Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK

Strange baryon highlights from BESIII

Nora Salone
BP3

Annual seminar of the Department of Fundamental Research

5^{th} December 2024

BESIII

The BESIII collaboration

Europe (18)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin,

Netherlands(1): KVI/University of Groningen

Russia(2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(3): University of Manchester, University of Oxford, University of Bristol

Poland(1): National Centre for Nuclear Research

Pakistan(2)

COMSATS Institute of Information Technology

University of the Punjab

India(1)

Indian Institute of Technology madras

China (54)

Beihang University, Central China Normal University, Central South University, China Center of Advanced Science and Technology, China University of Geosciences, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Hebei University, Henan University, Henan Normal University, Henan University of Science and Technology, Henan University of Technology, Huangshan College, Hunan University, Hunan Normal University, Inner Mongolia University, Institute of High Energy Physics, Institute of Modern Physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University,Peking University, Qufu Normal University, Renmin University of China, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, handong University of Technology,Shanghai Jiao Tong University, Soochow University,South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Yantai University , Yunnan University , Zhejiang University, Zhengzhou University

Mongolia(1)

Institute of Physics and Technology

Korea(1)

Chung-Ang University

Thailand(1)

Suranaree University of Technology

USA(3)

Carnegie Mellon University

Indiana University

University of Hawaii

Chile(1)

University of Tarapaca

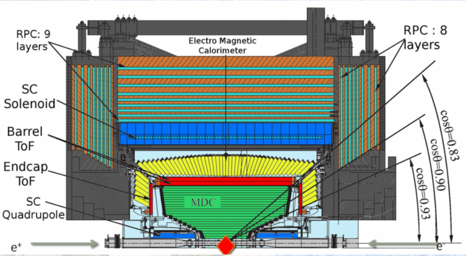
>600 members

From 82 institutions in 16 countries

From BESIII website

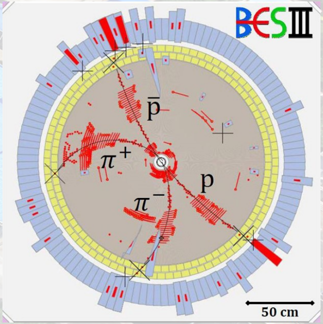
BESIII @ BEPCII

- Beijing **Electron-Positron** Collider (BEPCII)
  - e^+e^- collider: 1.85 GeV $< E_{CMS} <$ 4.95 GeV
  - $L_{peak} = 10^{33}$ cm^{-2} s^{-1}
  - Data taking since 2009



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

- Beijing **Spectrometer** (BESIII)
  - Covering 93% of 4π 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)



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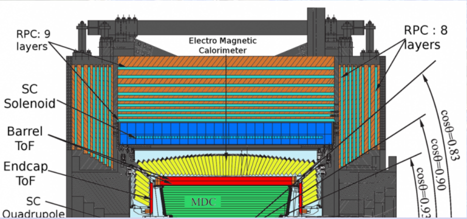

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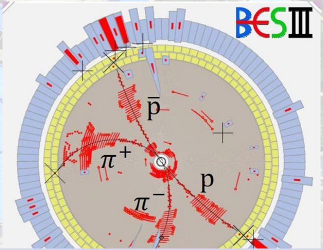


Scope

High-precision studies of hadron and τ-charm physics
100+ papers only in 2024 (inspireHEP)

Upgrade

June'24 – Jan '25: new colliding energy
$E_{CMS} \sim 4 - 5$ GeV: charm baryon production

Our group

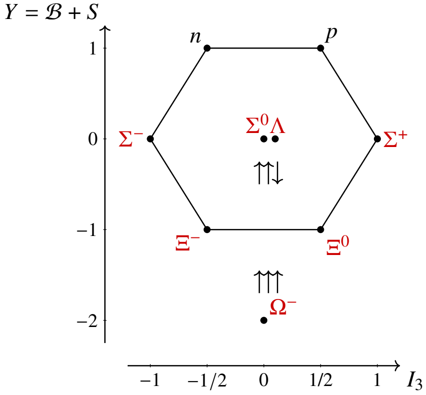
- Joined BESIII collaboration in **July 2021**
- Members:
  - prof. dr. hab. Andrzej Kupść (UU, NCBJ)
  - dr. Varvara Batozskaya (IHEP, NCBJ)
  - dr. Nora Salone (NCBJ)
  - dr. Marcin Berłowski (NCBJ)
- 2020-2024: NCN Preludium BIS PhD program No. 2019/35/O/ST2/02907
- Objectives of study: $Y\bar{Y}$ produced at e^+e^- colliders
  - CPV in nonleptonic s-baryon decays: Phys. Rev. D 105 (2022) 11, 116022
  - Baryon structure (s-baryon semileptonic decays): Phys. Rev. D 108 (2023) 1, 016011

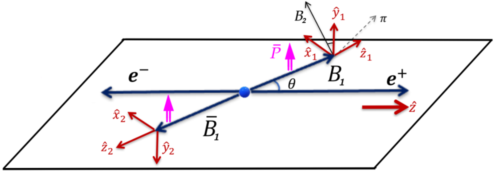
2024 BESIII highlights

1. $\Delta I = 1/2$ rule and CP symmetry in Λ decays
2. Extraction of hyperon structure function via HVP effects

Lowest-lying hyperons at BESIII

- World's largest charmonia sample – $10^{10} J/\psi,\ 3\times10^{9}\ \psi(2S)$
- Baryon-antibaryon pairs produced in **spin-entangled**, possibly **polarized** state.





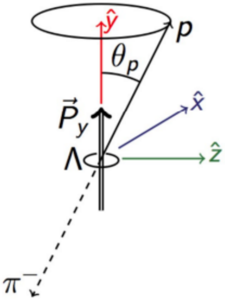
	Decay	$Br(\times10^{-4})$	$\epsilon(\%)$	$N_{obs}\times10^3$	Reference
J/ψ	$\Lambda\bar{\Lambda}$	19.43(33)	42.37(14)	441	PRD 95 (2017) 5, 052003
	$\Sigma^0\bar{\Sigma}^0$	11.64(23)	17.83(06)	111	″
	$\Sigma^+\bar{\Sigma}^-$	10.61(36)	24.1(7)	87	JHEP 11 (2021) 226
	$\Xi^0\bar{\Xi}^0$	11.65(43)	14.05(04)	135	PLB 770 (2017) 217-225
	$\Xi^-\bar{\Xi}^+$	10.40(74)	18.40(04)	43	PRD 93 (2016) 7, 072003
$\psi(2S)$	$\Lambda\bar{\Lambda}$	3.97(12)	42.83(34)	31	PRD 95 (2017) 5, 052003
	$\Sigma^0\bar{\Sigma}^0$	2.44(11)	14.79(12)	6.6	″
	$\Sigma^+\bar{\Sigma}^-$	2.52(10)	18.6(5)	5.4	JHEP 11 (2021) 226
	$\Sigma^-\bar{\Sigma}^+$	2.82(09)	5.26(5)	6.6	JHEP 12 (2022) 016
	$\Xi^0\bar{\Xi}^0$	2.73(13)	14.10(04)	11	PLB 770 (2017) 217-225
	$\Xi^-\bar{\Xi}^+$	2.78(15)	18.04(04)	5.3	PRD 95 (2017) 5, 052003
	$\Omega^-\bar{\Omega}^+$	0.585(28)	15.39(32)	4	PRL 126 (2021) 9, 092002

Nonleptonic decay parameters

From partial waves to observables:

- $B(1/2) \to b(1/2)\,\pi(0)$

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



$\Lambda \to p\pi^-$ decay

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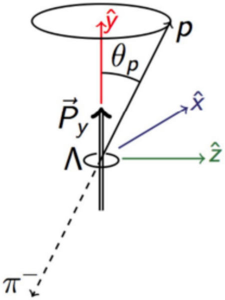
- Angular distribution
$\frac{d\Gamma}{d\Omega} \propto 1 + \alpha\,\mathbf{P}_\Lambda \cdot \hat{\mathbf{n}}$

$$\alpha = \frac{2\Re(S^*P)}{|S|^2 + |P|^2}$$

- Spin $\mathbf{s}_\Lambda \to \mathbf{s}_p$ rotation

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

measurable with $\mathbf{P}_\Lambda$, $\mathbf{P}_p$.



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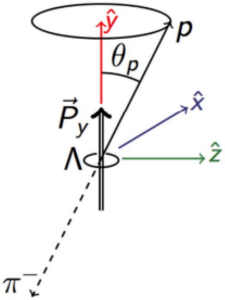

$\Lambda \to p\pi^-$ decay

CP tests [P. Adlarson, A. Kupść, PRD 100 (2019) 114005]

$$A_{\mathrm{CP}} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}, \quad B_{\mathrm{CP}} := \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}}, \quad \Phi_{\mathrm{CP}} = \frac{\phi + \bar{\phi}}{2}$$

CPV in hyperon decays

CPV signal in Y

- From interference of S- and P-waves
- $(\Delta I = 3/2)/(\Delta I = 1/2) \approx 5\%$

[NS, A. Kupść, V. Batozskaya et al., PRD 105, 116022 (2022)]

S, P amplitudes expanded up to $\mathcal{O}(\Delta I = 3/2)$:

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

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

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BESIII'22 [Nature 606, 64–69 (2022)]:

- first measurement of CP-odd phase difference

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

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BESIII'24 [PRL 132, 101801 (2024)]:

CP observables	
$\xi_P - \xi_S$	$(0.7 \pm 2.0^{+1.8}_{-0.5}) \times 10^{-2}$ rad
Φ_{CP}	$-0.003 \pm 0.008^{+0.003}_{-0.007}$ rad
A_{CP}^{Ξ}	$-0.009 \pm 0.008^{+0.007}_{-0.002}$
$A_{\mathrm{CP}}^{\Lambda}$	$-0.004 \pm 0.007^{+0.003}_{-0.004}$

CPV in hyperon decays

[NS, A. Kupść, V. Batozskaya et al., PRD 105, 116022 (2022)]

S, P amplitudes expanded up to $\mathcal{O}(\Delta I = 3/2)$:

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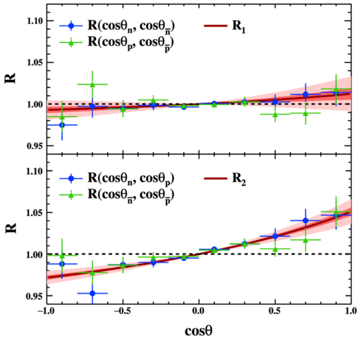
CPV signal in *Y*

- From interference of S- and P-waves
- $(\Delta I = 3/2)/(\Delta I = 1/2) \approx 5\%$

BESIII'24 [PRL 132, 101801 (2024)]:

	Our calculations '22	BESIII results '24
S_1/S_3	34.5 ± 7.1	$28.4 \pm 1.3^{+1.1}_{-1.0} \pm 3.9$
P_1/P_3	-20 ± 4	$-13.0 \pm 1.4^{+1.1}_{-1.2} \pm 0.7$

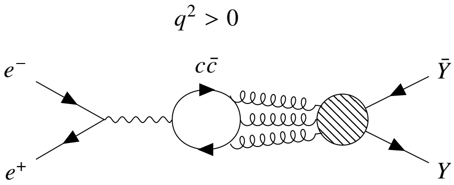


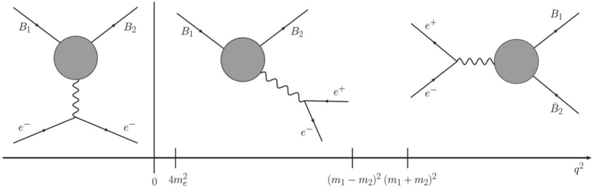
CP conservation, $\Delta I \nRightarrow 3/2$

$\alpha_{\Lambda-} = \alpha_{\Lambda 0} \Rightarrow R(n,\bar{n}) = R(p,\bar{p}) = 1$, $R(n,p) = R(\bar{n},\bar{p}) = 1$

Baryon polarization

- Annihilation process: time-like $q^2 > M_Y^2$, i.e. **complex form-factors**.
- Sachs **form-factors** $G^{\psi}_{E,M}$ parametrize charge/magnetization distributions.





[E. Perotti, PhD thesis, Uppsala Universitet]

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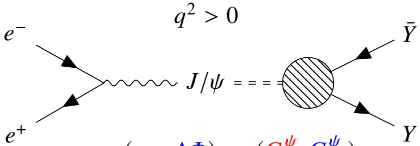
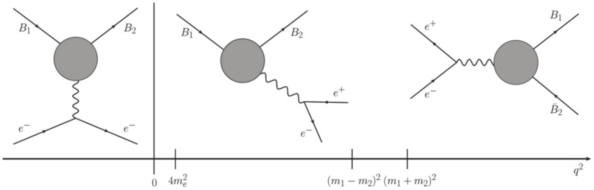


$$(\alpha_{\psi}, \Delta\Phi) \leftrightarrow (G^{\psi}_{E}, G^{\psi}_{M})$$

$$R = \left|\frac{G^{\psi}_{E}}{G^{\psi}_{M}}\right| \quad \Delta\Phi = \arg\left(\frac{G^{\psi}_{E}}{G^{\psi}_{M}}\right)$$



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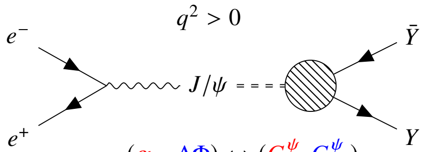
- Annihilation process: time-like $q^2 > M_Y^2$, i.e. **complex form-factors**.
- Sachs **form-factors** $G^{\psi}_{E,M}$ parametrize charge/magnetization distributions.
- Produced $B\bar{B}$ in $e^+e^- \to \gamma^*$ reaction can be **polarized**.



$(\alpha_\psi, \Delta\Phi) \leftrightarrow (G_E^\psi, G_M^\psi)$

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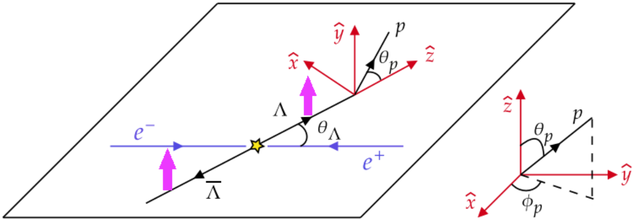
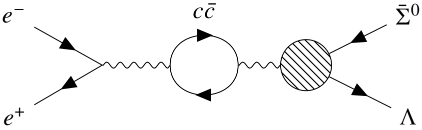


$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$ process [BESIII, PRL 129 (2022) 131801]

$$\mathbf{P}_\Lambda = \sqrt{1 - \alpha_\psi{}^2}\,\frac{\sin(\Delta\Phi)\cos\theta_\Lambda \sin\theta_\Lambda}{1 + \alpha_\psi \cos^2\theta_\Lambda}\hat{\mathbf{y}}$$

Hyperon structure

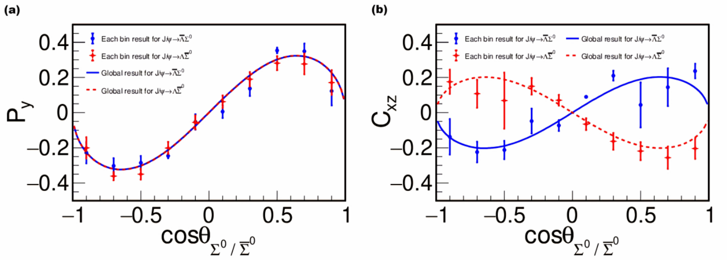
HVP-enchanced process



- Direct access to EM transition FF instead of $G^{\psi}_{E,M}$.
- Gather data in the high-energy time-like region.
- CP symmetry test:

$$\Delta\Phi_{\rm CP} = |\pi - (\Delta\Phi_{\bar{\Lambda}\Sigma^0} + \Delta\Phi_{\Lambda\bar{\Sigma}^0})|$$

R	$0.860 \pm 0.029 \pm 0.015$
$\Delta\Phi_{\bar{\Lambda}\Sigma^0}$	$(1.011 \pm 0.094 \pm 0.010)$ rad
$\Delta\Phi_{\Lambda\bar{\Sigma}^0}$	$(2.128 \pm 0.094 \pm 0.010)$ rad



[Nature Commun. 15 (2024) 1, 8812]

Thank you for the attention!