Highlights of light hadron decays at BESIII

Zhipeng Xie
(on behalf of BESIII collaboration)

University of Science and Technology of China

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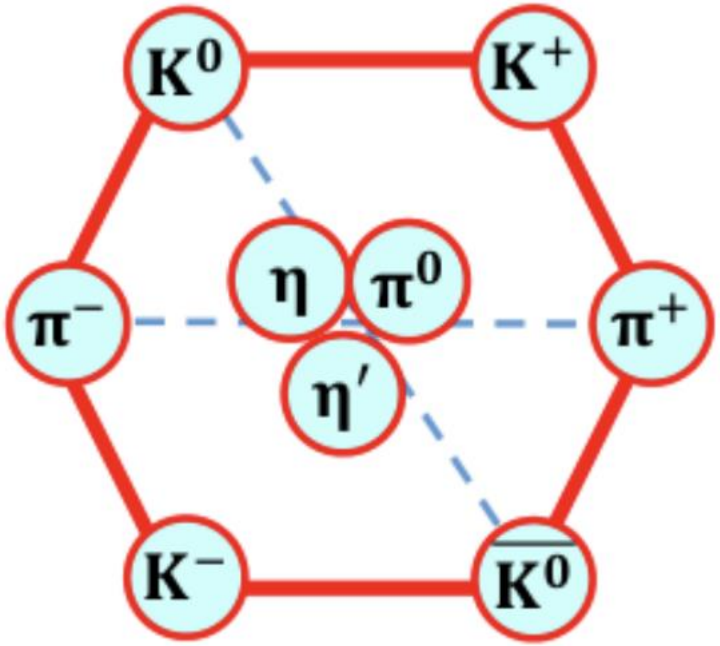
Outline

- Light meson decay
  - ✓ Decay mechanisms
  - ✓ Transition form factor
- Hyperon decay
  - ✓ CP test
  - ✓ Hyperon weak radiative decay
- Summary

Light Meson Physics

- **Light mesons**
  - ✓ it plays a central role in our understanding of quantum chromodynamics (QCD) at low energies.

- η/η' physics
  - ✓ η—η' mixing
  - ✓ The light quark masses
  - ✓ The fundamental discrete symmetries
  - ✓ Tests of effective field theories: ChPT and VMD
  - ✓ rare or forbidden η/η' decays

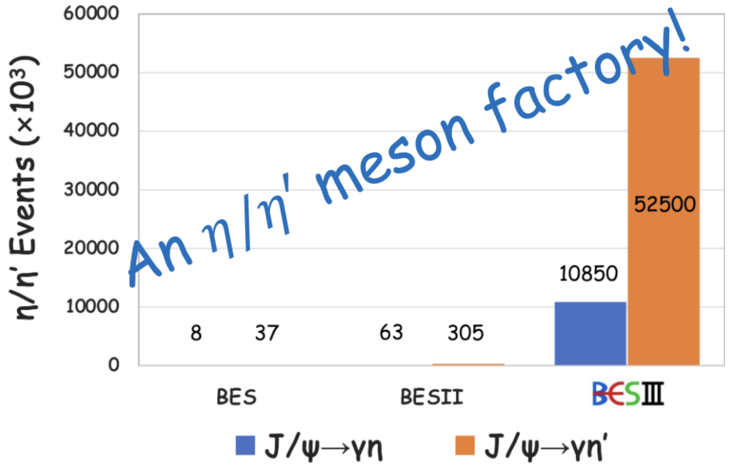


η/η' at BESIII

◆ BESIII is an η/η' factory

✓ The world's largest sample of J/ψ events(10^{10}) collected at BESIII detector offers a unique opportunity to investigate η and η' physics via the J/ψ radiative decays with unprecedented precision.

✓ An important role in η/η′ decays



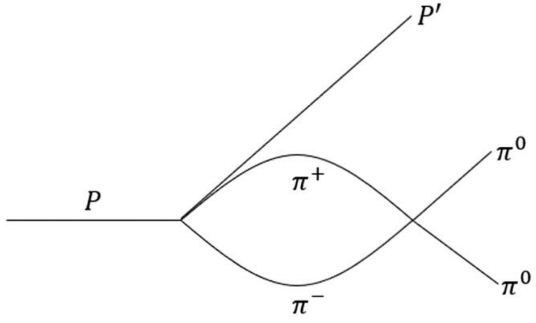
η REFERENCES

ABLIKIM	23AN	PR D107 092007	M. Ablikim *et al.*	(BESIII Collab.)
HAYRAPETY...	23A	PRL 131 091903	A. Hayrapetyan *et al.*	(CMS Collab.)
ABLIKIM	21AM	PR D104 092004	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	20A	JHEP 2010 047	D. Babusci *et al.*	(KLOE-2 Collab.)
ZHEVLAKOV	19	PR D99 031703	A.S. Zhevlakov *et al.*	(TMSK, MAINZ, TUBIN+)
ACHASOV	18B	PR D98 052007	M.N. Achasov *et al.*	(SND Collab.)
ADLARSON	18C	PL B784 378	P. Adlarson *et al.*	(WASA-at-COSY Collab.)
PRAKHOV	18	PR C97 065203	S. Prakhov *et al.*	(A2 Collab. at MAMI)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
ADLARSON	17B	PR C95 035208	P. Adlarson *et al.*	(A2 Collab. at MAMI)
ANASTASI	16A	JHEP 1605 019	A. Anastasi *et al.*	(KLOE-2 Collab.)
ARNALDI	16	PL B757 437	R. Arnaldi *et al.*	(NA60 Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ADLARSON	14A	PR C90 045207	P. Adlarson *et al.*	(WASA-at-COSY Collab.)
AGAKISHIEV	14	PL B731 265	G. Agakishiev *et al.*	(HADES Collab.)
NEFKENS	14	PR C90 025206	B.M.K. Nefkens *et al.*	(A2 Collab. at MAMI)
NIKOLAEV	14	EPJ A50 58	A. Nikolaev *et al.*	(MAMI-B, MAINZ, BONN)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
BABUSCI	13	PL B718 910	D. Babusci *et al.*	(KLOE/KLOE-2 Collab.)
BABUSCI	13A	JHEP 1301 119	D. Babusci *et al.*	(KLOE-2 Collab.)
AGAKISHIEV	12A	EPJ A48 64	G. Agakishiev *et al.*	(HADES Collab.)
GOSLAWSKI	12	PR D85 112011	P. Goslawski *et al.*	(COSY-ANKE Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

η′(958) REFERENCES

ABLIKIM	23AH	PRL 130 081901	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	22E	PR D105 112010	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	21I	PR D103 072006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	21J	PR D103 092005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	20E	PR D101 032001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19AW	PR D100 052015	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	19T	PRL 122 142002	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18	PR D97 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	18C	PRL 120 242003	M. Ablikim *et al.*	(BESIII Collab.)
ADLARSON	18A	PR D98 012001	P. Adlarson *et al.*	(A2 Collab. at MAMI)
GONZALEZ-S...	18A	EPJ C78 758	S. Gonzalez-Solis, E. Passemar	(BEIJ, IND+)
AAIJ	17D	PL B764 233	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	17	PRL 118 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	17T	PR D96 012005	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	16M	PR D93 072008	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15AD	PR D92 051101	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15G	PR D92 012014	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15O	PR D92 012001	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	15P	PR D92 012007	M. Ablikim *et al.*	(BESIII Collab.)
ACHASOV	15	PR D91 092010	M.N. Achasov *et al.*	(SND Collab.)
AKHMETSHIN	15	PL B740 273	R.R. Akhmetshin *et al.*	(CMD-3 Collab.)
PDG	15	RPP 2015 at pdg.lbl.gov		(PDG Collab.)
ABLIKIM	14M	PRL 112 251801	M. Ablikim *et al.*	(BESIII Collab.)
DONSKOV	14	MPL A29 1450213	S. Donskov *et al.*	(GAMS-4π Collab.)
PDG	14	CP C38 070001	K. Olive *et al.*	(PDG Collab.)
ABLIKIM	13	PR D87 012009	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13G	PR D87 032006	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13O	PR D87 092011	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	13U	PR D88 091502	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	12E	PRL 108 182001	M. Ablikim *et al.*	(BESIII Collab.)
PDG	12	PR D86 010001	J. Beringer *et al.*	(PDG Collab.)
ABLIKIM	11	PR D83 012003	M. Ablikim *et al.*	(BESIII Collab.)
ABLIKIM	11G	PR D84 032006	M. Ablikim *et al.*	(BESIII Collab.)

$\eta' \to \pi^0\pi^0\eta$

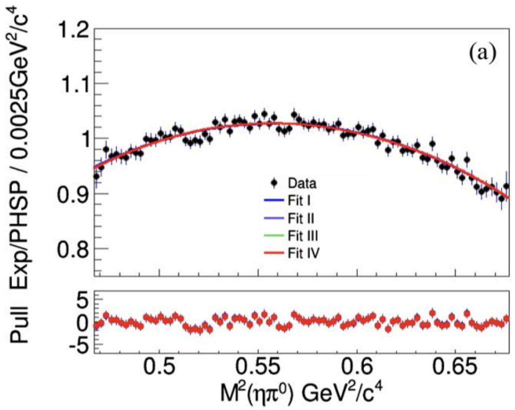


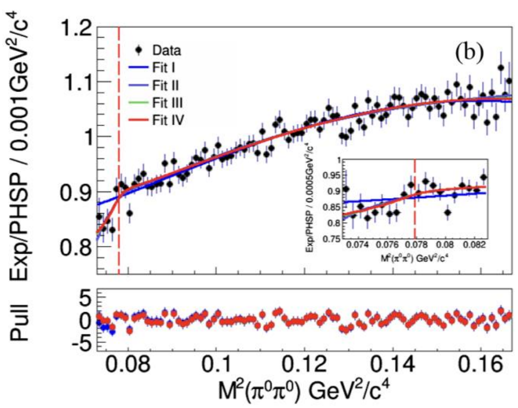
◆ Evidence of the cusp effect in $\eta' \to \pi^0\pi^0\eta$

✓ The loop contribution to the ππ scattering: the S-wave charge-exchange rescattering $\pi^+\pi^- \to \pi^0\pi^0$

✓ The cusp effect can shed light on the fundamental properties of QCD at low energies.

✓ Statistical significance of Fit with cusp effect is higher than 3σ

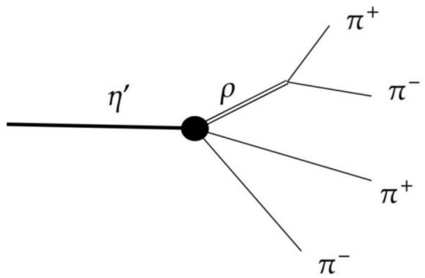


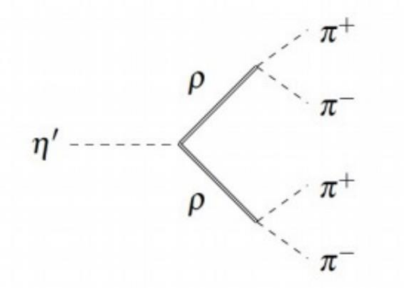


Phys. Rev. Lett. 130, 081901 With cusp effect

Parameters	Fit I	Fit II	Fit III	Fit IV
a	$-0.075 \pm 0.003 \pm 0.001$	-0.207 ± 0.013	-0.143 ± 0.010	$-0.077 \pm 0.003 \pm 0.001$
b	$-0.073 \pm 0.005 \pm 0.001$	-0.051 ± 0.014	-0.038 ± 0.006	$-0.066 \pm 0.006 \pm 0.001$
d	$-0.066 \pm 0.003 \pm 0.001$	-0.068 ± 0.004	-0.067 ± 0.003	$-0.068 \pm 0.004 \pm 0.001$
$a_0 - a_2$	-	0.174 ± 0.066	0.225 ± 0.062	$0.226 \pm 0.060 \pm 0.012$
a_0	-	0.497 ± 0.094	-	-
a_2	-	0.322 ± 0.129	-	-
Statistical Significance	-	3.4σ	3.7σ	3.6σ

$\eta' \to \pi^+\pi^-\pi^+\pi^-$





- **Amplitude analysis of $\eta' \to \pi^+\pi^-\pi^+\pi^-$**
  - ✓ Based on the ChPT and VMD model

$$A(\eta' \to \pi^+\pi^-\pi^+\pi^-) = \epsilon_{\mu\nu\alpha\beta} p_1^\mu p_2^\nu p_3^\alpha p_4^\beta$$

$$= \left(\left(\frac{s_{12}}{D_\rho(s_{12})} + \frac{s_{34}}{D_\rho(s_{34})} + \frac{s_{14}}{D_\rho(s_{14})} + \frac{s_{23}}{D_\rho(s_{23})}\right) + \alpha\left(\frac{M_\rho^2(s_{12}+s_{34})}{D_\rho(s_{12})D_\rho(s_{34})} - \frac{M_\rho^2(s_{14}+s_{23})}{D_\rho(s_{14})D_\rho(s_{23})}\right)\right)$$

  - ✓ The doubly virtual isovector form factor $\alpha = 1.22 \pm 0.33 \pm 0.04$ is extracted for the first time and in agreement with the prediction of the vector meson dominance mode.

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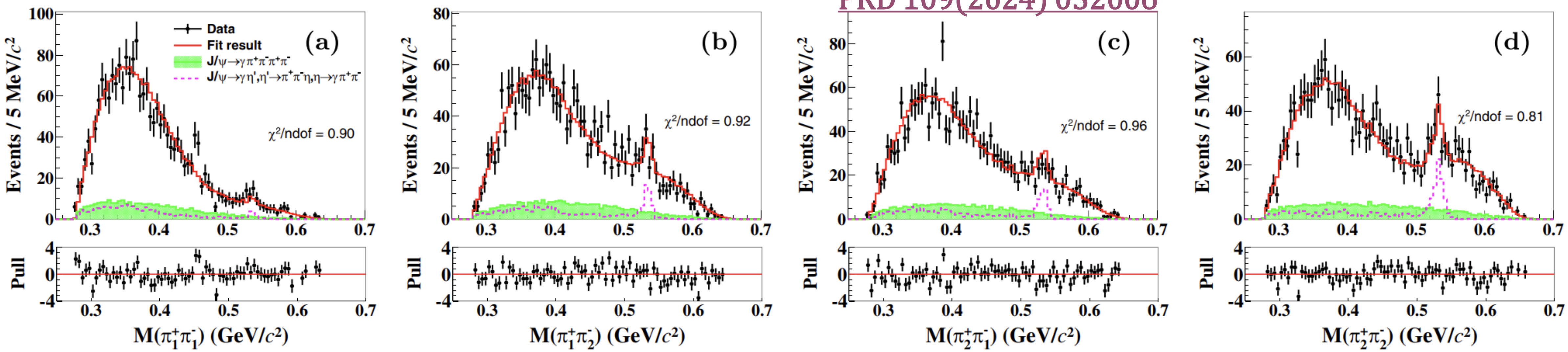
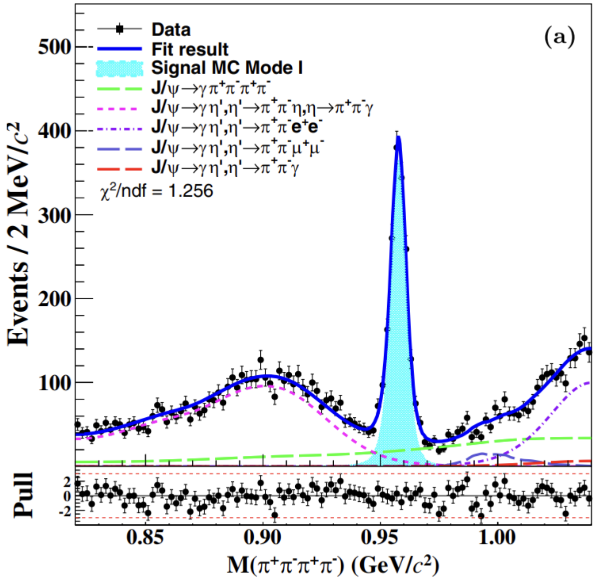
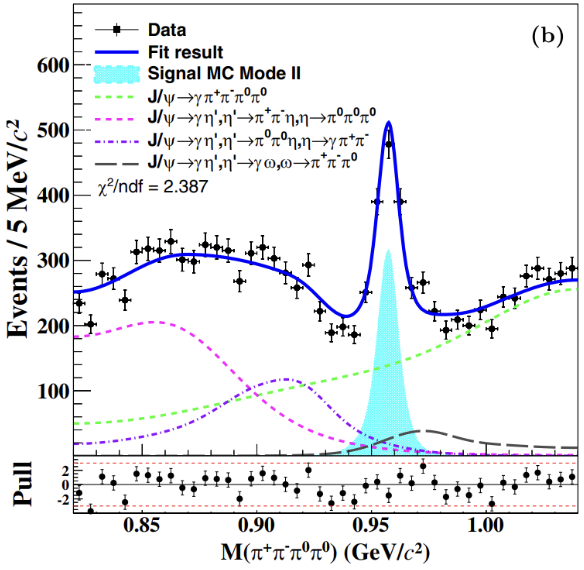


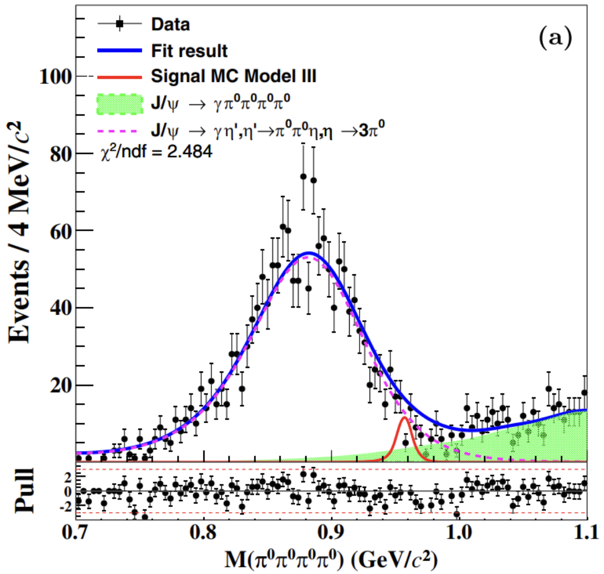
$\eta' \to \pi^+\pi^-\pi^+\pi^-$, $\eta' \to \pi^+\pi^-\pi^0\pi^0$, $\eta' \to 4\pi^0$

- **Observation of $\eta' \to \pi^+\pi^-\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\pi^0\pi^0$**
  - ✓ improved measurements of the branching fractions:
    - $B(\eta' \to \pi^+\pi^-\pi^0\pi^0) = (2.12 \pm 0.12 + 0.10) \times 10^{-4}$
    - $B(\eta' \to \pi^+\pi^-\pi^+\pi^-) = (8.56 \pm 0.25 + 0.23) \times 10^{-5}$

- **Searching for the rare decay $\eta' \to 4\pi^0$**
  - ✓ The upper limit of $B(\eta' \to 4\pi^0)$ at the 90% confidence level is determined to be 1.24×10^{-5}.







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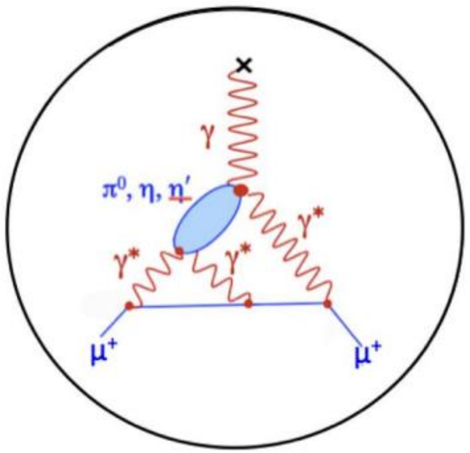
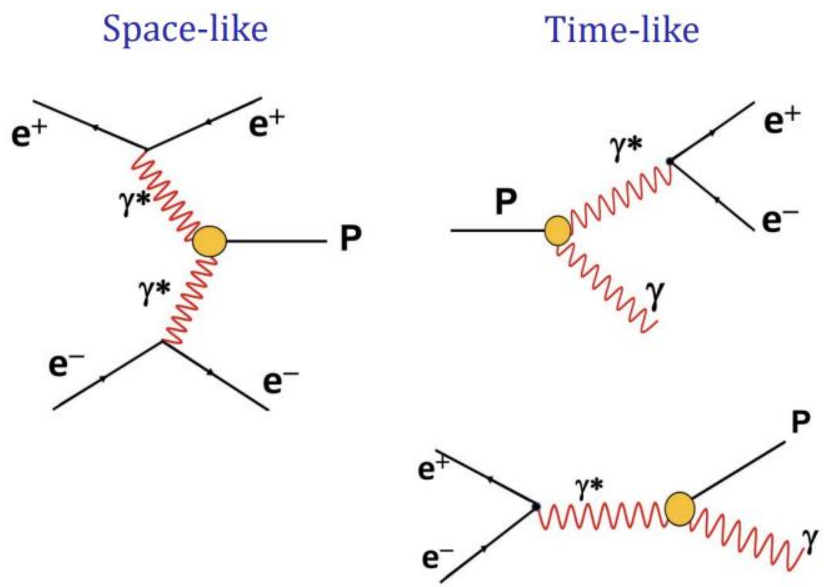
Transition form factor at BESIII

◆ Important input for HLbL contributions

- ✓ The coupling of π^0, η and η' with two photons in HLbL can be described using transition form factor (TFF).
- ✓ TFFs are experimentally accessible in three different processes
- ✓ The fusion of both photons to form a meson is described by the TFF

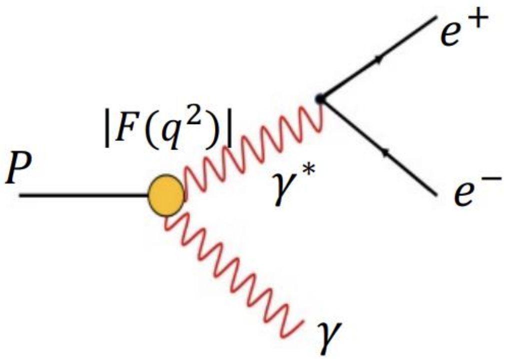
TFFs as experimental input !





$\eta/\eta' \to \gamma e^+ e^-$

- **Transition form factor of $\eta/\eta' \to \gamma e^+ e^-$**
  - The decay rate $\frac{d\Gamma(P\to\gamma l^+ l^-)}{dq^2\Gamma(P\to\gamma\gamma)} = \frac{2\alpha}{3\pi}\frac{1}{q}\sqrt{1-\frac{4m_l^2}{q^2}}\left(1+\frac{2m_l^2}{q^2}\right)\left(1-\frac{q^2}{m_P^2}\right)^3 |F(q^2)|^2$
  - Single-pole: $F(q^2) = \frac{1}{1-q^2/\Lambda^2}$ for $\eta \to \gamma e^+ e^-$
  - Multi-pole: $|F(q^2)|^2 = \frac{\Lambda^2(\Lambda^2+\gamma^2)}{(\Lambda^2-q^2)+\Lambda^2\gamma^2}$ for $\eta' \to \gamma e^+ e^-$
  - Slope parameter $b_{\eta'} = \frac{d|F(q^2)|}{dq^2}|_{q=0}$



- **Fit result**
  - $\Lambda_\eta = (0.749 \pm 0.027 \pm 0.007)\ \mathrm{GeV}/c^2$
  - $\Lambda_{\eta'} = (0.802 \pm 0.007 \pm 0.008)\ \mathrm{GeV}/c^2$
    $\gamma_{\eta'} = (0.113 \pm 0.010 \pm 0.002)\ \mathrm{GeV}/c^2$

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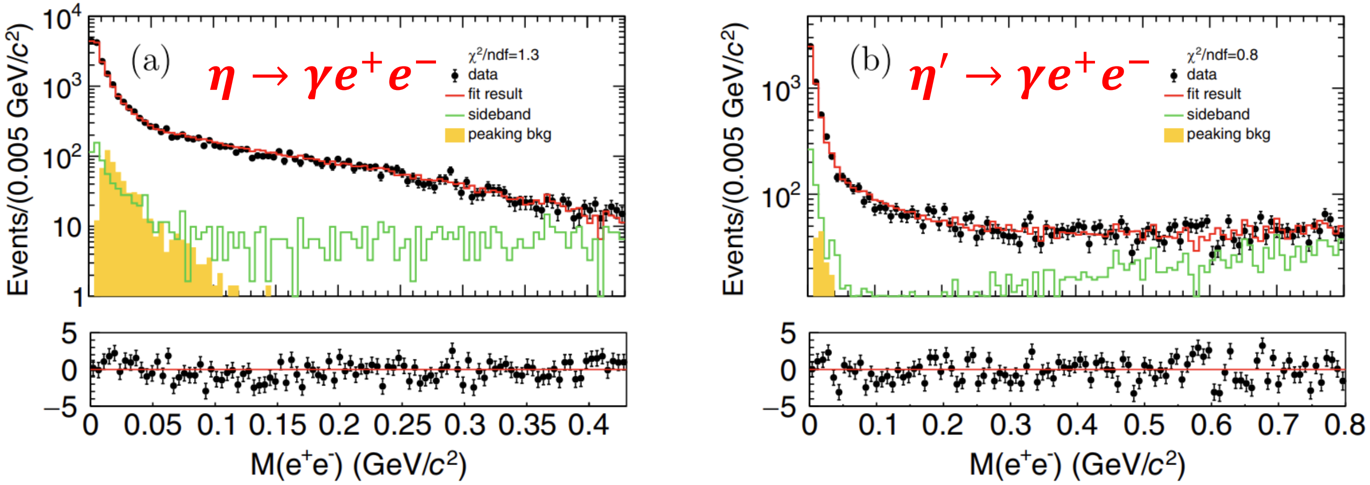


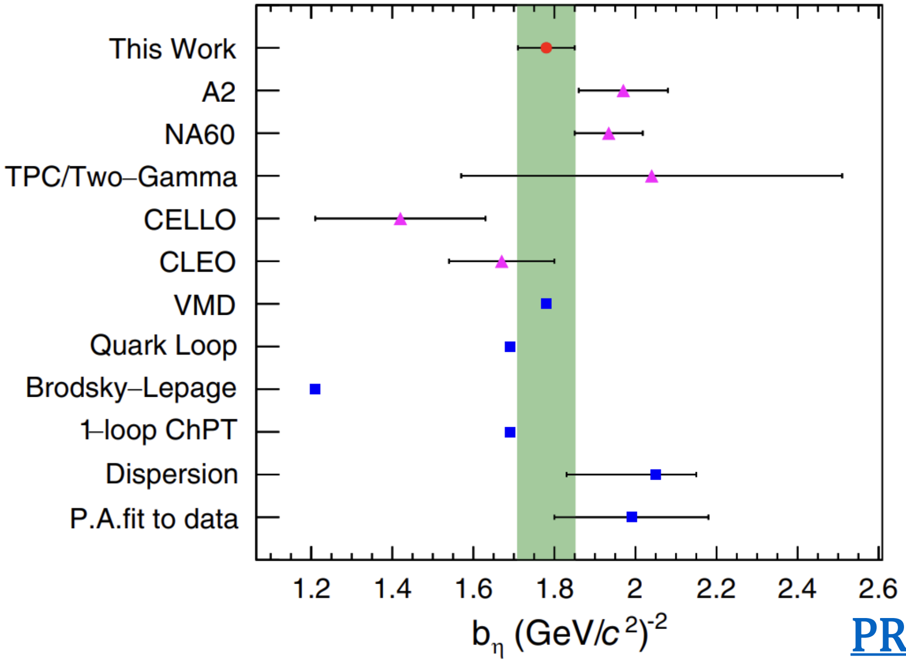
$\eta/\eta' \rightarrow \gamma e^+e^-$

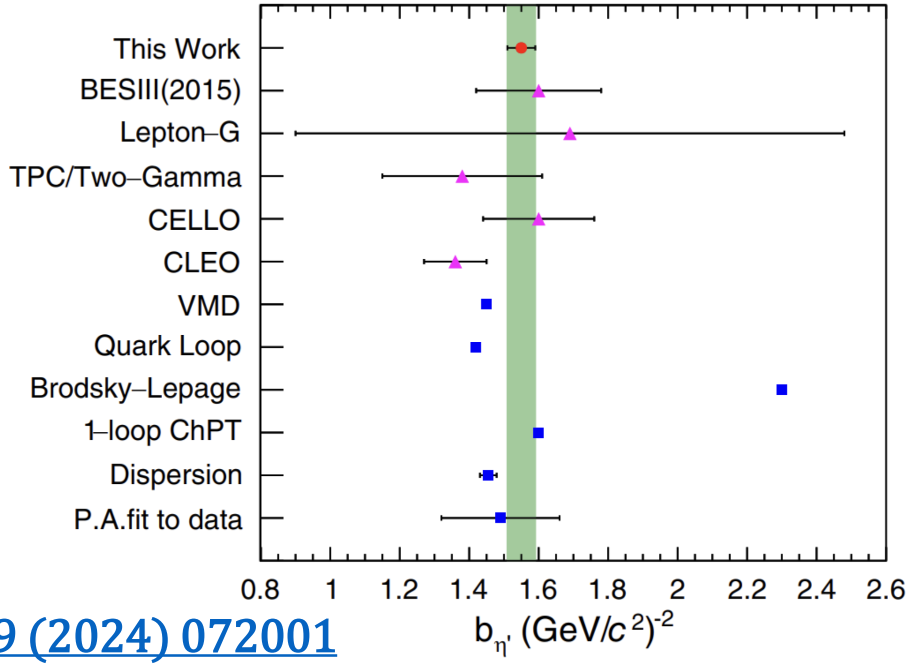
BESIII

◆ Slope parameter:

- ✓ $b_{\eta/\eta'} = \frac{d|F(q^2)|}{dq^2}|_{q^2=0}$ is in good agreement with previous work.

- ✓ The corresponding radii of interaction region of η and η' are calculated to be:
  - $R_\eta = (0.645 \pm 0.023 \pm 0.007)\text{fm}$
  - $R_{\eta'} = (0.596 \pm 0.005 \pm 0.006)\text{fm}$





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$\eta' \to \pi^+\pi^- l^+ l^-$

- Precision study of $\eta' \to \pi^+\pi^- l^+ l^-$
  - ✓ **Decay amplitude**

$$\overline{\left|A_{\eta'\to\pi^+\pi^-l^+l^-}\right|^2}(s_{\pi\pi}, s_{ll}, \theta_\pi, \theta_l, \varphi) = \frac{e^2}{8k^2}|M(s_{\pi\pi}, s_{ll})|^2 \lambda(M^2(\eta'), s_{\pi\pi}, s_{ll})(1-\beta_l^2 \sin^2\theta_l \sin^2\varphi) s_{\pi\pi} \beta_\pi^2 \sin^2\theta_\pi$$

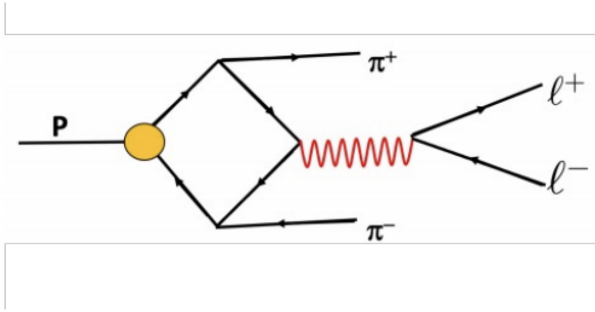
  - ✓ The magnetic form factor

$$M(s_{\pi\pi}, s_{ll}) = M_{mix} \times VMD(s_{\pi\pi}, s_{ll})$$

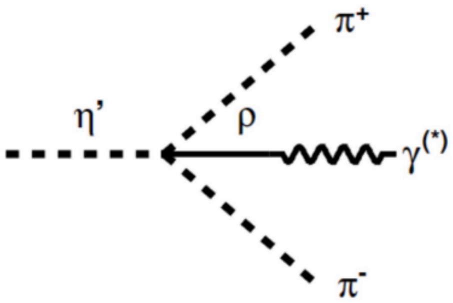
  - ✓ VMD factor

$$VMD(s_{\pi\pi}, s_{ll}) = 1 - \frac{3}{4}(c_1 - c_2 + c_3) + \frac{3}{4}(c_1 - c_2 - c_3)\frac{m_V^2}{m_V^2 - s_{ll} - i m_V \Gamma(s_{ll})} + \frac{3}{2} c_3 \frac{m_V^2}{m_V^2 - s_{ll} - i m_V \Gamma(s_{ll})} \frac{m_{V,\pi}^2}{m_{V,\pi}^2 - s_{\pi\pi} - i m_{V,\pi} \Gamma(s_{\pi\pi})}$$

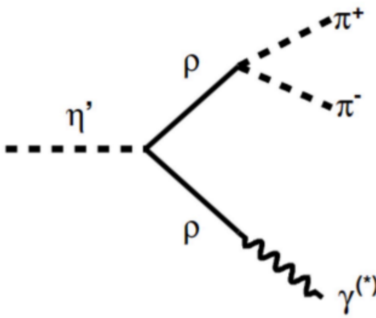
Box anomaly



VMD contribution



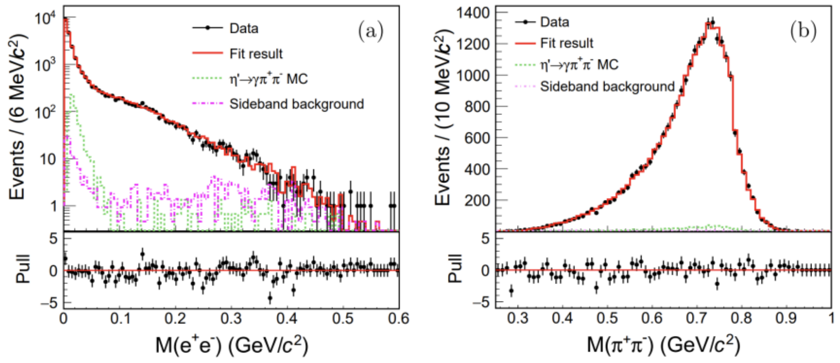
VMD contribution

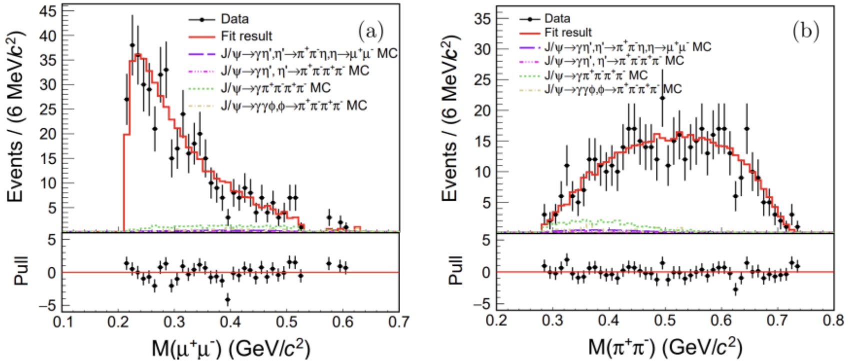


$\eta' \to \pi^+\pi^- l^+ l^-$

- **VMD models**
  - ✓ Hidden gauge model: $c_1 - c_2 = c_3 = 1$
  - ✓ Full VMD model: $c_1 - c_2 = \frac{1}{3}, c_3 = 1$
  - ✓ Modified VMD: $c_1 - c_2 \neq c_3$
- **Amplitude analysis result**

$\eta' \to \pi^+\pi^- e^+ e^-$





$\eta' \to \pi^+\pi^- \mu^+ \mu^-$

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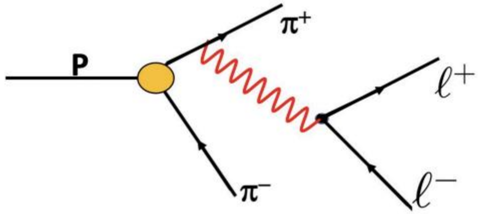
$\eta' \to \pi^+\pi^- e^+ e^-$	Model I	Model II	Model III
	$c_1 - c_2 = c_3 = 1$	$c_1 - c_2 = 1/3, c_3 = 1$	$c_1 - c_2 \neq c_3$
$m_V\,(\mathrm{MeV}/c^2)$	$954.3 \pm 87.8 \pm 36.4$	857.4 ± 76.5	787.5 ± 173.9
$m_{V,\pi}\,(\mathrm{MeV}/c^2)$	$765.3 \pm 1.2 \pm 20.2$	765.4 ± 1.2	764.8 ± 1.3
$m_\omega\,(\mathrm{MeV}/c^2)$	$778.7 \pm 1.3 \pm 17.3$	778.7 ± 1.3	778.7 ± 1.4
$\beta(10^{-3})$	$8.5 \pm 1.4 \pm 0.7$	8.5 ± 1.4	8.1 ± 1.5
θ	$1.4 \pm 0.3 \pm 0.1$	1.4 ± 0.3	1.4 ± 0.3
$c_1 - c_2$	1	1/3	-0.03 ± 1.09
c_3	1	1	1.03 ± 0.03
$\chi^2/ndof(e^+e^-, \pi^+\pi^-)$	77.9/82.0, 47.8/65.0	78.7/82.0, 47.6/65.0	79.4/82.0, 45.1/65.0
$b_{\eta'}\,(\mathrm{GeV}/c^2)^{-2}$	$1.10 \pm 0.20 \pm 0.07$	1.36 ± 0.24	1.61 ± 0.71

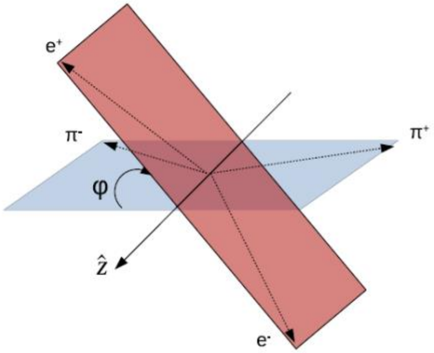
$\eta' \to \pi^+\pi^- \mu^+ \mu^-$	Model I	Model II	Model III
	$c_1 - c_2 = c_3 = 1$	$c_1 - c_2 = 1/3, c_3 = 1$	$c_1 - c_2 \neq c_3$
$m_V\,(\mathrm{MeV}/c^2)$	$649.4 \pm 55.9 \pm 35.6$	601.6 ± 25.7	589.6 ± 25.9
$m_{V,\pi}\,(\mathrm{MeV}/c^2)$	$757.3 \pm 24.1 \pm 18.0$	765.4 ± 18.8	774.4 ± 43.5
$c_1 - c_2$	1	1/3	0.01 ± 0.45
c_3	1	1	0.98 ± 0.40
$\chi^2/ndof(\mu^+\mu^-, \pi^+\pi^-)$	48.1/34.0, 32.9/46.0	48.3/34.0, 32.9/46.0	49.7/35.0, 32.4/46.0
$b_{\eta'}\,(\mathrm{GeV}/c^2)^{-2}$	$2.37 \pm 0.41 \pm 0.27$	2.76 ± 0.24	2.88 ± 0.25

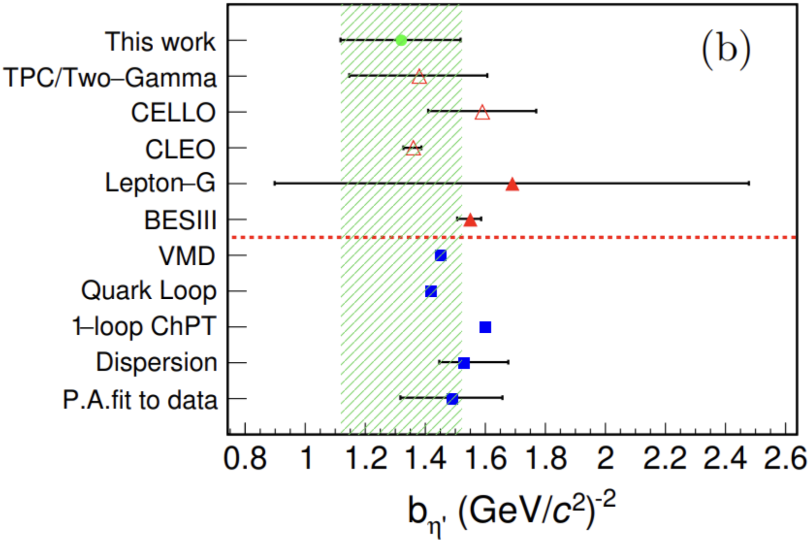
$\eta' \to \pi^+\pi^-l^+l^-$

- **The slope parameter of TFF**
  - ✓ $b_{\eta'} = 1.30 \pm 0.19 (\mathrm{GeV}/c^2)^{-2}$

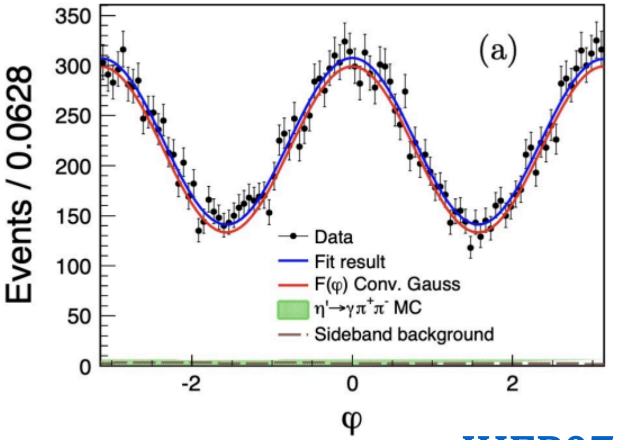


- **CP -violating asymmetry**
  - ✓ $F(\varphi) = 1 + b \cdot \sin^2\varphi + c \cdot \sin 2\varphi$
  - ✓ $A_{CP} = \frac{4c}{(2+b\pi)}$
    - For $\eta' \to \pi^+\pi^-e^+e^-$ $A_{CP} = (-0.21 \pm 0.73 \pm 0.01)\%$
    - For $\eta' \to \pi^+\pi^-\mu^+\mu^-$ $A_{CP} = (0.62 \pm 4.71 \pm 0.08)\%$

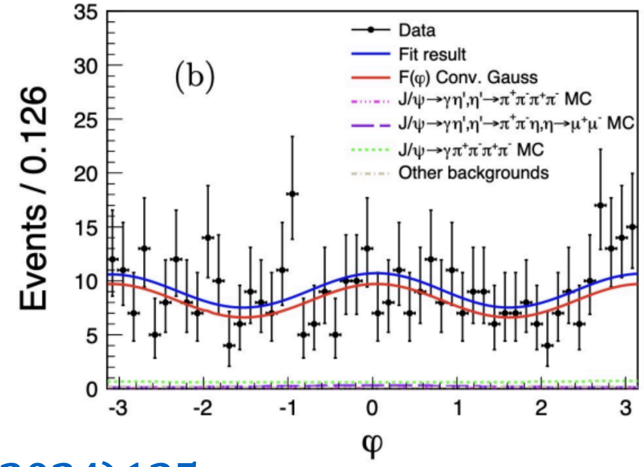




$\eta' \to \pi^+\pi^-e^+e^-$



$\eta' \to \pi^+\pi^-\mu^+\mu^-$



JHEP07(2024)135

CP observable in hyperon decay

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

T. D. Lee* and C. N. Yang

Institute for Advanced Study, Princeton, New Jersey

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Phys. Rev. 108, 1645 (1957)

- **CP tests in hyperon**
  - ✓ The amplitude of hyperon decay $\frac{1}{2} \rightarrow \frac{1}{2} + 0$ is $\mathcal{A} \sim S\sigma_0 + P\boldsymbol{\sigma} \cdot \hat{\boldsymbol{n}}$,

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

  - ✓ If CP conserved: $S \xrightarrow{CP} -S$, $P \xrightarrow{CP} P$ which mean $\alpha_Y \xrightarrow{CP} \alpha_{\bar{Y}} = -\alpha_Y$, $\beta_Y \xrightarrow{CP} \beta_{\bar{Y}} = -\beta_Y$
  - ✓ $\alpha_Y^2 + \beta_Y^2 + \gamma_Y^2 = 1 \rightarrow \beta_Y = \sqrt{1-\alpha_Y^2}\, sin(\phi_Y), \gamma_Y = \sqrt{1-\alpha_Y^2}\, cos(\phi_Y)$
  - ✓ CP observable: $A_{CP} = \frac{\alpha_Y + \alpha_{\bar{Y}}}{\alpha_Y - \alpha_{\bar{Y}}}$, $\Delta\phi_{CP} = \frac{\phi_Y - \phi_{\bar{Y}}}{2}$
  - ✓ $S = \sum S_j\, exp\{i(\xi_j^S + \delta_{2I}^S)\}, P = \sum P_j\, exp\{i(\xi_j^P + \delta_{2I}^P)\}$
  - ✓ $\bar{S} = \sum -S_j\, exp\{i(-\xi_j^S + \delta_{2I}^S)\}, \bar{P} = \sum P_j\, exp\{i(-\xi_j^P + \delta_{2I}^P)\}$
  - ✓ $A_{CP} = -tan(\delta_P - \delta_S) tan(\xi_P - \xi_S)$, $\Delta\phi_{CP} = \frac{\alpha_Y}{\sqrt{1-\alpha_Y^2}} cos\phi_Y tan(\xi_P - \xi_S)$

Hyperon production at BESIII

- **Polarized hyperon pairs produced in e^+e^- collisions**
  - ✓ Spin $\frac{1}{2} + \frac{\bar{1}}{2}$ baryon-antibaryon spin density matrix

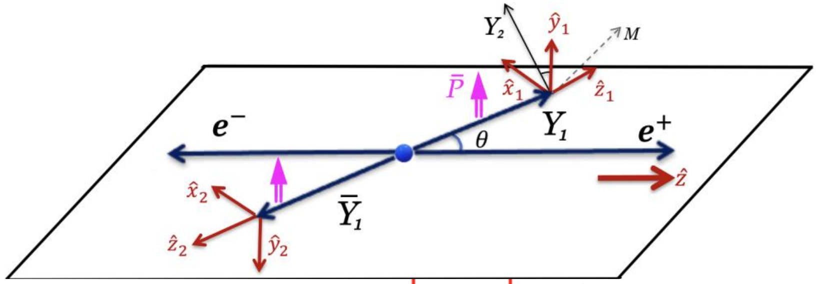
Y_1 transverse polarization

$$C_{\mu\bar{\nu}} = \begin{pmatrix} 1+\alpha_\psi \cos^2\theta & 0 & \beta_\psi \sin\theta\cos\theta & 0 \\ 0 & \sin^2\theta & 0 & \gamma_\psi \sin\theta\cos\theta \\ -\beta_\psi \sin\theta\cos\theta & 0 & \alpha_\psi \sin^2\theta & 0 \\ 0 & -\gamma_\psi \sin\theta\cos\theta & 0 & -\alpha_\psi - \cos^2\theta \end{pmatrix}$$

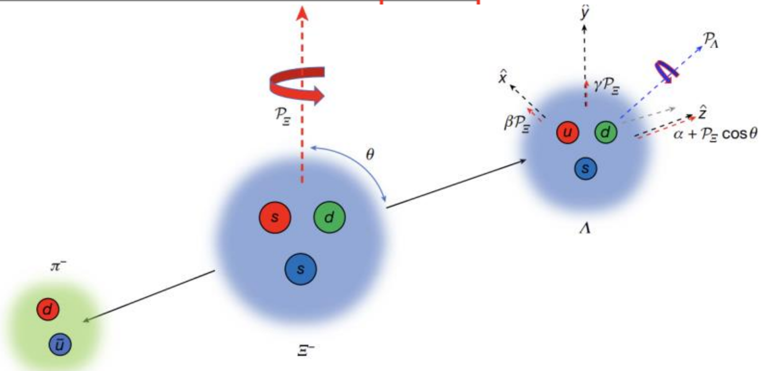
$\bar{Y}_1$ transverse polarization — spin-correlation terms

$$\beta_\psi = \sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi), \quad \gamma_\psi = \sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi) \qquad P_Y =$$

  - ✓ Unpolarized e^+e^- beams ⟶ transverse polarization (if $\Delta\Phi \neq 0$)
    - $$P_y(\cos\theta) = \frac{\sqrt{1-\alpha_\psi^2}\cos(\theta)\sin(\theta)}{1+\alpha_\psi\cos^2(\theta)}\sin(\Delta\Phi)$$



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



- **10 billion J/ψ events collected:**
  - ✓ Large BR in J/ψ decay
  - ✓ Quantum entangled pair productions
  - ✓ Polarized hyperon
  - ✓ High efficiency, background free

Nature volume 606, pages64–69 (2022)

$$\mathbf{P}_\Lambda \cdot \hat{\mathbf{z}} = \frac{\alpha_\Xi + \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}}{1 + \alpha_\Xi \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}},$$

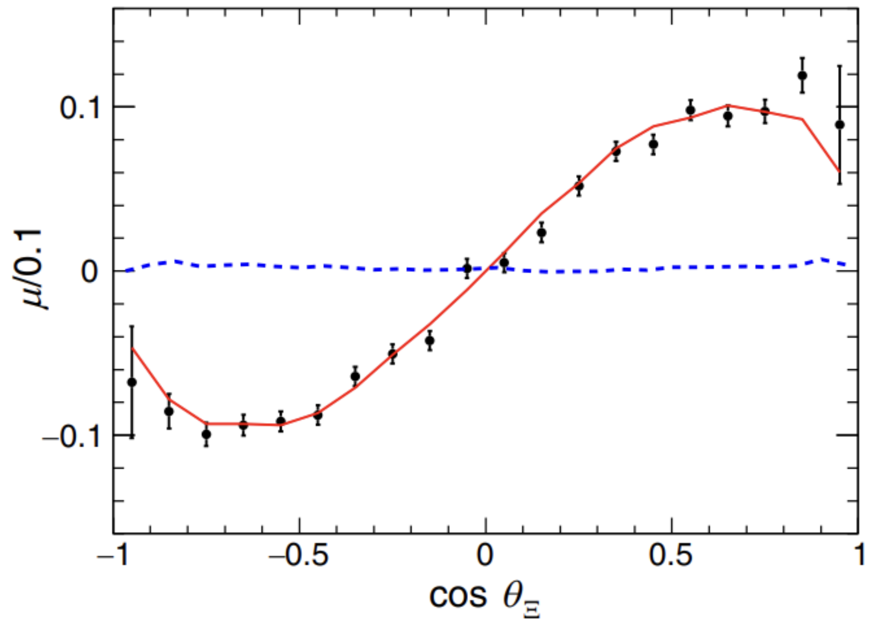
$$\mathbf{P}_\Lambda \times \hat{\mathbf{z}} = \mathcal{P}_\Xi \sqrt{1-\alpha_\Xi^2}\,\frac{\sin\phi_\Xi \hat{\mathbf{x}} + \cos\phi_\Xi \hat{\mathbf{y}}}{1 + \alpha_\Xi \mathbf{P}_\Xi \cdot \hat{\mathbf{z}}},$$

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

BESIII

- Tests of CP symmetry in entangled $\Xi^0 - \bar{\Xi}^0$ pairs
  - ✓ The most precise values for CP asymmetry observables of Ξ^0 decay are obtained.
  - ✓ For the first time, the weak and strong phase differences are determined which are the most precise results for any weakly decaying baryon.
  - ✓ Ξ^0 and $\bar{\Xi}^0$ decay parameters are determined with the most precise, which are improved by more than one order of magnitude over the previous measurements.

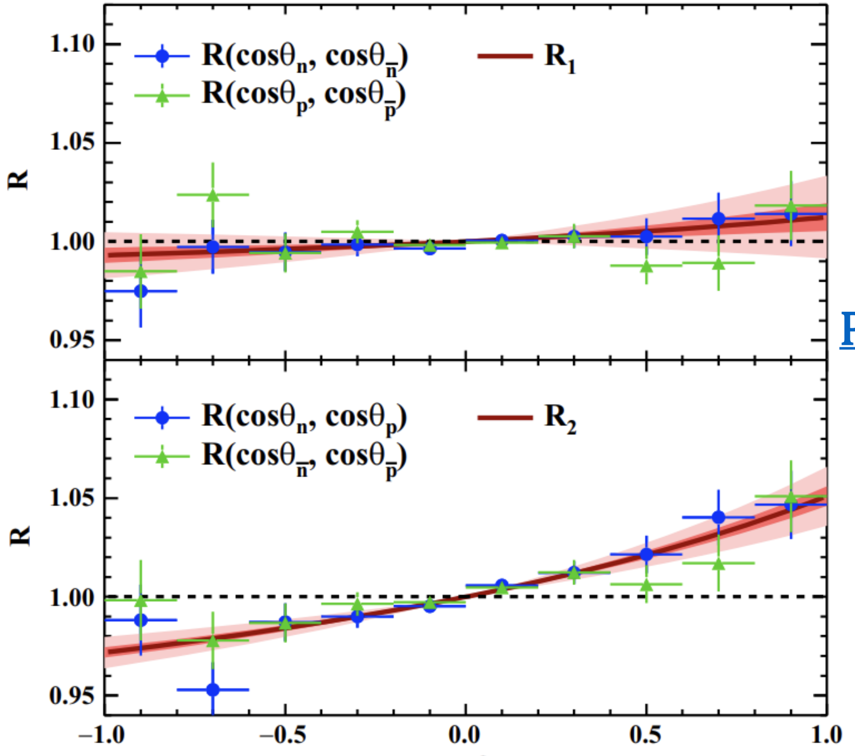
PRD 108(2023) L031106



Parameter	This work	Previous result
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$	0.66 ± 0.06 [42]
$\Delta\Phi$(rad)	$1.168 \pm 0.019 \pm 0.018$	...
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$	-0.358 ± 0.044 [49]
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$	0.363 ± 0.043 [49]
ϕ_Ξ(rad)	$0.0051 \pm 0.0096 \pm 0.0018$	0.03 ± 0.12 [49]
$\bar{\phi}_\Xi$(rad)	$-0.0053 \pm 0.0097 \pm 0.0019$	-0.19 ± 0.13 [49]
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$	0.7519 ± 0.0043 [20]
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$	-0.7559 ± 0.0047 [20]
$\xi_P - \xi_S$(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	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$	$(-0.7 \pm 8.5) \times 10^{-2}$ [49]
$\Delta\phi_{CP}^\Xi$(rad)	$(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$	$(-7.9 \pm 8.3) \times 10^{-2}$ [49]
A_{CP}^Λ	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$	$(-2.5 \pm 4.8) \times 10^{-3}$ [20]
$\langle\alpha_\Xi\rangle$	$-0.3770 \pm 0.0024 \pm 0.0014$	...
$\langle\phi_\Xi\rangle$(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 [20]

$e^+e^- \to J/\psi \to \Xi^- \bar{\Xi}^+ \to \Lambda\pi^-\bar{\Lambda}\pi^+ \to p\pi^-\pi^-\bar{n}\pi^0\pi^+$+c.c.

- Investigation of the $\Delta I = \frac{1}{2}$ Rule and Test of CP Symmetry
  - ✓ **The precisions of $\alpha_{\Lambda 0}$ for $\Lambda \to n\pi^0$ and $\bar{\alpha}_{\Lambda 0}$ for $\bar{\Lambda} \to \bar{n}\pi^0$ compared to world averages are improved by factors of 4 and 1.7**
  - ✓ **The ratio of decay asymmetry parameters of $\Lambda \to n\pi^0$ to that of $\Lambda \to p\pi^-$, $\langle\alpha_{\Lambda 0}\rangle/\langle\alpha_{\Lambda -}\rangle$, is smaller than unity more than 5σ, which signifies the existence of the ΔI =3/2 transition in Λ for the first time.**
  - ✓ CP test is also with the best precision to date.



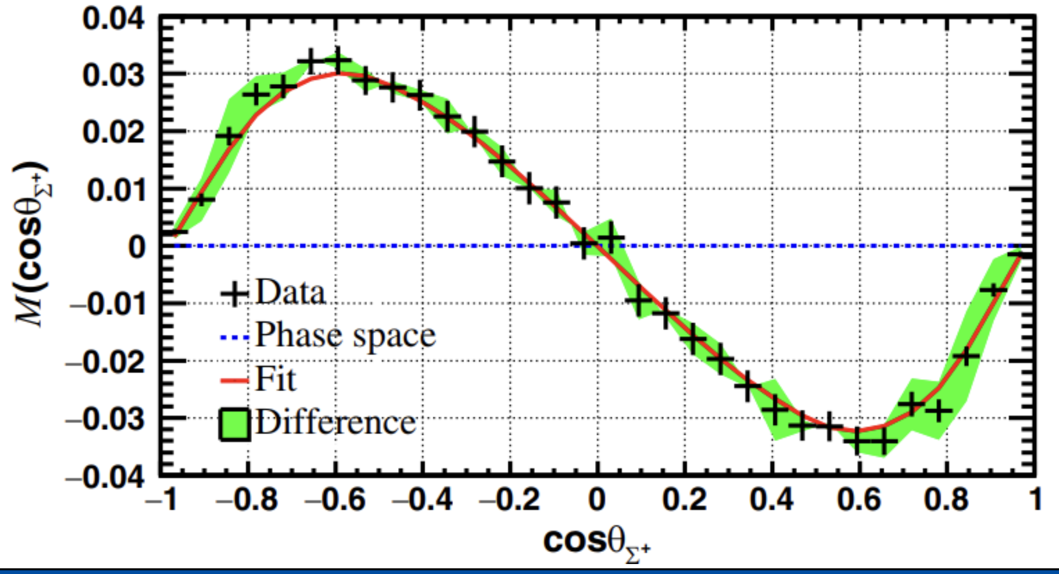
PRL 132(2024) 101801

Parameters	This work	Previous result
$\alpha_{J/\psi}$	$0.611 \pm 0.007^{+0.013}_{-0.007}$	$0.586 \pm 0.012 \pm 0.010$ [18]
$\Delta\Phi_{J/\psi}$ (rad)	$1.30 \pm 0.03^{+0.02}_{-0.03}$	$1.213 \pm 0.046 \pm 0.016$ [18]
α_Ξ	$-0.367 \pm 0.004^{+0.003}_{-0.004}$	$-0.376 \pm 0.007 \pm 0.003$ [18]
ϕ_Ξ (rad)	$-0.016 \pm 0.012^{+0.004}_{-0.008}$	$0.011 \pm 0.019 \pm 0.009$ [18]
$\bar{\alpha}_\Xi$	$0.374 \pm 0.004^{+0.003}_{-0.004}$	$0.371 \pm 0.007 \pm 0.002$ [18]
$\bar{\phi}_\Xi$ (rad)	$0.010 \pm 0.012^{+0.003}_{-0.013}$	$-0.021 \pm 0.019 \pm 0.007$ [18]
$\alpha_{\Lambda -}$	$0.764 \pm 0.008^{+0.005}_{-0.006}$	$0.7519 \pm 0.0036 \pm 0.0024$ [37]
$\alpha_{\Lambda +}$	$-0.774 \pm 0.009^{+0.005}_{-0.005}$	$-0.7559 \pm 0.0036 \pm 0.0030$ [37]
$\alpha_{\Lambda 0}$	$0.670 \pm 0.009^{+0.009}_{-0.008}$	0.75 ± 0.05 [29]
$\bar{\alpha}_{\Lambda 0}$	$-0.668 \pm 0.008^{+0.006}_{-0.008}$	$-0.692 \pm 0.016 \pm 0.006$ [17]
$\delta_P - \delta_S$ (rad)	$0.033 \pm 0.020^{+0.008}_{-0.012}$	$-0.040 \pm 0.033 \pm 0.017$ [18]
$\xi_P - \xi_S$ (rad)	$0.007 \pm 0.020^{+0.018}_{-0.005}$	$0.012 \pm 0.034 \pm 0.008$ [18]
A^Ξ_{CP}	$-0.009 \pm 0.008^{+0.007}_{-0.002}$	$0.006 \pm 0.013 \pm 0.006$ [18]
$\Delta\phi^\Xi_{CP}$ (rad)	$-0.003 \pm 0.008^{+0.003}_{-0.007}$	$-0.005 \pm 0.014 \pm 0.003$ [18]
A^-_{CP}	$-0.007 \pm 0.008^{+0.002}_{-0.003}$	$-0.0025 \pm 0.0046 \pm 0.0012$ [37]
A^0_{CP}	$0.001 \pm 0.009^{+0.005}_{-0.007}$	...
A^Λ_{CP}	$-0.004 \pm 0.007^{+0.003}_{-0.004}$	...
$\alpha_{\Lambda 0}/\alpha_{\Lambda -}$	$0.877 \pm 0.015^{+0.014}_{-0.010}$	1.01 ± 0.07 [29]
$\bar{\alpha}_{\Lambda 0}/\alpha_{\Lambda +}$	$0.863 \pm 0.014^{+0.012}_{-0.008}$	$0.913 \pm 0.028 \pm 0.012$ [17]

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

◆ Test of CP Symmetry in Hyperon to Neutron Decays

- ✓ The CP-odd weak decay parameters of the decays $\Sigma^+ \to n\pi^+(\alpha_+)$ and $\bar{\Sigma}^- \to \bar{n}\pi^-(\bar{\alpha}_-)$ are determined. $\bar{\alpha}_-$ is measured for the first time, and the accuracy of α_+ is improved by a factor of 4.
- ✓ The simultaneously determined decay parameters allow the first precision CP symmetry test for any hyperon decay with a neutron in the final state.



PRL 131(2023) 191802

Parameter	This Letter	Previous result
$\alpha_{J/\psi}$	$-0.5156 \pm 0.0030 \pm 0.0061$	$-0.508 \pm 0.006 \pm 0.004$ [26]
$\Delta\Phi_{J/\psi}$ (rad)	$-0.2772 \pm 0.0044 \pm 0.0041$	$-0.270 \pm 0.012 \pm 0.009$ [26]
α_+	$0.0481 \pm 0.0031 \pm 0.0019$	0.069 ± 0.017 [18]
$\bar{\alpha}_-$	$-0.0565 \pm 0.0047 \pm 0.0022$	...
α_+/α_0	$-0.0490 \pm 0.0032 \pm 0.0021$	-0.069 ± 0.021 [33]
$\bar{\alpha}_-/\bar{\alpha}_0$	$-0.0571 \pm 0.0053 \pm 0.0032$	...
A_{CP}	$-0.080 \pm 0.052 \pm 0.028$	...
$\langle\alpha_+\rangle$	$0.0506 \pm 0.0026 \pm 0.0019$	...

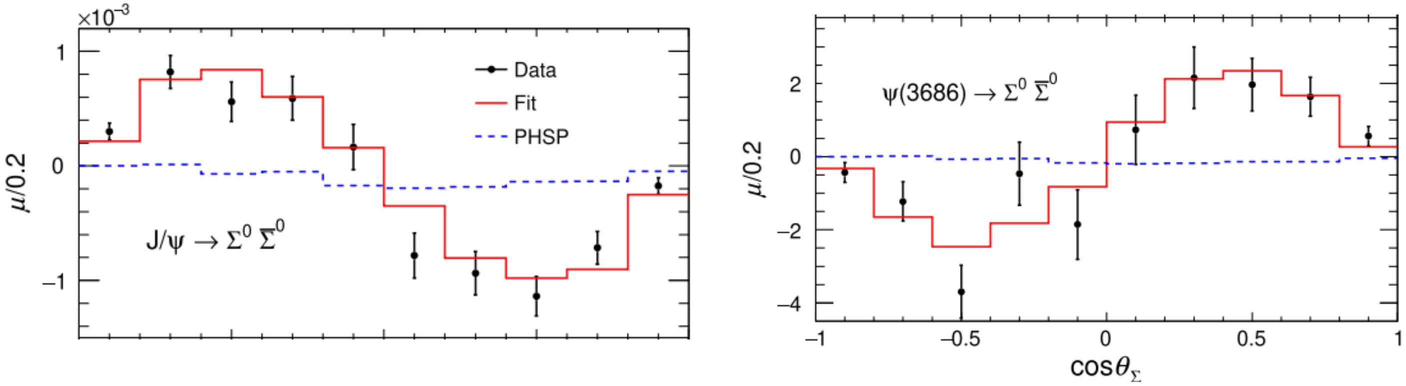
$e^+e^- \to J/\psi(\psi(3686)) \to \Sigma^0\,\bar{\Sigma}^0 \to \gamma\Lambda\gamma\bar{\Lambda} \to \gamma p\pi^-\gamma\bar{p}\pi^+$

BESIII

◆ Strong and Weak CP Tests in Sequential Decays of Polarized Σ^0 Hyperons

- ✓ The strong-CP symmetry ($A_{CP}^{\Sigma} = \alpha_{\Sigma^0} + \bar{\alpha}_{\Sigma^0}$) is tested for the first time. The weak-CP test is performed in the subsequent decays of their daughter particles Λ and $\bar{\Lambda}$.
- ✓ The **transverse polarizations** of the Σ^0 hyperons in J/ψ and $\psi(3686)$ decays are observed with opposite directions for the first time.
- ✓ The **ratios between the S-wave and D-wave** contributions of $J/\psi(\psi(3686)) \to \Sigma^0\,\bar{\Sigma}^0$ decay are obtained for the first time.

PRL 133(2024)101902



Parameter	This Letter	Previous results
$\alpha_{J/\psi}$	$-0.4133 \pm 0.0035 \pm 0.0077$	-0.449 ± 0.022 [52]
$\Delta\Phi_{J/\psi}$ (rad)	$-0.0828 \pm 0.0068 \pm 0.0033$	...
$\alpha_{\psi(3686)}$	$0.814 \pm 0.028 \pm 0.028$	0.71 ± 0.12 [52]
$\Delta\Phi_{\psi(3686)}$ (rad)	$0.512 \pm 0.085 \pm 0.034$	...
α_{Σ^0}	$-0.0017 \pm 0.0021 \pm 0.0018$	...
$\bar{\alpha}_{\Sigma^0}$	$0.0021 \pm 0.0020 \pm 0.0022$	...
α_{Λ}	$0.730 \pm 0.051 \pm 0.011$	0.748 ± 0.007 [44]
$\bar{\alpha}_{\Lambda}$	$-0.776 \pm 0.054 \pm 0.010$	-0.757 ± 0.004 [44]
A_{CP}^{Σ}	$(0.4 \pm 2.9 \pm 1.3) \times 10^{-3}$	...
A_{CP}^{Λ}	$(-3.0 \pm 6.9 \pm 1.5) \times 10^{-2}$	$(-2.5 \pm 4.8) \times 10^{-3}$ [2]

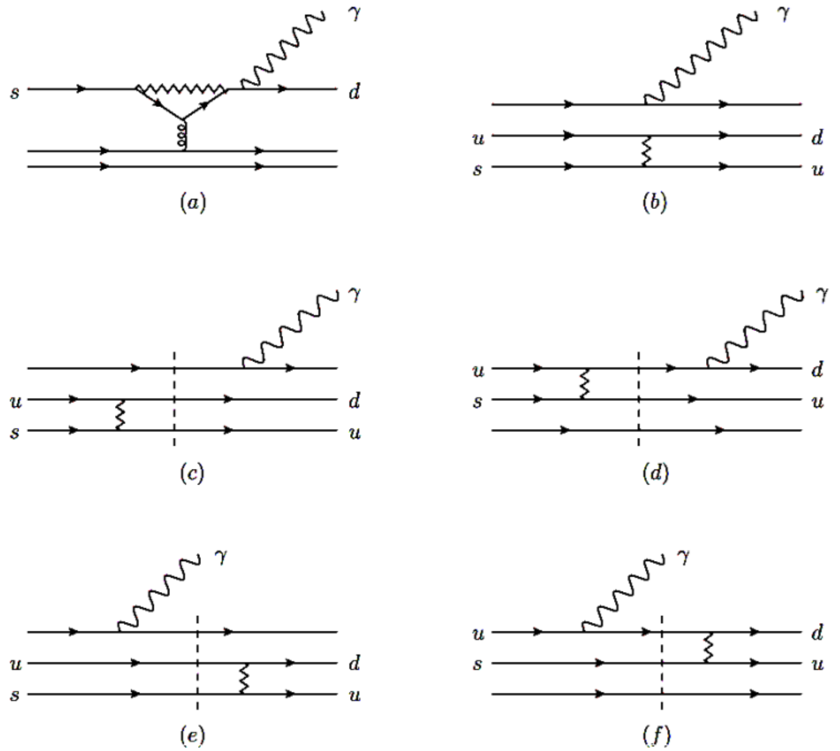
Hyperon weak radiative decay

◆ Hyperon weak radiative decay

- ✓ Interplay of the electromagnetic, weak, and strong interactions.
- ✓ Hara's theorem: Radiative hyperon decays have vanish PV amplitude and decay asymmetry in the limit of SU(3) symmetry.
  - ✓ Effective Lagrangian: $\mathcal{L} = \frac{eG_F}{2}\bar{B}_f\left(a^{PC} + b^{PV}\gamma_5\right)\sigma^{\mu\nu}B_iF_{\mu\nu}$
  - ✓ Decay width and decay asymmetry:

$$\Gamma = \frac{\mathrm{e}^2\mathrm{G}_\mathrm{F}^2}{\pi}\left(|a|^2 + |b|^2\right)\left|\vec{k}\right|^3, \alpha_\gamma = \frac{2Re(ab^*)}{|a|^2 + |b|^2}$$

  - ✓ α_γ=0?
- ✓ This process generally has a very small branching ratio and is difficult to measure.



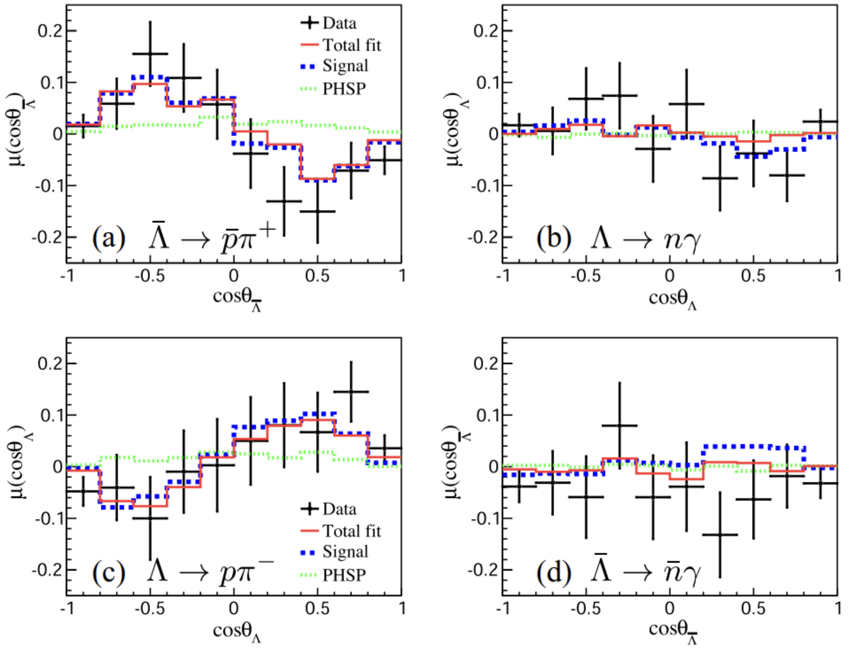
$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to n\gamma\bar{p}\pi^+$+c.c.

BESIII

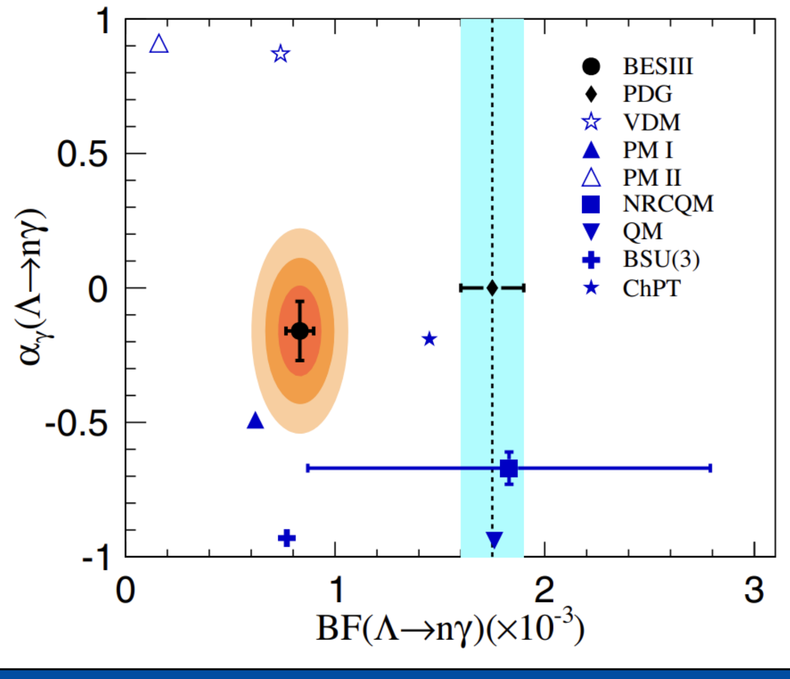
◆ Measurement of the Absolute Branching Fraction and Decay Asymmetry of $\Lambda \to n\gamma$

✓ The **absolute branching fraction** of the decay $\Lambda \to n\gamma$ is determined to be $(0.832 \pm 0.038 \pm 0.054) \times 10^{-3}$, which is a factor of **2.1 lower and 5.6 standard deviations** different than the previous measurement.

✓ The first determination of the **decay asymmetry parameter** α_γ is reported with a value of $-0.16 \pm 0.10 \pm 0.05$.



PRL 129(2022) 212002



$e^+e^- \to J/\psi \to \Sigma^+\bar{\Sigma}^- \to p\gamma\bar{p}\pi^0$+c.c.

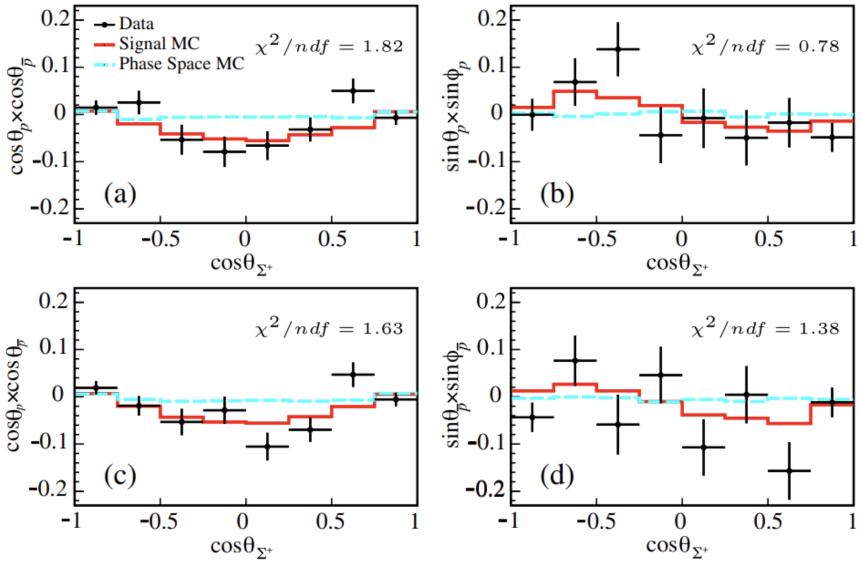
BESIII

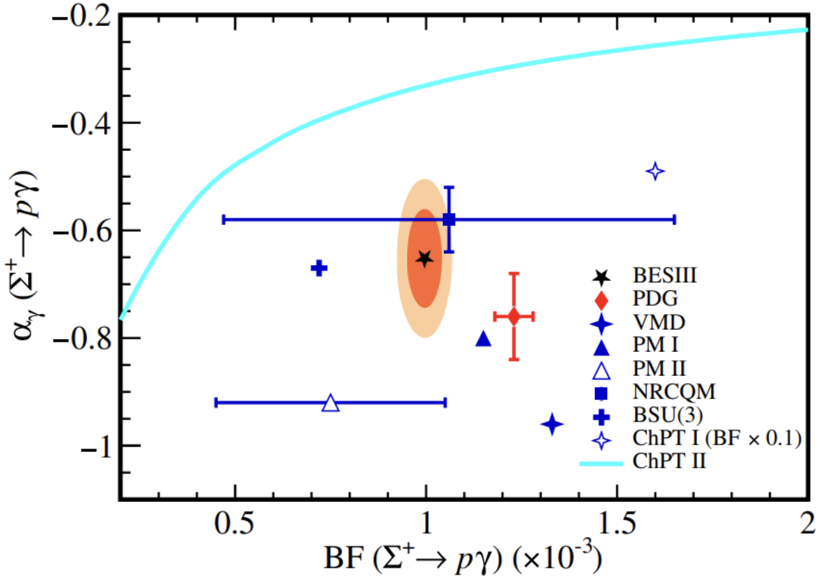
◆ Precision Measurement of the Decay $\Sigma^+ \to p\gamma$ in the Process $J/\psi \to \Sigma^+\bar{\Sigma}^-$

- ✓ The absolute branching fraction of the decay $\Sigma^+ \to p\gamma$ is measured to be $(0.996 \pm 0.021 \pm 0.018) \times 10^{-3}$, which is lower than its world average value by 4.2 standard deviations.

- ✓ The decay asymmetry parameter is determined to be $-0.652 \pm 0.056 \pm 0.020$.

PRL 130(2023) 211901





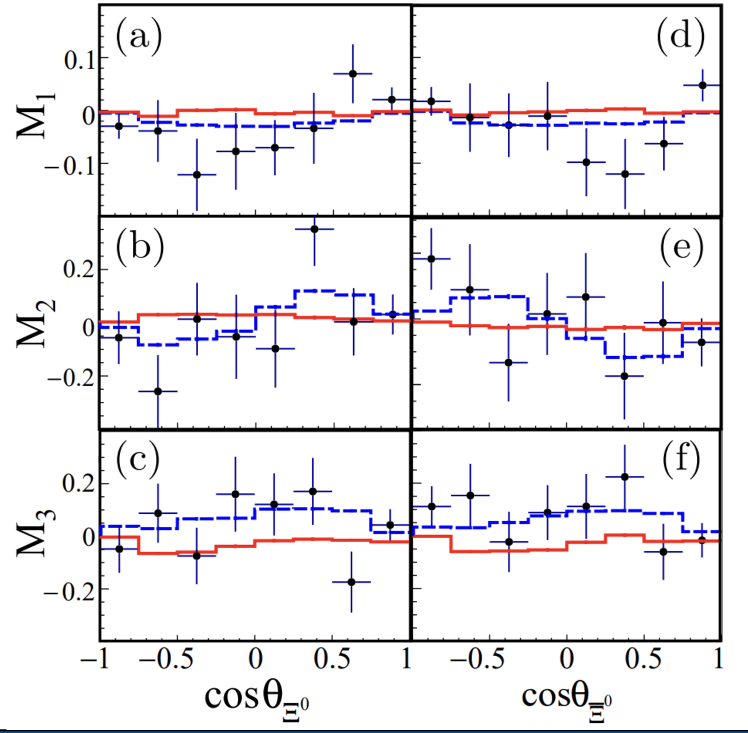
$e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0 \to \Lambda\gamma\bar{\Lambda}\pi^0 \to \gamma p\pi^-\gamma\gamma\bar{p}\pi^+ + c.c.$

BESIII

◆ Measurement of the Decay $\Xi^0 \to \Lambda\gamma$ with Entangled $\Xi^0\bar{\Xi}^0$ Pairs

- ✓ The **absolute branching fraction** of the decay $\Xi^0 \to \Lambda\gamma$ has been measured for the first time, and is $(1.347 \pm 0.066 \pm 0.054) \times 10^{-3}$.

- ✓ The **decay asymmetry parameter** is determined to be $-0.741 \pm 0.062 \pm 0.019$.



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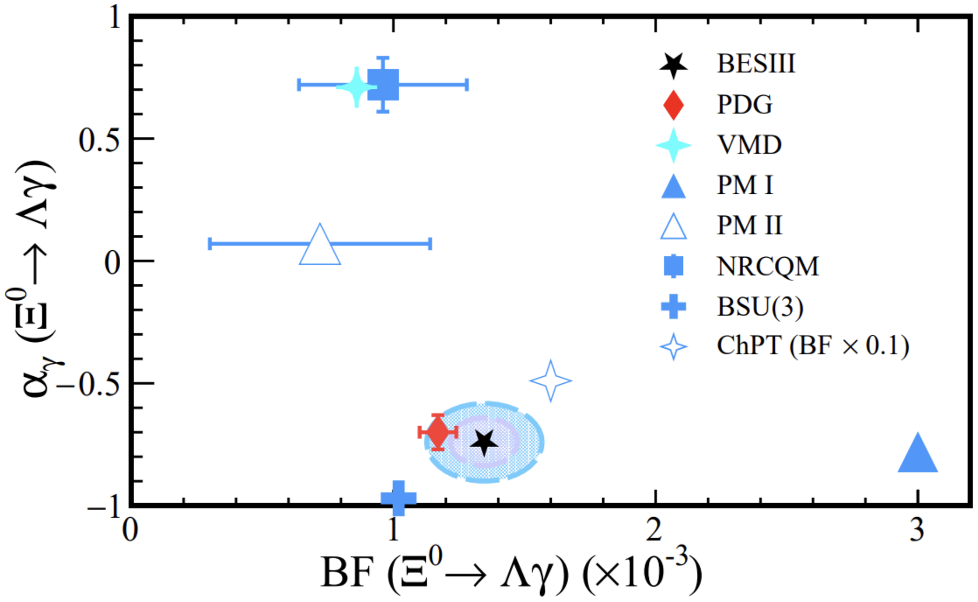

FB23 THE 23rd INTERNATIONAL CONFERENCE ON FEW-BODY PROBLEMS IN PHYSICS (FB23) Sept. 22-27, 2024 · Beijing, China

Summary

BESIII

◆ A set of interesting and important results from the light hadron decays are achieved:

- ✓ Light meson decays (η/η')
  - Decay mechanisms, Form factors, New physics…
- ✓ Hyperon decays
  - ✓ CP test and polarization measurement
  - ✓ Hyperon weak radiative decay

◆ More interesting results expected in the future!