Possible large *CP* violation in three-body decays of heavy baryon

arXiv:1507.04459

Zhen-Hua Zhang
zhangzh@usc.edu.cn

University of South China

HFCPV
Lanzhou
July 23, 2015

Outline

CPV in SM

Typical form of CP asymmetry in a decay process

$$A_{CP} \sim sin\phi sin\delta \tag{1}$$

- ϕ, weak phase in CKM matrix
- δ strong phase from strong interaction
  - perturbative, loop diagram of QCD (large scacle), QED,..., small
  - nonperturbative, QCD ($\sim \Lambda_{QCD}$), large

Motivation

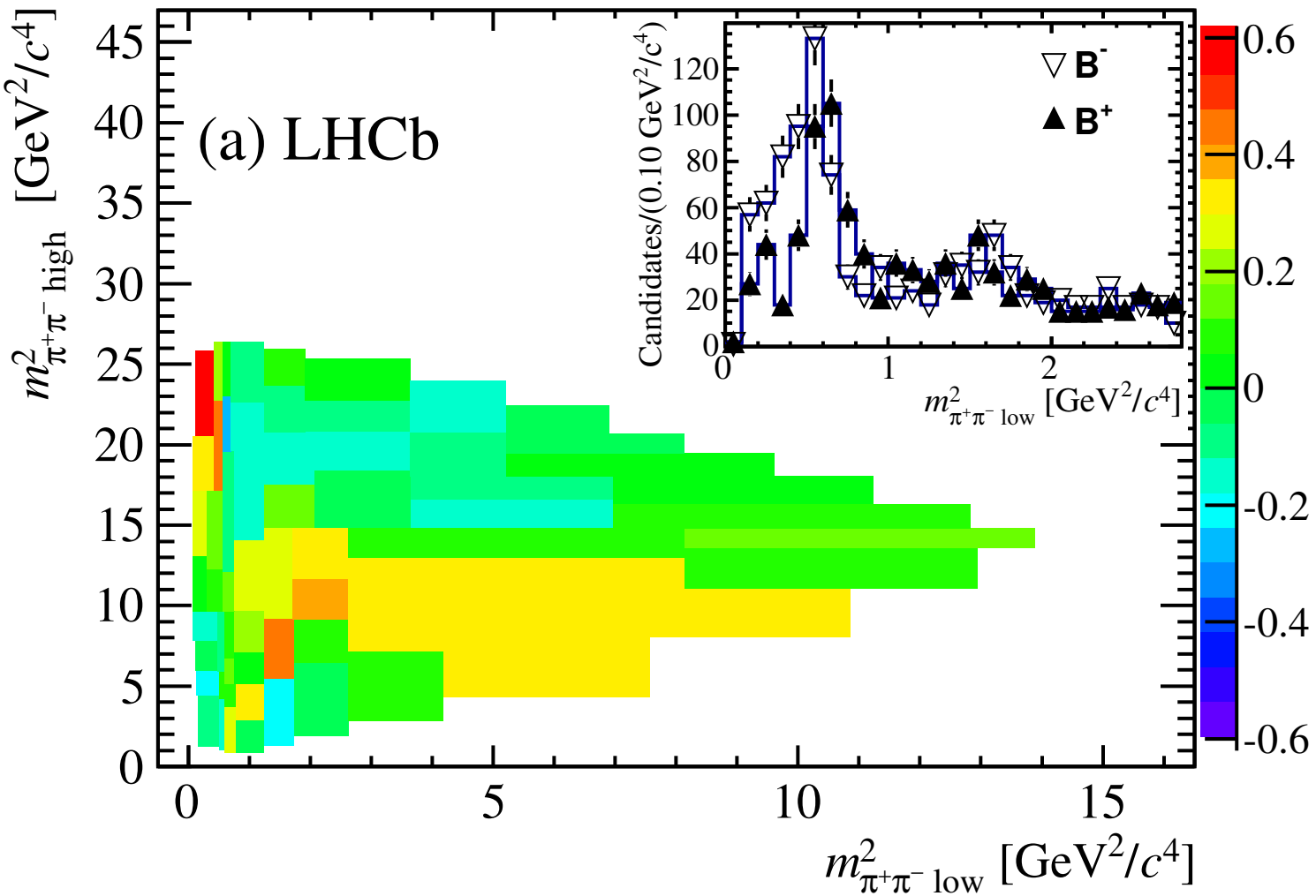

Figure : CP asymmetry for $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ by LHCb. (PRL112, 011801)

Motivation

- Regional *CP*V in three-body decays of B meson,LHCb [PRL112, 011801]
- theoretical study: Zhang,Guo,Yang [PRD87, 076007], Bhattacharya,Gronau,Rosner [PLB726,337],...
- simple picture: interference of amplitudes corresponding to $\rho^0(770)$ and $f_0(500)$

$$\mathscr{M}_{B^+\to\pi^+\pi^+\pi^-} = \mathscr{M}_{B^+\to\pi^+\rho(\to\pi^+\pi^-)} + \mathscr{M}_{B^+\to\pi^+ f(\to\pi^+\pi^-)} \qquad (2)$$

Q: Could similar interference behaviour happen in b-baryon decay?

- interference of two intermediate baryons H_A and H_B

$$\mathscr{M}_{\Lambda_b \to M_1 M_2 H_3} = \mathscr{M}_{\Lambda_b \to M_1 H_A(\to M_2 H_3)} + \mathscr{M}_{\Lambda_b \to M_1 H_B(\to M_2 H_3)} \tag{3}$$

- interference of a baryon resonance H with a meson resonance M

$$\mathscr{M}_{\Lambda_b \to M_1 M_2 H_3} = \mathscr{M}_{\Lambda_b \to M_1 H(\to M_2 H_3)} + \mathscr{M}_{\Lambda_b \to H M(\to M_1 M_2)} \tag{4}$$

Decay width for $\Lambda_b^0 \to p\pi^0\pi^-$ around resonances $\rho^0(770)$ and $N^+(1440)$

In the overlap region of ρ^0 and N^+, the decay amplitude can be expressed as

$$\mathscr{M} = \frac{\langle p\pi^0|\hat{\mathscr{H}_1}|N^+\rangle\langle\pi^- N^+|\hat{\mathscr{H}}_{\rm eff}|\Lambda_b^0\rangle}{s_0 - m_N^2 + im_N\Gamma_N} + \frac{\langle\pi^0\pi^-|\hat{\mathscr{H}_2}|\rho^-\rangle\langle p\rho^-|\hat{\mathscr{H}}_{\rm eff}|\Lambda_b^0\rangle}{s - m_\rho^2 + im_\rho\Gamma_\rho}.$$

- $\hat{\mathscr{H}}_{\rm eff}$: weak Hamiltonian
- $\hat{\mathscr{H}_1}$ strong, Yukawa type; $\hat{\mathscr{H}_2}$ strong, scalarQED type

The differential *CP* asymmetry is then defined as

$$A_{CP} = \frac{\overline{|\mathscr{M}|^2} - \overline{|\bar{\mathscr{M}}|^2}}{\overline{|\mathscr{M}|^2} + \overline{|\bar{\mathscr{M}}|^2}}. \tag{5}$$

- factorization approach for matrix elements $\langle \pi^- N^+(p\rho)|\hat{\mathscr{H}}_{\rm eff}|\Lambda_b^0\rangle$,
- determine coupling constants of $\hat{\mathscr{H}}_1$ and $\hat{\mathscr{H}}_2$ from exp.data
- the relative strong phase of $\mathscr{H}_1$ and $\mathscr{H}_2$, δ, is treated as a free parameter
- The form factors for $\Lambda_b \to N^+$ are not available – rough estimation

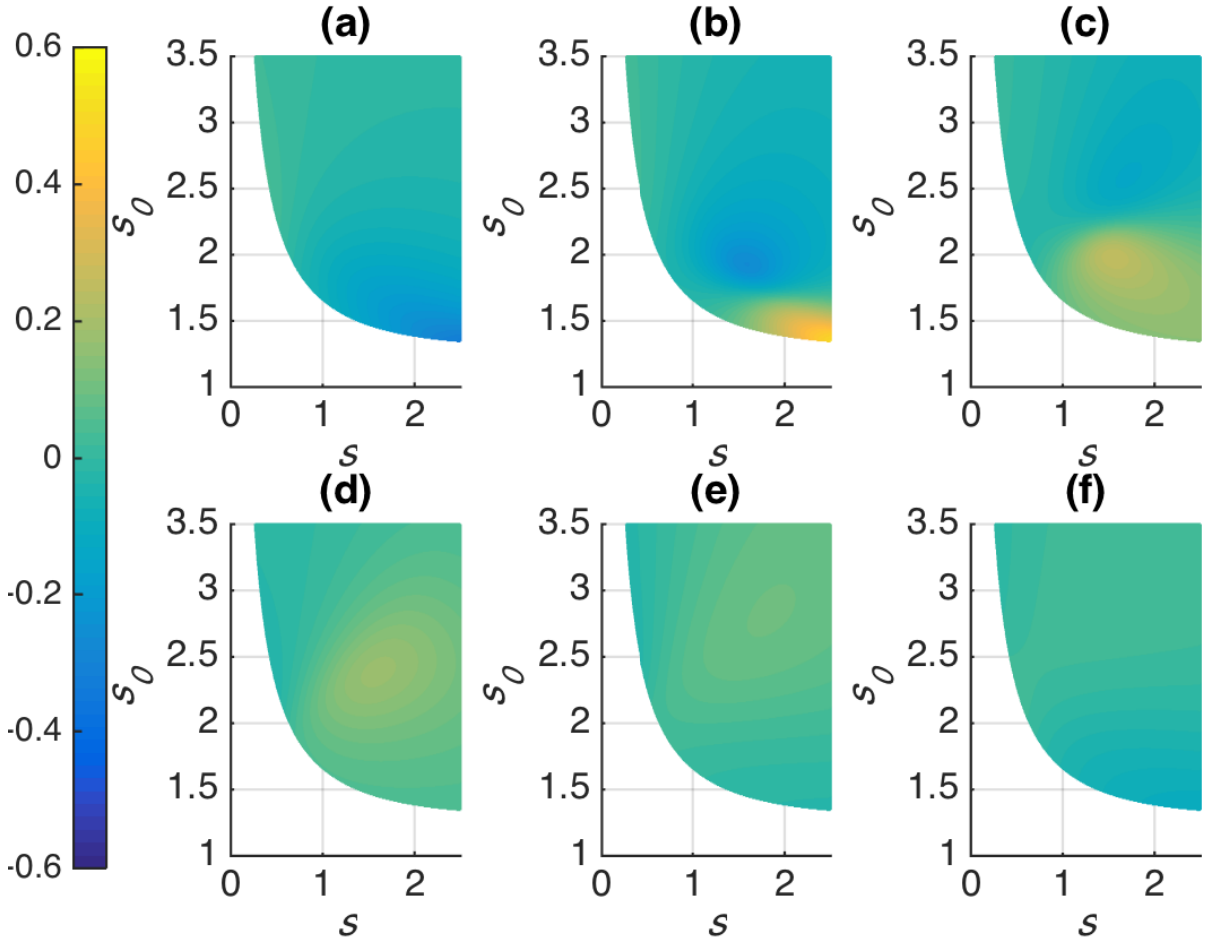

Figure : Differential *CP* asymmetries (in unit of %) distributions in the overlap region of the phase space for various values of δ. The six diagrams (a) to (f) correspond to δ taking values form 0 to $5\pi/3$ for every $\pi/3$. The invariant mass squares s and s_0 are in units of GeV^2.

The regional *CP* asymmetry

$$A_{CP}^{\Omega} = \frac{\Gamma^{\Omega} - \bar{\Gamma}^{\Omega}}{\Gamma^{\Omega} + \bar{\Gamma}^{\Omega}}, \tag{6}$$

where Ω is some region of the phase space, Γ^{Ω} and $\bar{\Gamma}^{\Omega}$ are the regional decay width for $\Lambda_b^0 \to p\pi^0\pi^-$ and $\overline{\Lambda}_b^0 \to \bar{p}\pi^0\pi^+$, respectively, with the former one taking the form

$$\Gamma^{\Omega} = \frac{1}{256\pi^3 m_{\Lambda_b}^3} \int_{\Omega} ds ds_0 \overline{|\mathscr{M}|^2}. \tag{7}$$

We will focus on $\Omega_{\rm OL}$:

$$m_\rho + \Gamma_\rho < \sqrt{s} < m_\rho + 2\Gamma_\rho,\ \ m_N - \frac{\Gamma_N}{2} < \sqrt{s_0} < m_N + \frac{\Gamma_N}{2}. \qquad (8)$$

The reason for this choice:

- Exclude the pollution of other resonances.
- Amplitude corresponding to resonances $\rho^-(770)$ is larger than that of $N^+(1440)$.

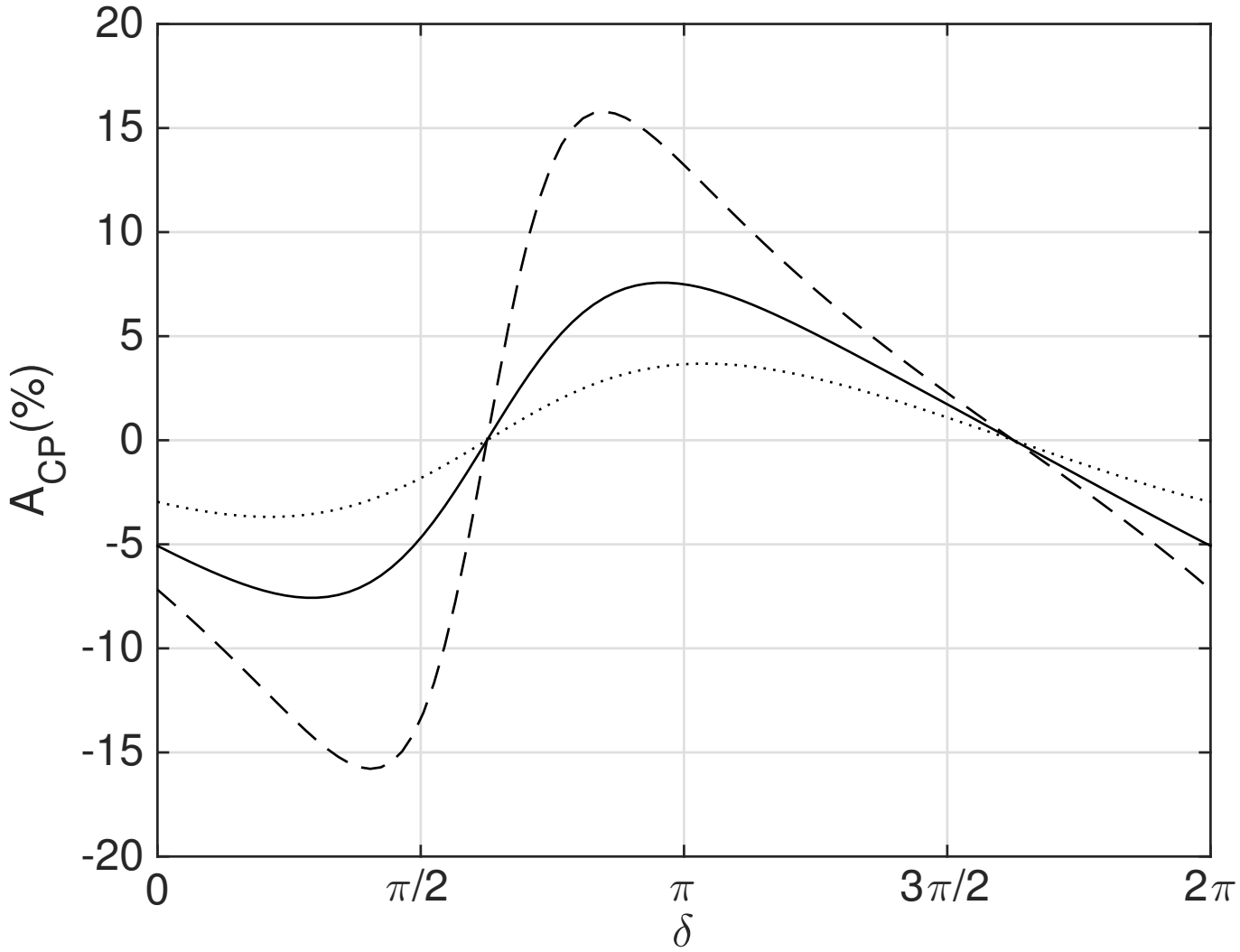

Figure : *CP* asymmetries in Region $\Omega_{\rm OL}$ as a function of the strong phase δ. The dashed, solid, and dotted curves are for $F^{\Lambda_b\to p}/F^{\Lambda_b\to N^+} = 0.5$, 1, and 2.

Conclusion

- Interference of resonances in Λ_b decays can result in differential and regional *CP*V in phase space.
- Long-range strong phase δ is essential.
- More information about decay form factors is needed.

Thanks!