Some concerns on CPV measurements in $J/\psi \to \Lambda\bar{\Lambda}$

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Introduction

- BESIII modified the decay parameter of Λ and improve the precision of CP asymmetry

$$\alpha_-^{PDG} = 0.642 \pm 0.013 \Rightarrow 0.750 \pm 0.009 \pm 0.004$$

$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = 0.006 \pm 0.012 \pm 0.007$$

- We believe there is still something wrong with this measurement!

Outline

- The sources of CPV
- Methods for CPV measurement
- Challenge and Opportunity

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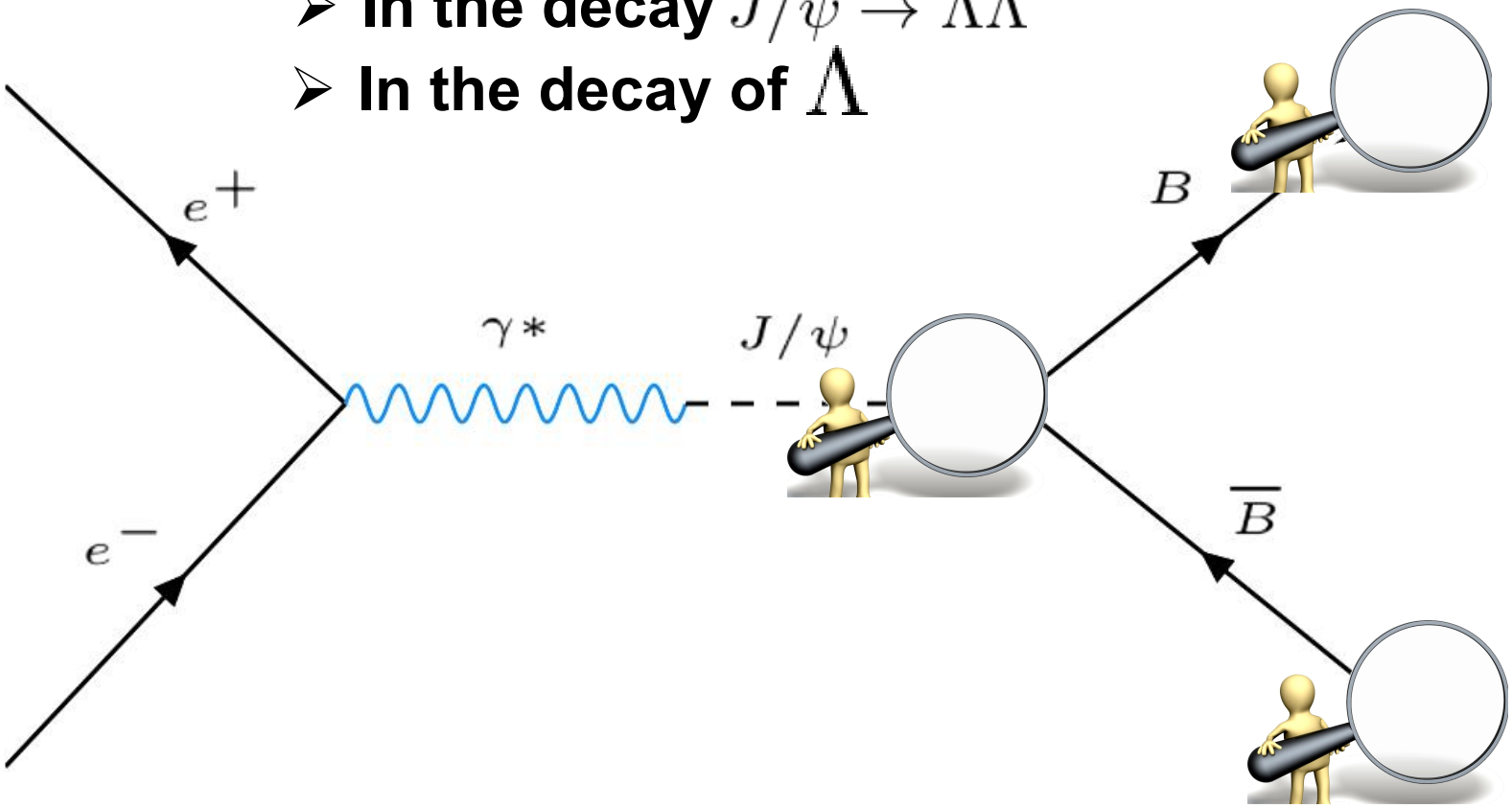
Where is the CPV?

- In the decay $J/\psi \to \Lambda\bar{\Lambda}$
- In the decay of Λ



Where is the CPV?

-In the decay of J/ψ (type I-A)

The amplitude is

$$M = j_\mu K_\mu$$

with haronic current

$$K_\mu = \bar{u}(p_1)\left[F_1\gamma_\mu - \frac{F_2}{4M}(\gamma_\mu.\not{Q} - \not{Q}.\gamma_\mu) + (p_{1\mu} - p_{2\mu})\eta\frac{G_M}{p_B}\gamma_5\right]\nu(p_2)$$

The red term violates CP, caused by electric dipole moment, CP violating Z-Λ coupling etc. [Phys.Rev.D 47 (1993)]

$$L_{c-\Lambda} = -\frac{2}{3}\frac{g_V}{M^2}ed_\Lambda(p_1^\mu - p_2^\mu)\bar{c}\gamma_\mu c\bar{\Lambda}i\gamma_5 \quad \eta = i\frac{2}{3}\frac{p_B}{G_M}\frac{g_V}{M^2}ed_\Lambda$$

Where is the CPV?

-In the decay of Λ (type I-B)

The decay parameters

$$\Gamma_\Lambda \propto 1-\alpha_-\vec{s}_\Lambda.\vec{p}_\pi \qquad \Gamma_{\bar{\Lambda}} \propto 1-\alpha_+\vec{s}_{\bar{\Lambda}}.\vec{p}_\pi$$

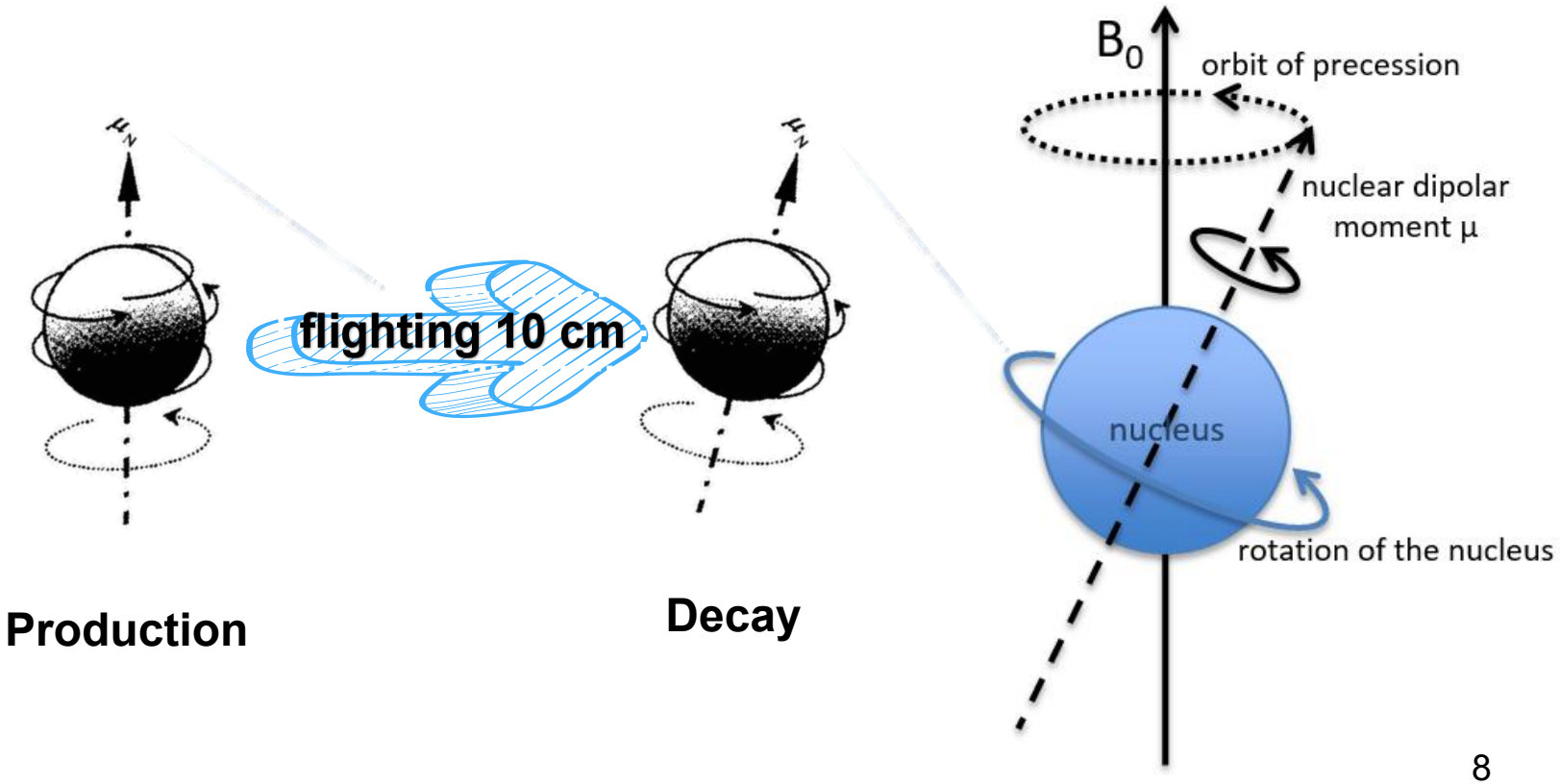
Defination of Acp

$$A_{CP}=\frac{\alpha_-+\alpha_+}{\alpha_--\alpha_+} \qquad \Delta=\frac{\Gamma_\Lambda-\Gamma_{\bar{\Lambda}}}{\Gamma_\Lambda+\Gamma_{\bar{\Lambda}}} \qquad A=\frac{\Gamma_\Lambda\alpha_- -\Gamma_{\bar{\Lambda}}\alpha_+}{\Gamma_\Lambda\alpha_- +\Gamma_{\bar{\Lambda}}\alpha_-}$$

The Acp is 4×10^{-5} in SM [Phys. Rev. D 34, 833 (1986), Phys. Rev. D 67, 056001 (2003)]

Where is the CPV?

-experiment bias (type II)



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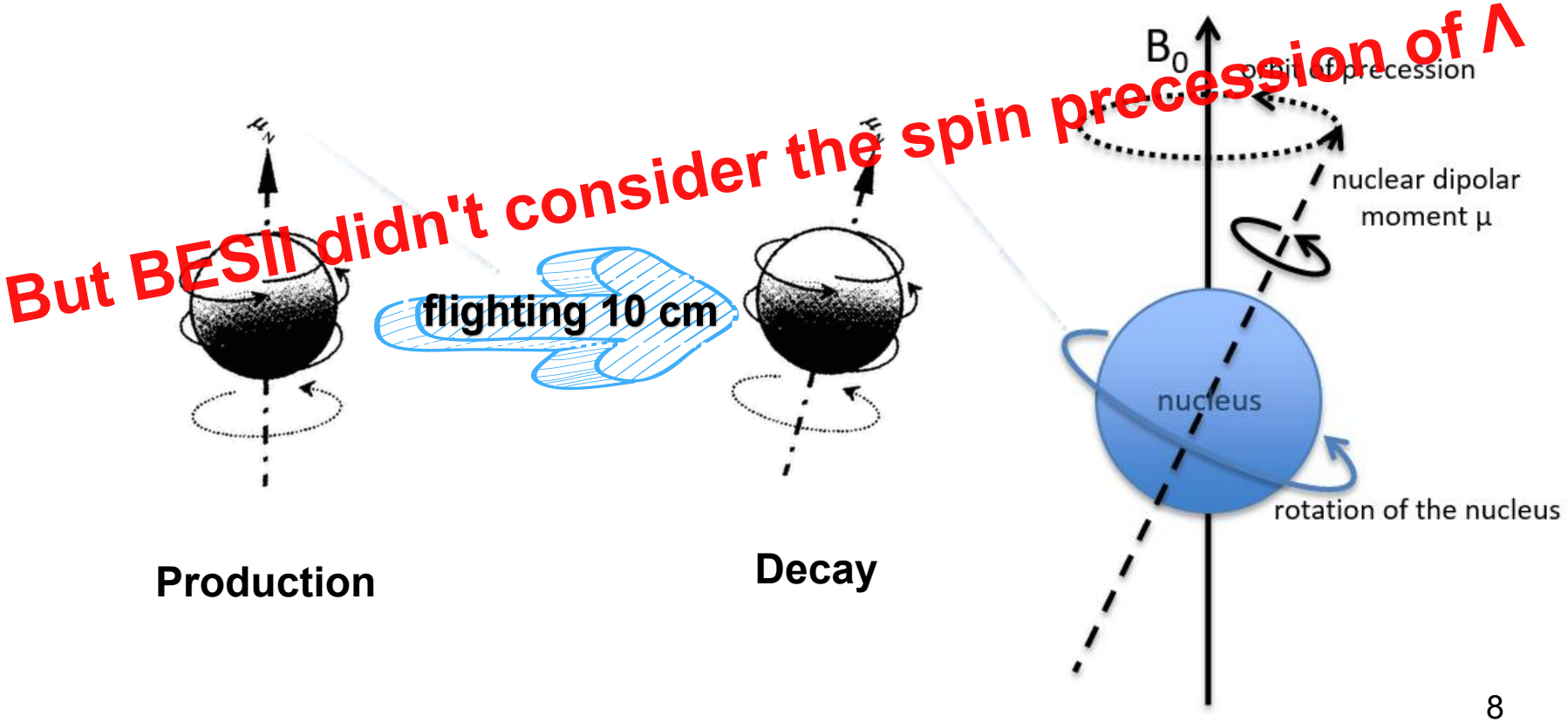

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arXiv:1907.01151 [hep-ph]

Spin precession

The change of spin direction

$$\begin{pmatrix} \hat{s}_1'^x \\ \hat{s}_1'^y \\ \hat{s}_1'^z \end{pmatrix} = \begin{pmatrix} 1 & -\omega t \hat{B}'_z & \omega t \hat{B}'_y \\ \omega t \hat{B}'_z & 1 & -\omega t \hat{B}'_x \\ -\omega t \hat{B}'_y & \omega t \hat{B}'_x & 1 \end{pmatrix} \begin{pmatrix} \hat{s}_1^x \\ \hat{s}_1^y \\ \hat{s}_1^z \end{pmatrix}$$

$$\omega = -\frac{2\mu_\Lambda B}{\hbar}$$

precession angle is about 0.017 rad

- B=1.0T
- $s_1$is the spin direction of Λ
- t = 2×10^{-10}s
- $\mu_\Lambda = -0.613 \pm 0.04\mu_N$

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Spin precession(2)

The cross-section for the production of $\Lambda\overline{\Lambda}$

NuovoCim. A109, 241 (1996)
Nucl. Phys. A771, 169 (2006) [hep-ph/0511240]
Phys. Rev. D75, 074026(2007) [hep-ph/0702122]

$$\frac{d\sigma}{d\cos\theta} \sim 1 + \alpha_\psi \cos^2\theta + \sin^2\theta \hat{s}_1^x \hat{s}_2^x + \alpha_\psi \sin^2\theta \hat{s}_1^y \hat{s}_2^y - \left(\alpha_\psi + \cos^2\theta\right) \hat{s}_1^z \hat{s}_2^z + \sqrt{1-\alpha_\psi^2} \cos\Phi \sin\theta \cos\theta \left(\hat{s}_1^x \hat{s}_2^z - \hat{s}_1^z \hat{s}_2^x\right) + \sqrt{1-\alpha_\psi^2} \sin\Phi \sin\theta \cos\theta (\hat{s}_1^y - \hat{s}_2^y),$$

- θ is the angle between Λ and e+
- α_ψ decay parameter of J/ψ
- $\Phi = \mathrm{Arg}[G_E/G_M]$

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Spin precession(3)

Conside the spin precession

$$\frac{d\sigma}{d\cos\theta d\Omega_1 d\Omega_2} \sim 1 + \alpha_\psi\alpha_-\alpha_+\cos^2\theta n_p^x n_{\bar{p}}^x + \alpha_\psi\alpha_-\alpha_+\sin^2\theta n_p^y n_{\bar{p}}^y - \alpha_-\alpha_+\left(\alpha_\psi+\cos^2\theta\right)n_p^z n_{\bar{p}}^z$$
$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos\Phi\sin\theta\cos\theta\left(n_p^x n_{\bar{p}}^z - n_p^z n_{\bar{p}}^x\right) + \sqrt{1-\alpha_\psi^2}\sin\Phi\sin\theta\cos\theta(\alpha_- n_p^y - \alpha_+ n_{\bar{p}}^y)$$
$$+\omega t\alpha_-\alpha_+\sin^2\theta\left(\hat{B}'_z\left(\hat{n}_{\bar{p}}^x\hat{n}_p^y - \hat{n}_p^x\hat{n}_{\bar{p}}^y\right) - \hat{B}'_y\left(\hat{n}_p^x\hat{n}_{\bar{p}}^z + \hat{n}_{\bar{p}}^x\hat{n}_p^z\right)\right)$$
$$+\omega t\alpha_\psi\alpha_-\alpha_+\sin^2\theta\left(-\hat{B}'_z\hat{n}_p^x\hat{n}_{\bar{p}}^y + \hat{B}'_z\hat{n}_{\bar{p}}^x\hat{n}_p^y - \hat{B}'_x\hat{n}_p^y\hat{n}_{\bar{p}}^z + \hat{B}'_x\hat{n}_{\bar{p}}^y\hat{n}_p^z\right) - \omega t\alpha_-\alpha_+\left(\alpha_\psi+\cos^2\theta\right)\left(\hat{B}'_y\hat{n}_p^x\hat{n}_{\bar{p}}^z\right.$$
$$\left.-\hat{B}'_x\hat{n}_p^y\hat{n}_{\bar{p}}^z + \hat{B}'_y\hat{n}_{\bar{p}}^x\hat{n}_p^z + \hat{B}'_x\hat{n}_{\bar{p}}^y\hat{n}_p^z\right) + \omega t\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos\Phi\sin\theta\cos\theta\left(\hat{B}'_x\hat{n}_p^x\hat{n}_{\bar{p}}^y + \hat{B}'_x\hat{n}_{\bar{p}}^x\hat{n}_p^y + \hat{B}'_z\hat{n}_p^y\hat{n}_{\bar{p}}^z\right.$$
$$\left.+\hat{B}'_z\hat{n}_{\bar{p}}^y\hat{n}_p^z\right) + \omega t\sqrt{1-\alpha_\psi^2}\sin\Phi\sin\theta\cos\theta\left(-\alpha_-\hat{B}'_z\hat{n}_p^x + \alpha_-\hat{B}'_x\hat{n}_p^z - \alpha_+\hat{B}'_z\hat{n}_{\bar{p}}^x + \alpha_+\hat{B}'_x\hat{n}_{\bar{p}}^z\right),$$

- $n_{p,\bar{p}}$ is the direction of proton (anti-proton) in the rest frame of $\Lambda(\bar{\Lambda})$
- ω the precession frequence
- t the average lifetime of Λ

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Difference Methods

- Define CP-odd observable

$$A_{CP} = \frac{N_+ - N_-}{N_+ + N_-}$$

- Maximum Likelihood Fit to the over-all distribution
- Others

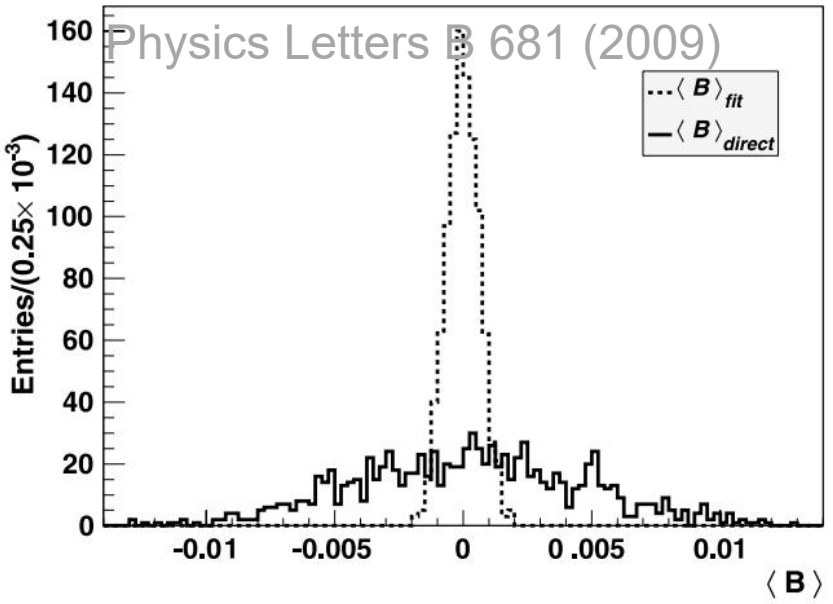
Difference Methods

- Define CP-odd observable Phys. Rev. D 49 (1994) 4548

$$B = \hat{\mathbf{P}} \cdot (\hat{\mathbf{q}}_1 \times \hat{\mathbf{q}}_2)$$

P is the direction of the momentum of Λ
and $q_{1,2}$ are the directions of the momenta of p and $\bar{p}$ in the rest frames of Λ and $\bar{\Lambda}$ respectively

The ML fit is better



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Spin precession(4)

We choose the ML fit

The probability distribution function is defined

$$\mathcal{P} = \frac{1}{N}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta \mathrm{d}\Omega_1 \mathrm{d}\Omega_2},$$

$$-\ln\mathcal{L} = -\sum_{i=1}^{n}\ln\mathcal{P}_i,$$

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Spin precession(5)

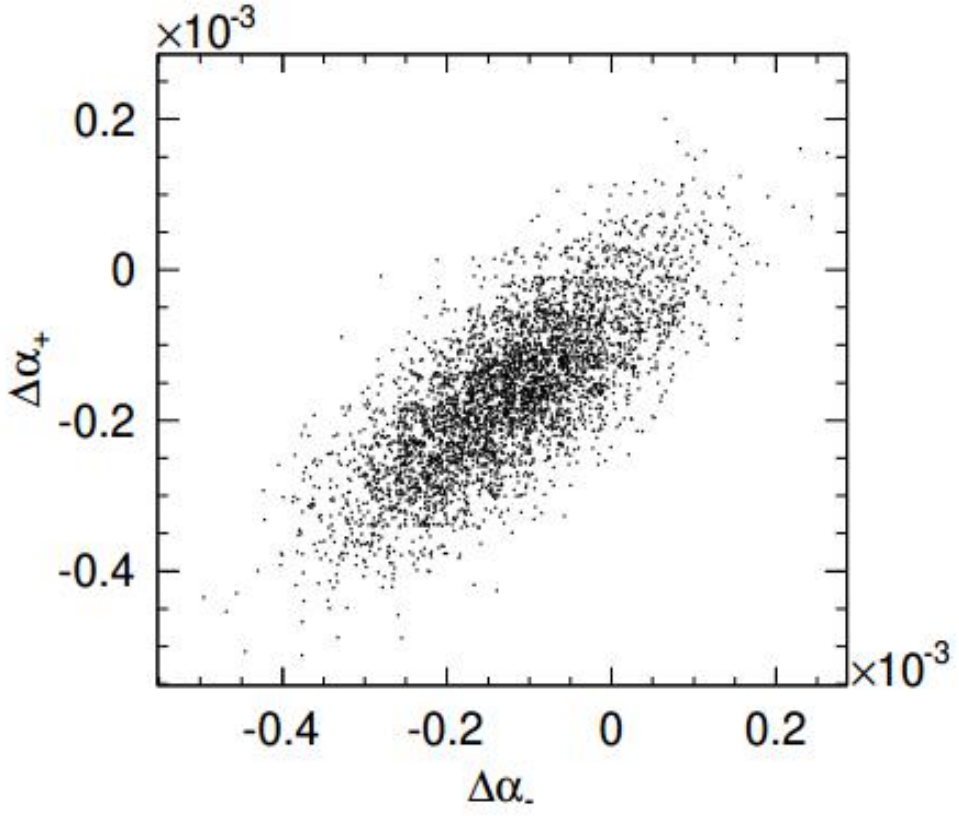
Toy MC: No CPV

$$\Delta\alpha_{\pm} = \alpha_{\pm}^{\mathrm{corr}} - \alpha_{\pm}^{\mathrm{exp}}$$

exp : PDF without spin precession
corr: PDF with spin precession

Additional "CP" asymmetry will be caused

$$A_{CP} = \frac{\Delta\alpha_{-} + \Delta\alpha_{+}}{\alpha_{-} - \alpha_{+}} = -2\times10^{-5}$$



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Opportunity and Challenge

- How well does SU(3) favor symmetry work ?

	p	Λ	Σ^+	Σ^0	Ξ^-
Branching fraction（10^{-3}）	2.121±0.029	1.89±0.09	1.50±0.24	1.172±0.032	0.97±0.08
$\alpha_{J/\psi}$	0.595±0.019	0.461±0.009	刮奖区	-0.449±0.020	刮奖区
Φ(°)	42.4±0.8	刮奖区	刮奖区	刮奖区	刮奖区

Opportunity and Challenge

- BEPCII have produced 10^{10} J/ψ sample
- The Super J/ψ factory will produce 1000 times data of BEPCII's
  - 400 000 ΛΛ̄ will be reconstructed by BESIII
  - About 400 000 000 ΛΛ̄ will be reconstructed by Super-Charm factor
  - A_{cp} could reach 10^{-4}~10^{-5}

Challenge

- Reduce Systemtic uncertainty (understudying)
- Enough CPU/GPU for ML fit (understudying)
- Any Potential effection that may bring bias

Summary

- We discuss the spin precession effect on the CP asymmetry measurement
- An additional CP asymmetry of order 10^{-5} will be caused

Thanks!

The A_{cp} v.s. B