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National Centre for Nuclear Research
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Phenomenology of hyperon non-leptonic decays

Nora Salone

National Centre for Nuclear Research

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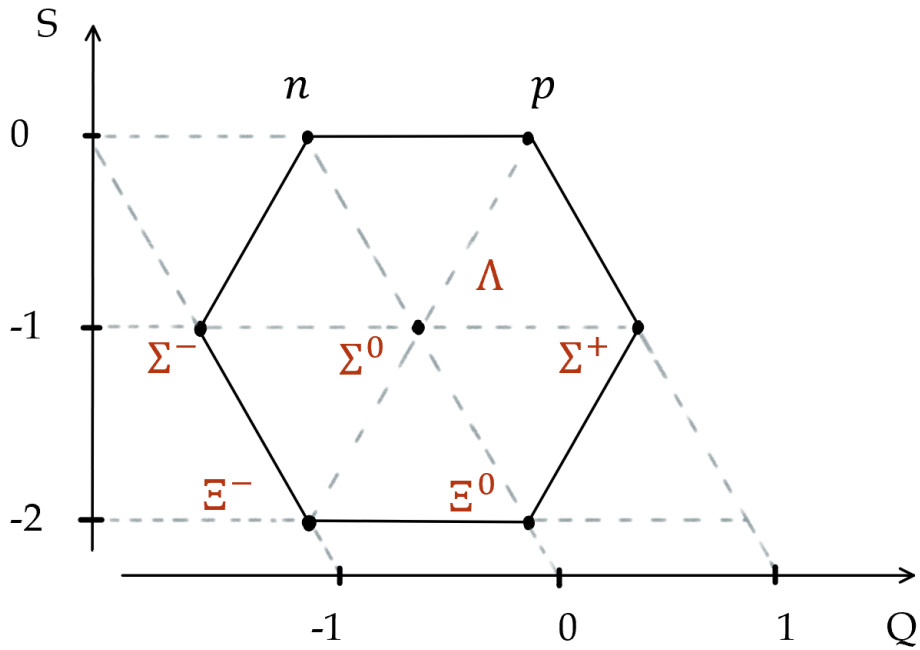
- $\Delta S = 1$ transitions of lowest-lying *s*-baryons



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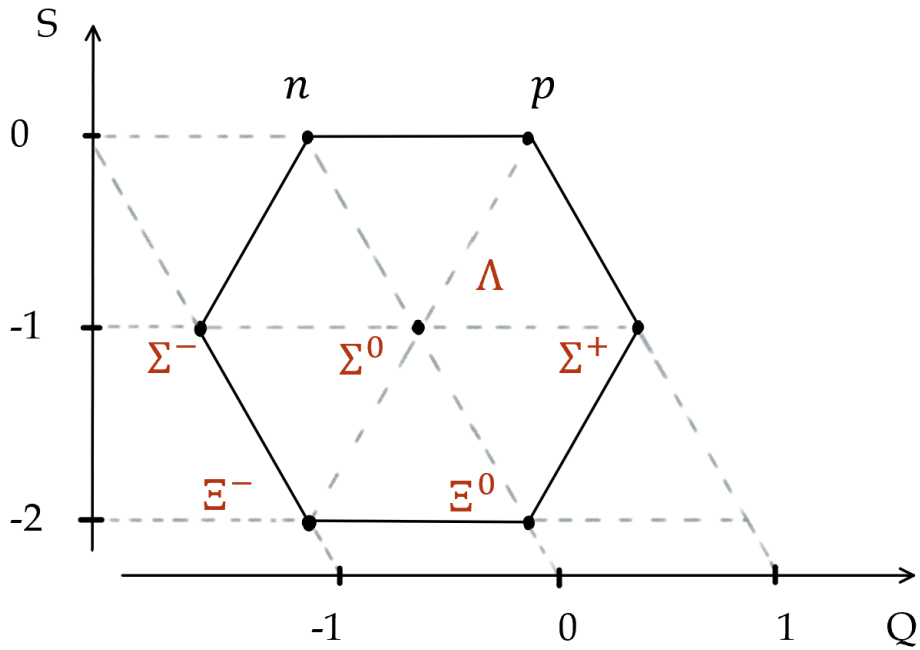

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- $Y\bar{Y}$ spin-entangled pairs produced at e^+e^- collider: feasibility studies.

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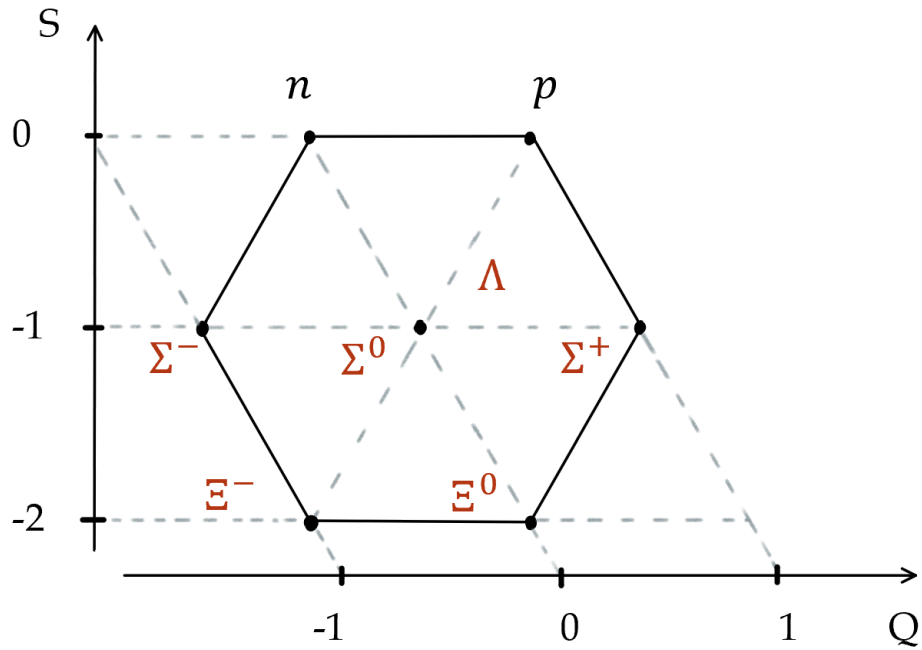

Focus on:

- $Y\bar{Y}$ spin-entangled pairs produced at e^+e^- collider: feasibility studies.
- Y decays theoretical description in χPT.

Hyperon decay formalism

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

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

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CP-odd and final state interaction phases

[Donoghue et al.(1986)]

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

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Two measurable parameters

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

Two CP violation tests

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

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

Two CP violation tests

$$A_{CP} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}$$
$$\Phi_{CP} = \frac{\phi + \bar{\phi}}{2}$$

Motivation: new data landscape

nature physics

LETTERS

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

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

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Article | Open Access | Published: 01 June 2022

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

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Nature **606**, 64–69 (2022) | Cite this article
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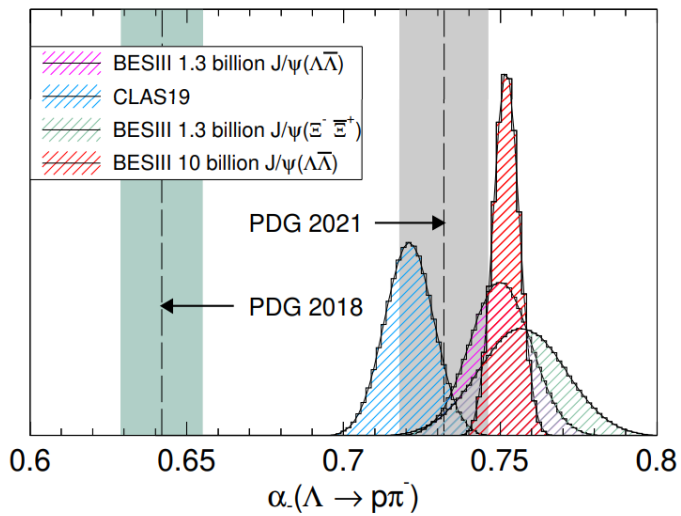
Precise Measurements of Decay Parameters and CP Asymmetry with Entangled Λ–$\bar{\Lambda}$ Pairs

M. Ablikim *et al.* (BESIII Collaboration)
Phys. Rev. Lett. **129**, 131801 – Published 22 September 2022

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



CPV in hyperon decays

$$S, P = f(\xi_{S,P}, \delta_{S,P}) \quad \Longrightarrow \quad \begin{cases} \alpha \propto \Re(S^* P) \\ \sin\phi \propto \Im(S^* P) \end{cases}$$

S, P amplitudes expanded up to LO $\Delta I = 1/2$ linear corrections

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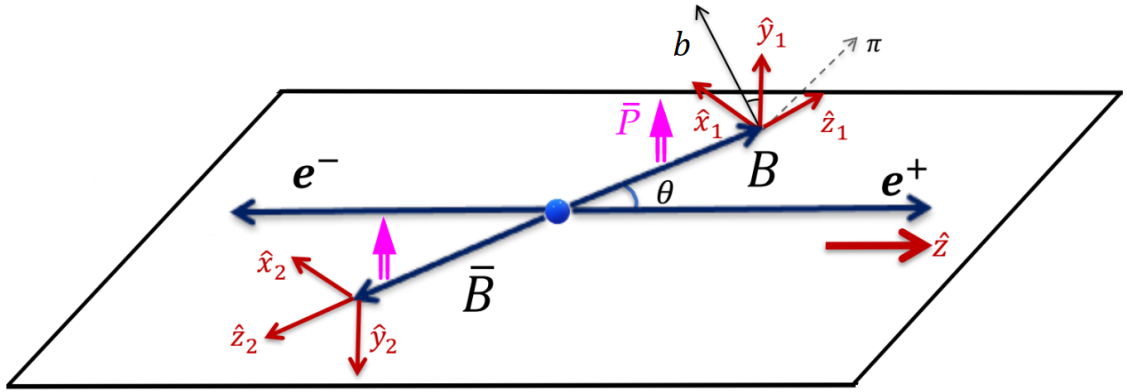
- first measurement of CP-odd phase difference

[BESIII collab. (2022)] : $\xi_P - \xi_S = (1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad

SM : $\xi_P - \xi_S = (-2.1 \pm 1.7) \times 10^{-4}$ rad

Lowest-lying hyperons @ BESIII

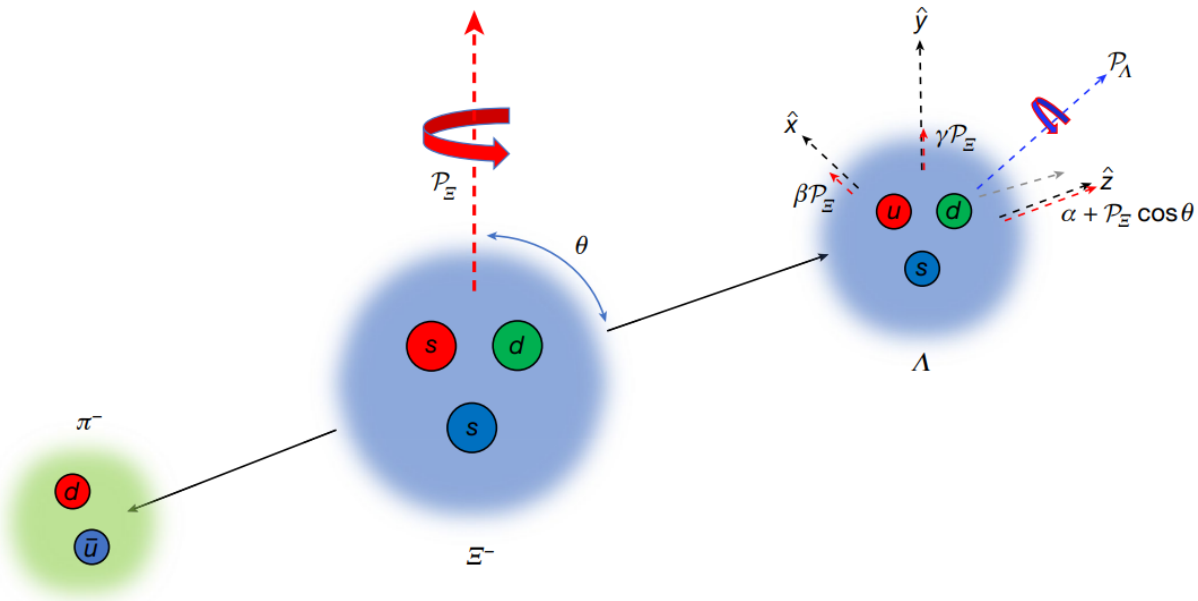
- World's largest charmonia sample in BESIII - 10^{10} J/ψ, 3×10^9 $\psi(2S)$
- Baryon-antibaryon production in spin-entangled state



[V. Batozskaya, BEACH22]

Decay	$\mathcal{B}(\times 10^{-4})$	α_ψ	$\Delta\Phi$ (rad)	BESIII collaboration
$J/\psi \to \Lambda\bar{\Lambda}$	19.43(3)	0.461(9)	0.740(13)	[2019, 2017a]
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	15.0(24)	−0.508(7)	−0.270(15)	[2008, 2020]
$J/\psi \to \Sigma^-\bar{\Sigma}^+$	..	..	..	ongoing analysis
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	11.64(4)	−0.449(20)	..	[2017a]
$J/\psi \to \Xi^0\bar{\Xi}^0$	11.65(43)	0.66(6)	..	[2017b]
$J/\psi \to \Xi^-\bar{\Xi}^+$	9.7(8)	0.586(16)	1.213(48)	[2020, 2022]

Baryon polarization @ BESIII



$\vec{\mathbf{P}}_B$ polarization:

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

Final b angular distribution:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\Omega} \propto 1 + \alpha_B \vec{\mathbf{P}}_B \cdot \hat{\mathbf{n}}$$

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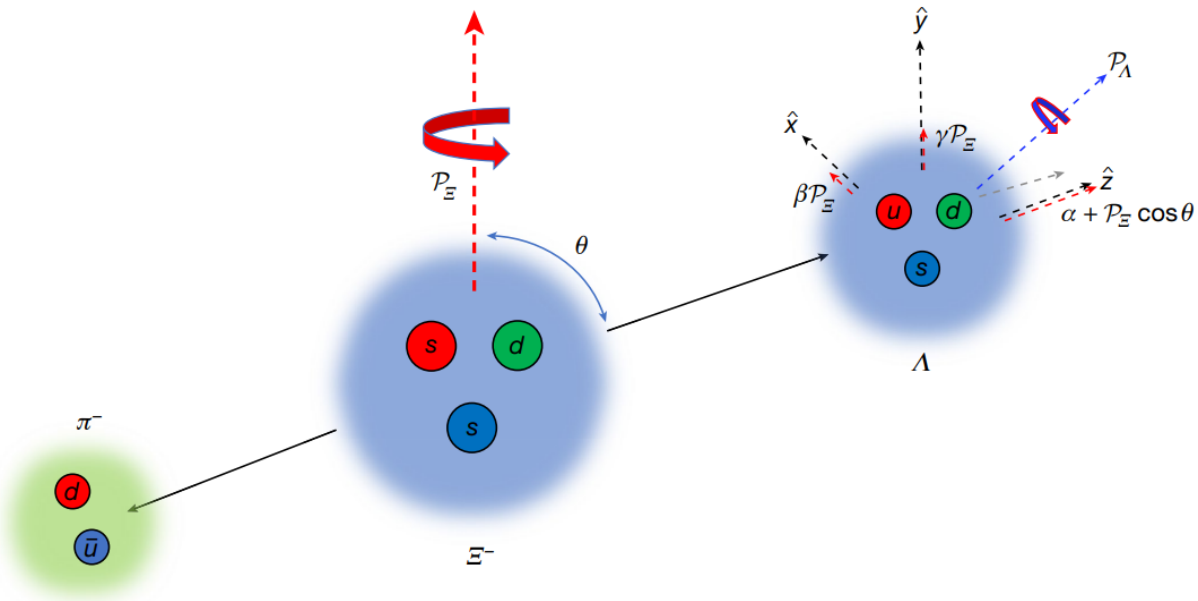

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Joint $B\bar{B}$ density matrix [Perotti et al. (2019)]:

$$\rho_{B\bar{B}} = \sum_{\mu,\nu=0}^{3} C_{\mu\nu}\sigma_\mu^B \otimes \sigma_\nu^{\bar{B}}$$

Baryon polarization with polarized beam

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

Nora Salone, Patrik Adlarson, Varvara Batozskaya, Andrzej Kupsc, Stefa
Phys. Rev. D **105**, 116022 – Published 27 June 2022

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

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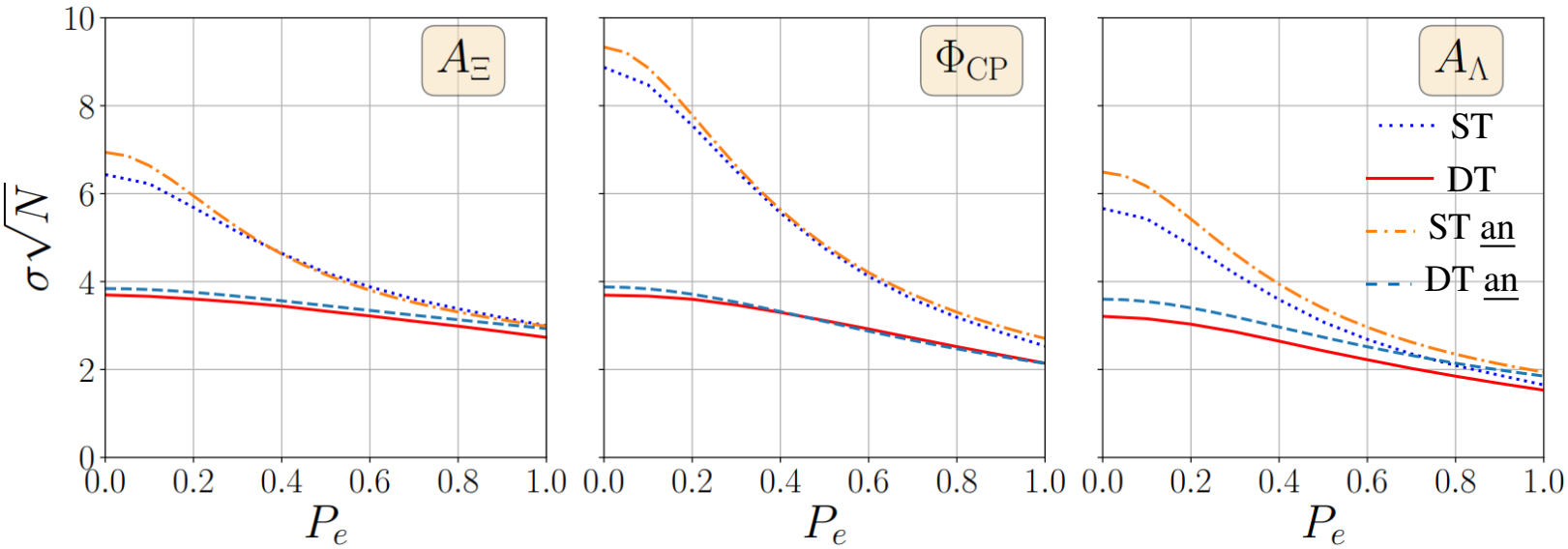
Baryon polarization with polarized beam

CP tests uncertainties, P_e-dependent:



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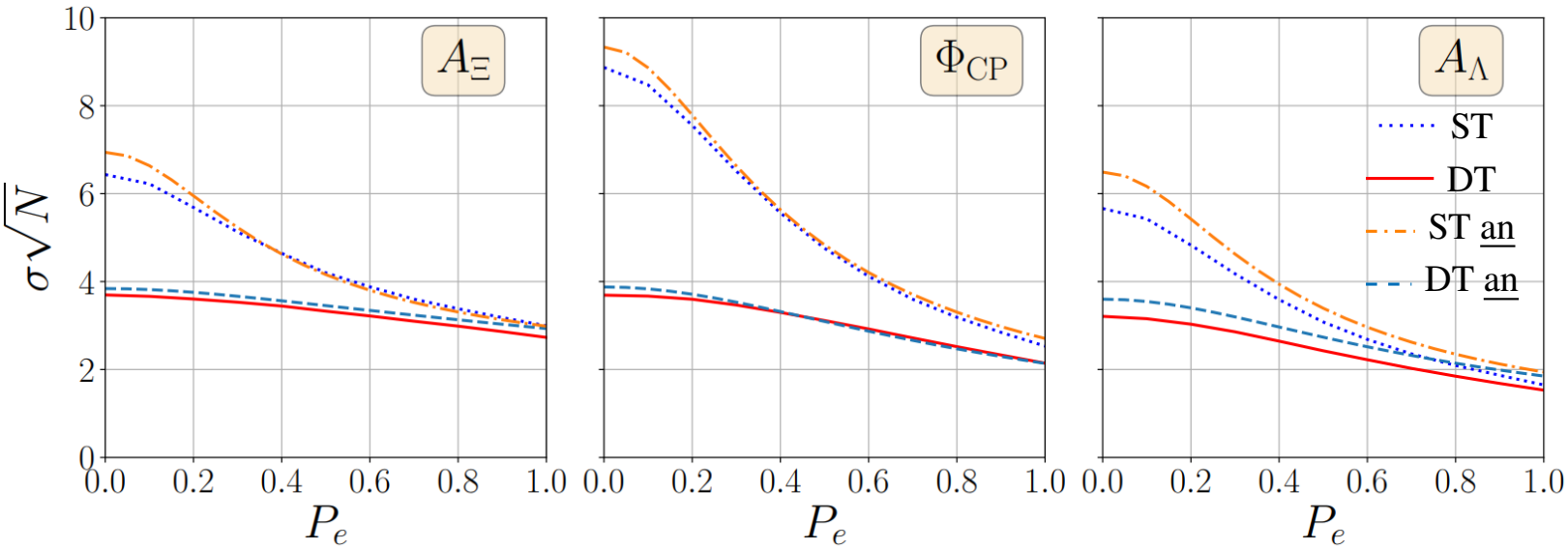

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Beam polarization: a useful tool on the road to reach SM CPV uncertainties!

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

- **Focus on** $\Delta S = 1$, $B \to b\pi$ decays in χPT up to 1-loop corrections

[1] NAWA grant no. PPN/STA/2021/1/00011/U/00001

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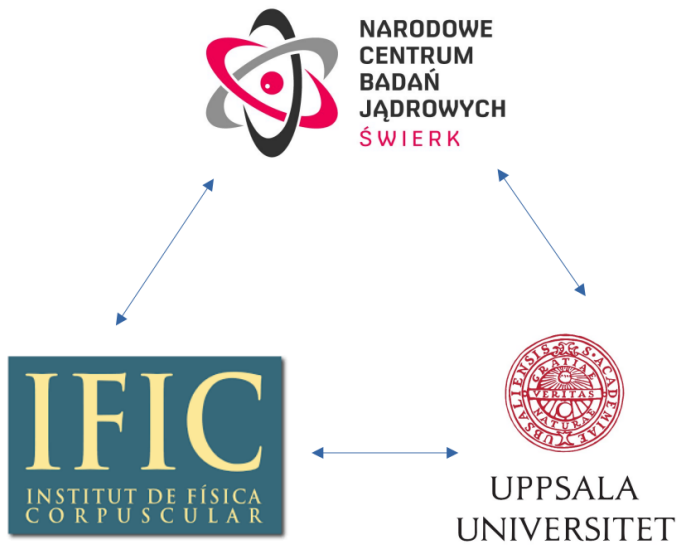
- joint, ongoing collaboration Warsaw - Uppsala - Valencia



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Starting point

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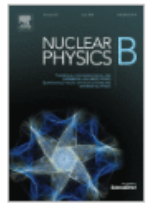
Nuclear Physics B

Volume 375, Issue 3, 25 May 1992, Pages 561-581



Hyperon non-leptonic decays in chiral perturbation theory

Elizabeth Jenkins

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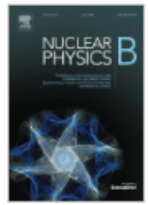

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Hyperon nonleptonic decays in chiral perturbation theory reexamined

A. Abd El-Hady and Jusak Tandean

Phys. Rev. D **61**, 114014 – Published 9 May 2000

Non-leptonic hyperon decays in chiral perturbation theory

B. Borasoy & Barry R. Holstein

The European Physical Journal C - Particles and Fields **6**, 85–107 (1999)

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How do new data + relativistic approach affect S, P-wave description?

Preliminary results

Decay	S	S_{old}	P	P_{old}
$\Sigma^+ \to n\pi^+$	0.06(1)	0.06(1)	1.81(1)	1.81(1)
$\Sigma^+ \to p\pi^0$	−1.38(2)	−1.43(5)	1.24(3)	1.17(7)
$\Sigma^- \to n\pi^-$	1.88(1)	1.88(1)	−0.06(1)	−0.06(1)
$\Lambda \to p\pi^-$	1.38(1)	1.42(1)	0.63(1)	0.52(2)
$\Lambda \to n\pi^0$	−1.03(1)	−1.04(1)	−0.41(1)	−0.39(4)
$\Xi^- \to \Lambda\pi^-$	−1.99(1)	−1.98(1)	0.39(1)	0.48(2)
$\Xi^0 \to \Lambda\pi^0$	1.51(1)	1.52(2)	0.27(1)	0.33(2)

Table: Comparison between amplitude values [Jenkins(1992)].

Conclusions and outlook

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Thank you for the attention!