CP ASYMMETRIES IN STRANGE BARYON DECAY

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AUTHORS' BRIEF INTRODUCTION

- Ikaros I. Bigi, Professor in Uni. of Notre Dame,

2004 Sakurai prize, *"For pioneering theoretical insights that pointed the way to the very fruitful experimental study of CP violation in B decays, and for continuing contributions to the fields of CP and heavy flavor physics."*

Hai-Bo Li, distinguished professor in IHEP, Beijing, Physics coordinator in BESIII collaboration.

STATUS AND MOTIVATION

- CP violation (CPV) in $K_L \to \pi^+\pi^-$ 1963, 1964
- Tiny *direct* CPV in $K_L \to \pi^+\pi^-$ vs. $K_L \to \pi^0\pi^0$ 1990, NA31/NA48 and KTeV experiments
- Particle Data Group 2016:

$$|\epsilon_K|_{\mathrm{exp.}} = (2.228 \pm 0.011) \cdot 10^{-3}\,,$$
$$\mathrm{Re}(\epsilon'/\epsilon_K)_{\mathrm{exp.}} = (1.66 \pm 0.23) \cdot 10^{-3}\,;$$

- Buras et al [*JHEP* 1511 (2015) 202] Standard Model: not produce the exp.data

$$\mathrm{Re}(\epsilon'/\epsilon_K)_{\text{“Buras”}} = (0.86 \pm 0.32) \cdot 10^{-3}\,.$$

- Lattice [N. Garron, *PoS CD* 15 (2016) 034, UKQCD]

$$\mathrm{Re}(\epsilon'/\epsilon_K)_{\mathrm{LQCD}} = (0.138 \pm 0.515 \pm 0.443) \cdot 10^{-3}.$$

These data consistent with SM, or some possible hints of New Dynamics

STATUS AND MOTIVATION

- CP violation (CPV) established in decays of strange & beauty meson, but none for baryons ---exception from very recently LHCb measurement on regional CPV [*Nature Physics* **13**, 391–396 (2017)]

  based on SM: [Donoghue, Xiao-Gang He, Pakvasa PRD1986]

$$A_{\mathrm{CP}}(\Lambda \to p\pi^-) \sim (0.05 - 1.2) \cdot 10^{-4}$$
$$A_{\mathrm{CP}}(\Xi^- \to \Lambda\pi^-) \sim (0.2 - 3.5) \cdot 10^{-4}$$

  combined [Tandeau and Valencia, PRD2003]

$$-0.5\cdot 10^{-4} \leq A_{\Lambda\Xi} \equiv \frac{\alpha_\Lambda\alpha_\Xi - \alpha_{\bar\Lambda}\alpha_{\bar\Xi}}{\alpha_\Lambda\alpha_\Xi + \alpha_{\bar\Lambda}\alpha_{\bar\Xi}} \leq 0.5\cdot 10^{-4}.$$

  HyperCP measurement [2004, 2009]:

$$A_{\Lambda\Xi} = (0.0 \pm 5.1 \pm 4.4) \cdot 10^{-4}$$

- Strange and charm baryon? We have proposed BESIII collaboration to measure $\Lambda_c^+ \to p\pi^+\pi^-\pi^0$ phase space bins and dihedral angle phi bins
- A new important era starts with BESIII data by the end of 2018, also trigger $J/\psi \to \Lambda\bar{\Lambda}$ studies in LHCb.
  - 1.3*10^9 Jpsi events has already been accumulated
  - 10^10 Jpsi events are planned by the end of 2018
- Next we will point out different paths to find CP asymmetries.

- The decays of strange baryon are mostly two-body final states

① Rescattering effects are sizable

$$\mathrm{BR}(\Lambda \to p\pi^-) = 0.639 \pm 0.005$$
$$\mathrm{BR}(\Lambda \to n\pi^0) = 0.358 \pm 0.005$$

② The impact of rescattering is not obvious when one does not employ spin

$$\mathrm{BR}(\Sigma^- \to n\pi^-) = (99.848 \pm 0.005) \times 10^{-2}$$

③ Source of strange baryons

$$\mathrm{BR}(J/\psi \to \bar{\Lambda}\Lambda) = (1.61 \pm 0.15) \cdot 10^{-3}$$
$$\mathrm{BR}(J/\psi \to \Lambda\bar{\Lambda}\pi^+\pi^-) = (4.3 \pm 1.0) \cdot 10^{-3}$$
$$\mathrm{BR}(J/\psi \to \bar{p}p) = (2.120 \pm 0.029) \cdot 10^{-3}$$
$$\mathrm{BR}(J/\psi \to \bar{p}p\pi^+\pi^-) = (6.0 \pm 0.5) \cdot 10^{-3}$$

④ CPT invariance tells us

$$A_{\mathrm{CP}}(\Lambda \to p\pi^-) \simeq -A_{\mathrm{CP}}(\Lambda \to n\pi^0)$$
$$A_{\mathrm{CP}}(\Sigma^+ \to p\pi^0) \simeq -A_{\mathrm{CP}}(\Sigma^+ \to n\pi^+).$$

first concentrate on $\Lambda \to p\pi^-$

For a two-body decay, event number is the only observable without spins included. [production asymmetries not problem for BES and ppbar collider, but do care for LHCb]

DECAY PARAMETER ASYMMETRY

- X,Y spin-1/2 baryon

$$J/\psi \to \bar{Y}Y \to [\bar{X}\bar{\pi}][X\pi]$$

$$\alpha_Y^{(X)} = \langle \vec{\sigma}_Y \cdot (\vec{\sigma}_X \times \vec{\pi}_X) \rangle \,,\ \alpha_{\bar{Y}}^{(\bar{X})} = \langle \vec{\sigma}_{\bar{Y}} \cdot (\vec{\sigma}_{\bar{X}} \times \vec{\pi}_{\bar{X}}) \rangle \,.$$

$$\langle A_{\mathrm{CP}}^{(X)} \rangle = \frac{\alpha_Y^{(X)} + \alpha_{\bar{Y}}^{(\bar{X})}}{\alpha_Y^{(X)} - \alpha_{\bar{Y}}^{(\bar{X})}}$$

- Jacob-Wick helicity formalism to make angular analysis, to extract decay parameter α

$$\alpha_{\bar{\Lambda}}^{(\bar{p})} = -0.755 \pm 0.083$$

$$\alpha_{\Lambda}^{(p)} = 0.642 \pm 0.013.$$

- Based on BES2010 data, 10% accuracy -->1% not trivial
- Now we are talking 0.1% sensitivity by the end of 2018
- Higgs boson, searching for 40 years
- *It is not trivial at all, but as usual, there is a price for the prize!*

T-ODD TRIPLE-PRODUCT TERM

$C_T = (\vec{p}_X \times \vec{p}_\pi) \cdot \vec{p}_{\bar{X}}$ $\quad$ $\bar{C}_T = (\vec{p}_{\bar{X}} \times \vec{p}_{\bar{\pi}}) \cdot \vec{p}_X$

$$\langle A_T \rangle = \frac{N(C_T > 0) - N(C_T < 0)}{N(C_T > 0) + N(C_T < 0)}$$

$$\langle \bar{A}_T \rangle = \frac{N(\bar{C}_T > 0) - N(\bar{C}_T < 0)}{N(\bar{C}_T > 0) + N(\bar{C}_T < 0)} .$$

N is the event number

Thus

$$\mathcal{A}_T = \frac{1}{2}\left[\langle A_T \rangle + \langle \bar{A}_T \rangle\right] = \langle A_T \rangle \neq 0$$

← CPV observable

$$\mathcal{A}_T(d) = \frac{N(C_T > |d|) - N(C_T < -|d|)}{N(C_T > |d|) + N(C_T < -|d|)}$$

← Second step

1. Fake CP asymmetry due to final state interaction
2. The charge conjugate of this channel is itself, defferent for $D^0(\bar{D}^0) \to K\bar{K}\pi\pi/4\pi.$

Here it is untagged sample!

SENSITIVITY STUDY

Channel	# of events	Sensitivity on $\mathcal{A}_T$
$J/\psi \to \Lambda\bar{\Lambda} \to [p\pi^-][\bar{p}\pi^+]$	2.6×10^6	0.06%
$J/\psi \to \Sigma^+\bar{\Sigma}^- \to [p\pi^0][\bar{p}\pi^0]$	2.5×10^6	0.06%
$J/\psi \to \Xi^0\bar{\Xi}^0 \to [\Lambda\pi^-][\bar{\Lambda}\pi^+]$	1.1×10^6	0.1%
$J/\psi \to \Xi^-\bar{\Xi}^+ \to [\Lambda\pi^0][\bar{\Lambda}\pi^0]$	1.6×10^6	0.08%

TABLE I. The numbers of reconstructed events after considering decay branching fractions, tracking, and particle identification. The sensitivity is estimated without considering possible background dilutions, which should be small at the BESIII experiment. Estimations are based on the 10^{10} J/ψ data which will be collected by the BESIII collaboration by the end of 2018 (and the branching fractions from PDG2016). Systematic uncertainties are expected to be of the same order as the statistical uncertainties shown in the table.

SUBTLETIES

- If there is polarized baryon source, $\Xi^0 \to \Lambda\pi \to (p\pi)\pi$, one may construct more observables from helicity amplitudes, angular analysis [Kang, Li, Lu, A.Datta 2011]
- Quark-hadron duality, in particle, close to thresholds

$J/\psi \to \bar{\Sigma}^-\Sigma^+ \to [\bar{p}\pi^0][p\pi^0]$, $\Delta(1232)\overline{\Delta}(1232)$ as backgrounds,

$M(\Sigma^+) \simeq 1189$ MeV $M(\Delta(1232)) \simeq 1232$ MeV width 117MeV,

BES backgounds small <= second vertex technique

- Another challenge $J/\psi \to \bar{\Xi}^+\Xi^- \to \bar{\Lambda}\pi^+\Lambda\pi^-$

CPV come from $\Xi \to \Lambda\pi$ or $\Lambda \to p\pi^-$ or their interference

"Accuracy" will improve a lot, also super tau-charm factory?

Thanks