Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK

# Discrete symmetry tests using hyperon-antihyperon data

Nora Salone

Annual seminar of the Department of Fundamental Research

16th December 2022

BESIII

# Our group

- Joined BESIII collaboration in **July 2021**
- Members
  - dr. Varvara Batozskaya (IHEP, NCBJ)
  - dr. Marcin Berłowski (NCBJ)
  - prof. dr. hab. Andrzej Kupść (UU, NCBJ)
  - mgr. Nora Salone (NCBJ)[1]
- Objectives of study
  - CPV in s-quark baryon decays: nonleptonic, semileptonic, radiative
  - $Y\bar{Y}$ produced at $e^+e^-$ colliders

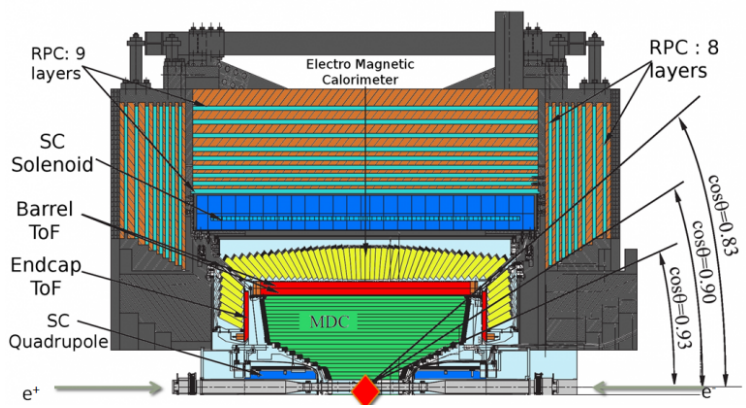
[1]NCN grant 2019/35/O/ST2/02907

# BESIII @ BEPCII

- Beijing Electron-Positron Collider (BEPCII)
  - $e^+e^-$ collider with 2.0 GeV < $E_{\mathrm{CMS}}$ < 4.95 GeV
  - $L_{\mathrm{peak}} = 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
  - Data taking since 2009

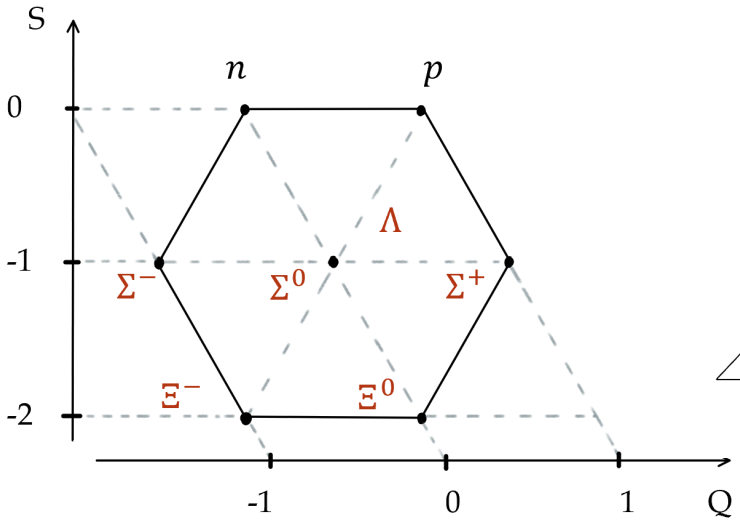
[Nucl. Instrum. Meth. A598 (2009) 7]

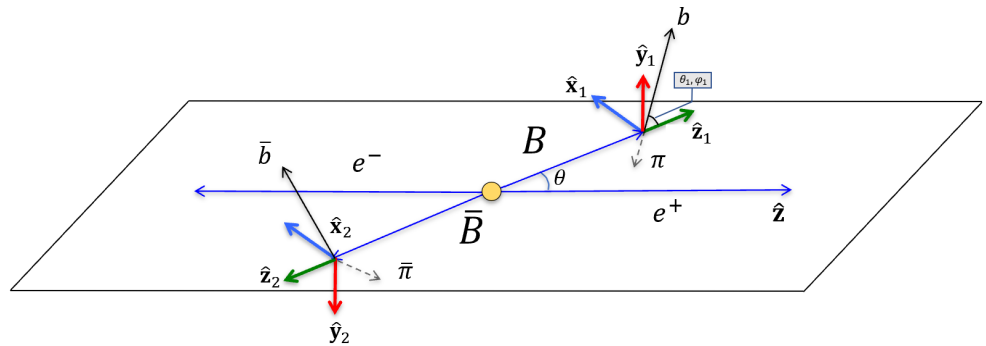
- Beijing Spectrometer (BESIII)
  - Optimized for flavor physics
  - Covering 93% of $4\pi$ solid angle
  - 1.0 T super-conducting solenoid
  - Momentum resolution: $\sigma(p)/p = 0.5\%$ at 1 GeV/c
  - Time resolution: 68 (65) ps in the barrel (end cap)



# Lowest-lying hyperons at BESIII

- World's largest charmonia sample in BESIII - $10^{10} J/\psi$, $3 \times 10^9\ \psi(2S)$
- Baryon-antibaryon production in spin-entangled state




| Decay | $\mathcal{B}(\times 10^{-4})$ | $\epsilon(\%)$ | $N_{\rm obs}$ | Reference |
|---|---|---|---|---|
| $J/\psi \to \Lambda\bar{\Lambda}$ | $19.43 \pm 0.03 \pm 0.33$ | $42.37 \pm 0.14$ | $441 \times 10^3$ | [PRD95(2017)052003] |
| $J/\psi \to \Sigma^0\bar{\Sigma}^0$ | $11.64 \pm 0.04 \pm 0.23$ | $17.83 \pm 0.06$ | $111 \times 10^3$ | [PRD93(2016)072003] |
| $J/\psi \to \Xi^-\bar{\Xi}^+$ | $10.40 \pm 0.06 \pm 0.74$ | $18.40 \pm 0.04$ | $43 \times 10^3$ | |
| $\psi(2S) \to \Lambda\bar{\Lambda}$ | $3.97 \pm 0.02 \pm 0.12$ | $42.83 \pm 0.34$ | $31 \times 10^3$ | [PRD95(2017)052003] |
| $\psi(2S) \to \Sigma^0\bar{\Sigma}^0$ | $2.44 \pm 0.03 \pm 0.11$ | $14.79 \pm 0.12$ | $6.6 \times 10^3$ | [PRD93(2016)072003] |
| $\psi(2S) \to \Xi^-\bar{\Xi}^+$ | $2.78 \pm 0.05 \pm 0.14$ | $18.04 \pm 0.04$ | $5.3 \times 10^3$ | |

# Hyperon decay formalism

Weak parity-conserving (P) and
-violating (S) amplitudes

$$\mathcal{A} = S + P\vec{\sigma} \cdot \hat{n}$$

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

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Two measurable parameters

$$\alpha = \frac{2\Re(S^* P)}{|S|^2 + |P|^2}$$
$$\beta = \frac{2\Im(S^* P)}{|S|^2 + |P|^2} = \sqrt{1-\alpha^2}\sin\phi$$

$$A_{\mathrm{CP}} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}$$
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# Updated values

nature physics

LETTERS

https://doi.org/10.1038/s41567-019-0494-8

**Polarization and entanglement in baryon–antibaryon pair production in electron–positron annihilation**

**The BESIII Collaboration***

[Nature Phys. 15 (2019) 631]

Article | Open Access | Published: 01 June 2022

**Probing CP symmetry and weak phases with entangled double-strange baryons**

The BESIII Collaboration

*Nature* **606**, 64–69 (2022) | Cite this article

**11k** Accesses | **7** Citations | **96** Altmetric | Metrics

[Nature 606, 64–69 (2022)]

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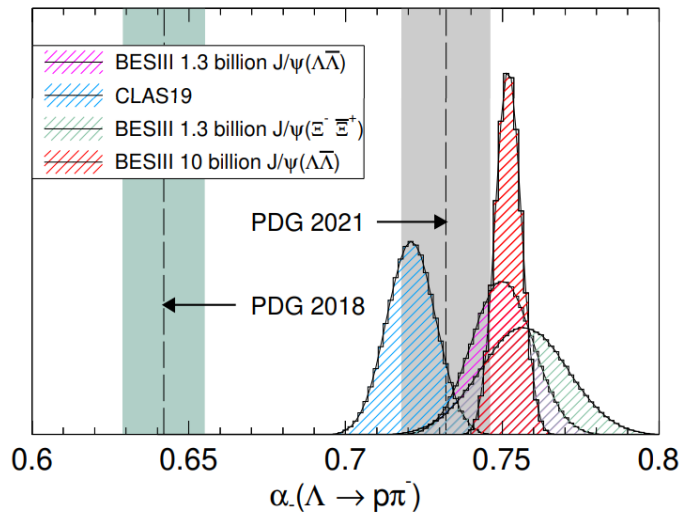
Precise Measurements of Decay Parameters and $CP$ Asymmetry with Entangled $\Lambda$–$\bar{\Lambda}$ Pairs

M. Ablikim *et al.* (BESIII Collaboration)

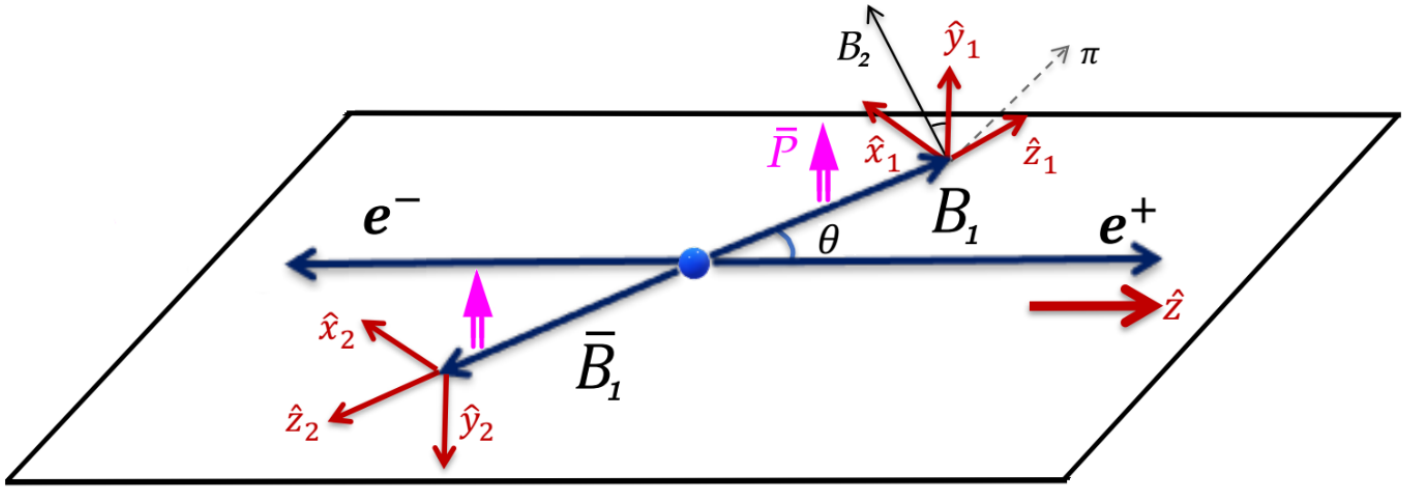
Phys. Rev. Lett. **129**, 131801 – Published 22 September 2022




[Phys.Rev.Lett. 129 (2022) 131801]

$$A_\Lambda = -\tan(\delta_P^\Lambda - \delta_S^\Lambda)\tan(\xi_P^\Lambda - \xi_S^\Lambda) = -0.0025(46)$$

# Baryon polarization in BESIII




[V. Batozskaya, BEACH22]

Produced $B$ polarization from unpolarized $e^-$ beam:

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

Decay angular distribution:

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

# Baryon polarization with polarized beam

PHYSICAL REVIEW D **105,** 116022 (2022)

**Study of *CP* violation in hyperon decays at super-charm-tau factories with a polarized electron beam**

Nora Salone,[1] Patrik Adlarson,[2] Varvara Batozskaya,[3,1] Andrzej Kupsc,[2,1,*] Stefan Leupold,[2] and Jusak Tandean[4]

With a **polarized** $e^-$ beam: $P_x, P_z \neq 0$

$$\begin{pmatrix} 1+\alpha_\psi \cos^2\theta & \gamma_\psi P_e \sin\theta & \beta_\psi \sin\theta\cos\theta & (1+\alpha_\psi) P_e \cos\theta \\ \gamma_\psi P_e \sin\theta & \sin^2\theta & 0 & \gamma_\psi \sin\theta\cos\theta \\ -\beta_\psi \sin\theta\cos\theta & 0 & \alpha_\psi \sin^2\theta & -\beta_\psi P_e \sin\theta \\ -(1+\alpha_\psi) P_e \cos\theta & -\gamma_\psi \sin\theta\cos\theta & -\beta_\psi P_e \sin\theta & -\alpha_\psi - \cos^2\theta \end{pmatrix}$$

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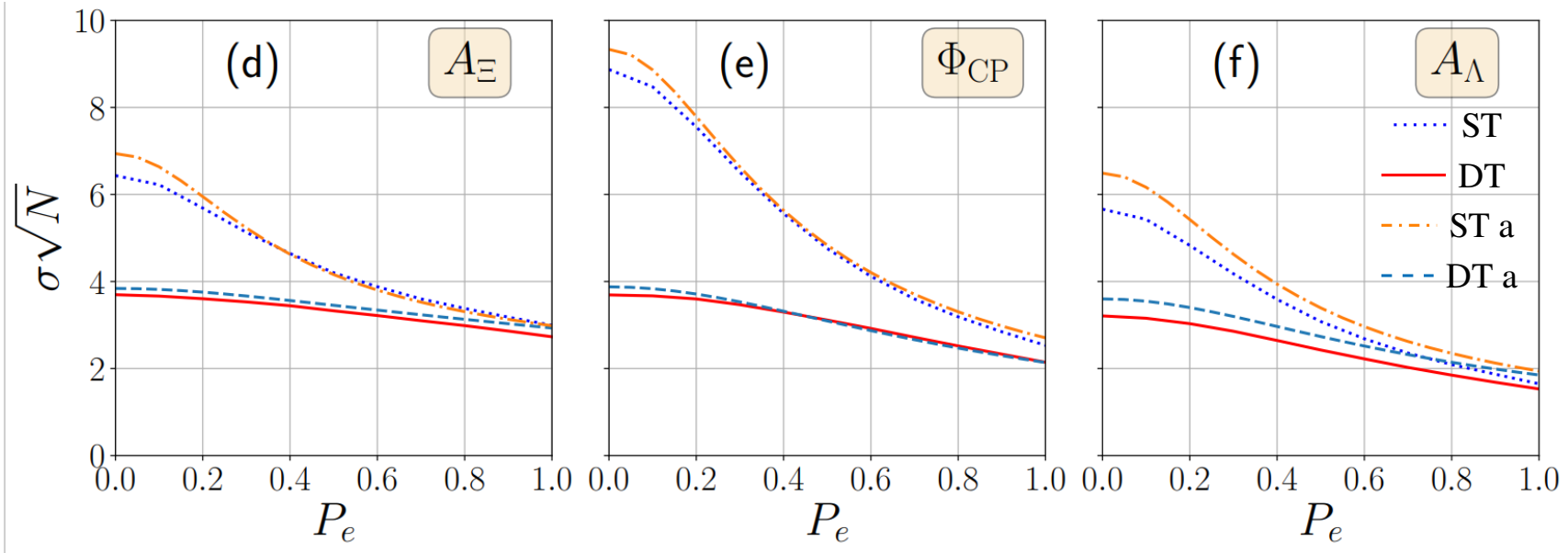
# Baryon polarization with polarized beam

CP tests sensitivities, $P_e$-dependent:




- Quantifiable improvement in predicted sensitivities with $P_e \neq 0$
- Contributions from baryon polarization and spin-entanglement can be distinguished using developed analytical approach

# CPV in hyperon decays

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

$$\Phi_{\mathrm{CP}} = \frac{\alpha}{\sqrt{1-\alpha^2}}\cos\phi\,\tan(\xi_P - \xi_S)$$

$S$, $P$ amplitudes expanded up to LO
$\Delta I = 1/2$ linear corrections
[PRD105(2022)116022]

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[PRD105(2022)116022]

[Nature 606, 64–69 (2022)]:

- first measurement of CP-odd phase difference

$$\xi_P - \xi_S = (1.2 \pm 3.4 \pm 0.8) \times 10^{-2}\,\text{rad} \qquad \text{SM}: \xi_P - \xi_S = (-2.1 \pm 1.7) \times 10^{-4}\,\text{rad}$$

- First measurement of $\Xi^-$ polarization and decay parameters (directly)

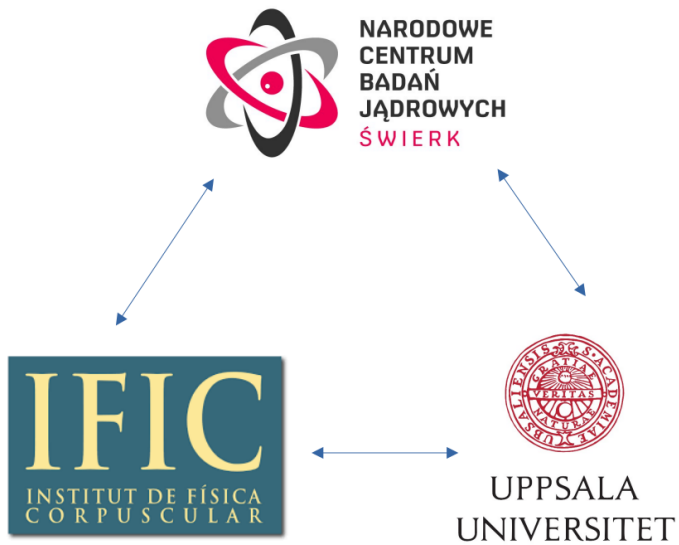
$$\Delta\Phi = 1.213 \pm 0.046 \pm 0.016$$

$$\alpha_\Xi = -0.376 \pm 0.007 \pm 0.003,\ \phi_\Xi = 0.011 \pm 0.019 \pm 0.009\ \text{rad}$$

# Nonleptonic decays review

New data situation from BESIII called for an update of the theoretical predictions:

- $\Delta S = 1$, $B_1 \to B_2\pi$ decays in $\chi PT$ up to 1-loop corrections
- updated values of $S$, $P$ amplitudes and baryon-meson coupling
- funded by NAWA "Preludium Bis 1" grant no. PPN/STA/2021/1/00011/U/00001
- 6-month fellowship in Uppsala University, Sweden
- joint, ongoing collaboration Warsaw - Uppsala - Valencia



Thank you for the attention!