\times10^{-5} e\tilde{d}_s} + 1.98\times10^{-5} e\tilde{d}_d - 2.14\times10^{-5} e\tilde{d}_u$$

$$d_n = -(0.20\pm0.01)d_u + (0.78\pm0.03)d_d + \boxed{(0.0027\pm0.0016)d_s} - (0.55\pm0.28)e\tilde{d}_u - (1.1\pm0.55)e\tilde{d}_d$$

The QCD theta-term is neglected

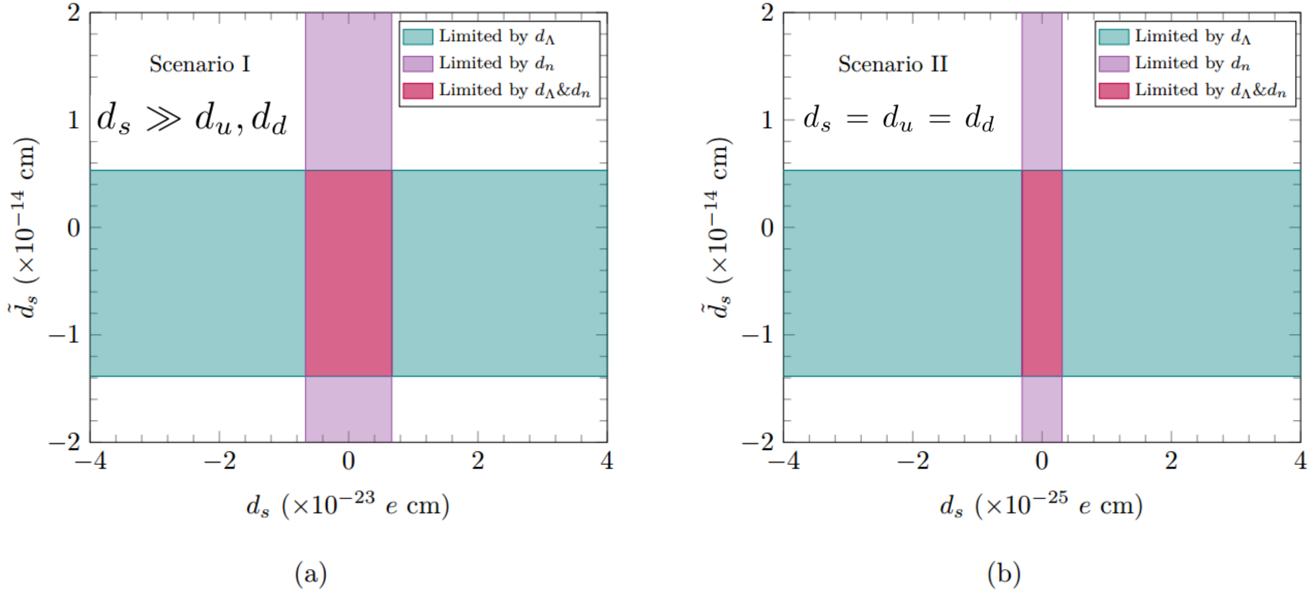


Figure 2: Constraints on the s-quark EDM d_s and CEDM $\tilde{d}_s$ from the measurements on the Λ and n EDMs.

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 $K \rightarrow \pi\pi$, 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 $\Delta I = 1/2,\ 3/2$,

$$\boxed{\begin{aligned} A_{\Lambda\to p\pi^-} &= \sqrt{2}\,A_\Lambda^{(1)} - A_\Lambda^{(3)}, \\ A_{\Lambda\to n\pi^0} &= -A_\Lambda^{(1)} - \sqrt{2}\,A_\Lambda^{(3)}\end{aligned}}$$

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

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