Probing Bottom-Baryon CP Violation with Final-State Re-scattering

冯天亮
兰州大学

合作者：尚慧强，秦溱，于福升
To appear

第二十一届全国重味物理和CP破坏研讨会@北京

Outline

- Introduction
- Branching ratio and CP violation
- Discussions
- Summary

Introduction

- **CPV is deeply connected to the fundamental puzzle matter-antimatter**

- **2025.03: Chinese scientists first observed baryon CP violation--5-sigma**

$$\mathcal{A}_{CP} = (2.45 \pm 0.46 \pm 0.10)\% \,.$$

nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > articles > article

Article | Open access | Published: 16 July 2025

Observation of charge–parity symmetry breaking in baryon decays

LHCb Collaboration

Nature **643**, 1223–1228 (2025) | Cite this article

10.1038/s41586-025-09119-3

Decay topology	Mass region (GeV/c^2)	$\mathcal{A}_{CP}$
$\Lambda_b^0 \to R(pK^-)R(\pi^+\pi^-)$	$m_{pK^-} < 2.2$ $m_{\pi^+\pi^-} < 1.1$	$(5.3 \pm 1.3 \pm 0.2)\%$
$\Lambda_b^0 \to R(p\pi^-)R(K^-\pi^+)$	$m_{p\pi^-} < 1.7$ $0.8 < m_{\pi^+K^-} < 1.0$ or $1.1 < m_{\pi^+K^-} < 1.6$	$(2.7 \pm 0.8 \pm 0.1)\%$
$\Lambda_b^0 \to R(p\pi^+\pi^-)K^-$	$m_{p\pi^+\pi^-} < 2.7$	$(5.4 \pm 0.9 \pm 0.1)\%$
$\Lambda_b^0 \to R(K^-\pi^+\pi^-)p$	$m_{K^-\pi^+\pi^-} < 2.0$	$(2.0 \pm 1.2 \pm 0.3)\%$

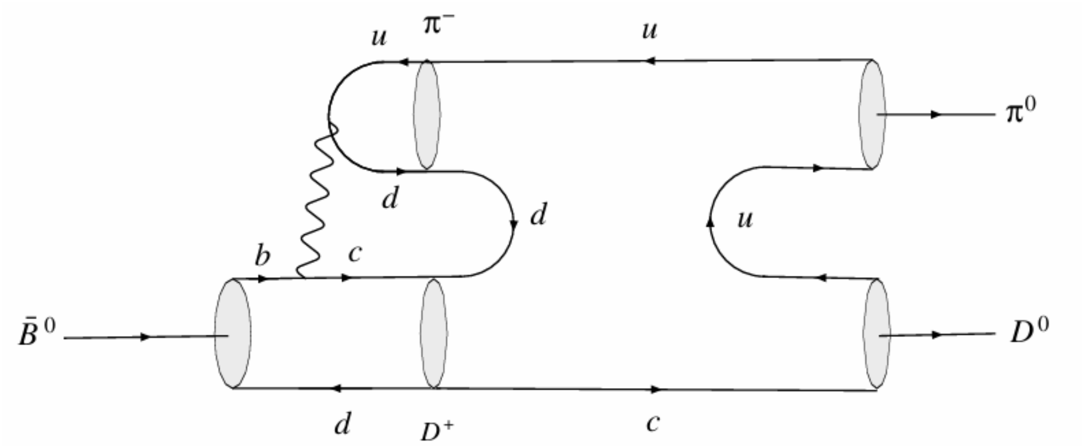
- **This pushes us to expand our goals. FSI is now applied to calculate baryonic CP violation**

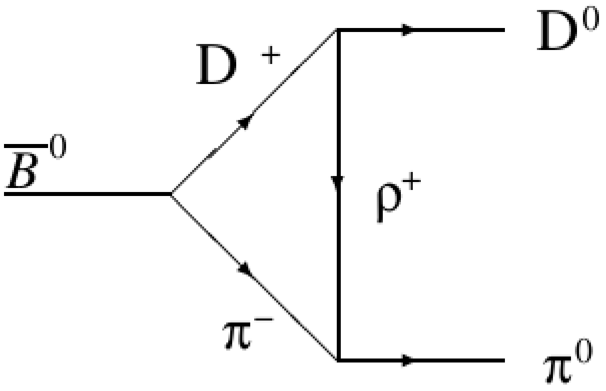
Introduction

1/4

Final state interactions in hadronic B decays

The FSI framework is introduced covering both experimental and theoretical aspects.



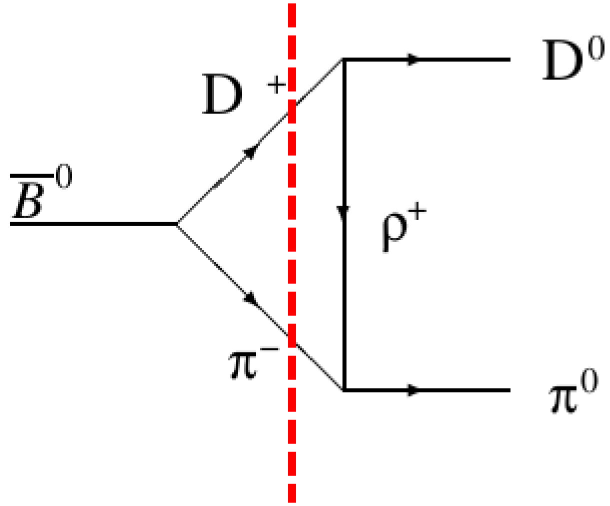


H.Y.Cheng, C.K.Chua, A.Soni 2005

10.1103/PhysRevD.71.014030

Introduction

1/4



$$\mathrm{Abs}(4a) = \frac{1}{2}\int \frac{d^3\vec{p}_1}{(2\pi)^3 2E_1}\frac{d^3\vec{p}_2}{(2\pi)^3 2E_2}(2\pi)^4\delta^4(p_B - p_1 - p_2)A(\overline{B}^0 \to D^+\pi^-)$$
$$\times\, i\frac{1}{\sqrt{2}}\beta g_V \frac{F^2(t, m_\rho)}{t - m_\rho^2 + im_\rho\Gamma_\rho}(-i)g_{\rho\pi\pi}(p_1 + p_3)^\mu(p_2 + p_4)^\nu\left(-g_{\mu\nu} + \frac{k_\mu k_\nu}{m_\rho^2}\right)$$
$$= \int_{-1}^{1}\frac{|\vec{p}_1| d\cos\theta}{16\pi m_B}\frac{1}{\sqrt{2}}g_V g_{\rho\pi\pi}\beta A(\overline{B}^0 \to D^+\pi^-)\frac{F^2(t, m_\rho)}{t - m_\rho^2 + im_\rho\Gamma_\rho}H_1,$$

Introduction

1/4

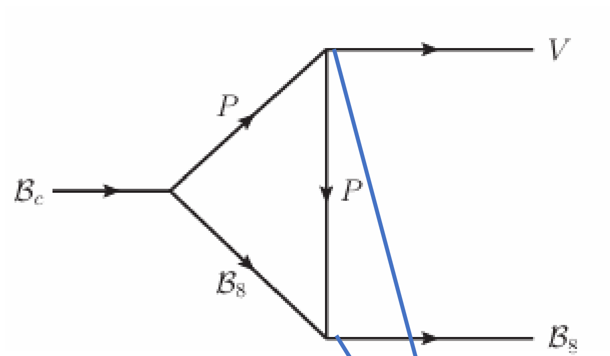
$$
\begin{aligned}
\mathrm{Abs}(4a) = &\frac{1}{2}\int \frac{d^3\vec{p}_1}{(2\pi)^3 2E_1}\frac{d^3\vec{p}_2}{(2\pi)^3 2E_2}(2\pi)^4\delta^4(p_B - p_1 - p_2)A(\overline{B}^0 \to D^+\pi^-) \\
&\times i\frac{1}{\sqrt{2}}\beta g_V \frac{F^2(t, m_\rho)}{t - m_\rho^2 + i m_\rho \Gamma_\rho}(-i) g_{\rho\pi\pi}(p_1 + p_3)^\mu (p_2 + p_4)^\nu \left(-g_{\mu\nu} + \frac{k_\mu k_\nu}{m_\rho^2}\right) \\
= &\int_{-1}^{1} \frac{|\vec{p}_1| d\cos\theta}{16\pi m_B}\frac{1}{\sqrt{2}} g_V g_{\rho\pi\pi}\beta A(\overline{B}^0 \to D^+\pi^-)\frac{F^2(t, m_\rho)}{t - m_\rho^2 + i m_\rho \Gamma_\rho} H_1,
\end{aligned}
$$

Cutkosky cutting $\longrightarrow$ only calculate the imaginary part

Provide CPV $\longrightarrow$ need strong phase

2/4 Final-state rescattering mechanism of charmed baryon decays

Introduce a form factor to compute the complete loop integral



- Hadronic form factors
- divergences in loop integrals
- off-shell effects

$$\mathcal{F} = \left(\frac{\Lambda_1^2 - m_1^2}{\Lambda_1^2 - p_1^2}\right)\left(\frac{\Lambda_2^2 - m_2^2}{\Lambda_2^2 - p_2^2}\right)$$

Model parameter $\Lambda = m + \eta\Lambda_{QCD}$

$$\begin{aligned}\mathcal{M}[P,\mathcal{B}_8;P] = &-i\int\frac{d^4k}{(2\pi)^4} g_{BBP}\cdot g_{VPP}\bar{u}(p_4,s_4)\gamma_5(\not{p}_2+m_2)(A+B\gamma_5)u(p,s)\\ &\times\varepsilon_\mu^*(p_3,\lambda_3)(p_1+k)^\mu\frac{\mathcal{F}}{(p_1^2-m_1^2+i\epsilon)(p_2^2-m_2^2+i\epsilon)(k^2-m_k^2+i\epsilon)}\end{aligned}$$

C.P.Jia, H.Y.Jiang, J.P.Wang and F.S.Yu 2024
10.1007/JHEP11(2024)072

2/4

Decay modes	Topology	$\mathcal{B}R_{\rm SD}(\%)$	$\mathcal{B}R_{\rm LD}(\%)$	$\mathcal{B}R_{\rm tot}(\%)$	$\mathcal{B}R_{\rm exp}(\%)$
$\Lambda_c^+ \to \Lambda^0 \rho^+$	T, C', E_2, B	6.12	$2.30^{+1.18}_{-1.94}$	$6.26^{+2.44}_{-1.39}$	4.06 ± 0.52
$\Lambda_c^+ \to \Sigma^+ \rho^0$	C', E_2, B	–	–	$0.77^{+1.38}_{-0.53}$	< 1.7
$\Lambda_c^+ \to \Sigma^+ \omega$	C', E_2, B	–	–	$2.06^{+0.40}_{-1.78}$	1.7 ± 0.21
$\Lambda_c^+ \to \Sigma^+ \phi$	E_1	–	–	$0.33^{+0.08}_{-0.29}$	0.39 ± 0.06
$\Lambda_c^+ \to p \bar{K}^{*0}$	C, E_1	3.26×10^{-3}	$3.76^{+1.37}_{-3.43}$	$3.70^{+1.29}_{-3.39}$	1.96 ± 0.27
$\Lambda_c^+ \to \Xi^0 K^{*+}$	E_2, B	–	–	$1.94^{+0.40}_{-1.68}$	–
Decay modes	Topology	$\mathcal{B}R_{\rm SD}(\times 10^{-3})$	$\mathcal{B}R_{\rm LD}(\times 10^{-3})$	$\mathcal{B}R_{\rm tot}(\times 10^{-3})$	$\mathcal{B}R_{\rm exp}(\times 10^{-3})$
$\Lambda_c^+ \to \Lambda^0 K^{*+}$	T, C', E_2, B	2.92	$2.78^{+1.28}_{-1.02}$	$4.71^{+0.48}_{-0.20}$	–
$\Lambda_c^+ \to \Sigma^0 K^{*+}$	C', E_2, B	–	–	$1.60^{+0.89}_{-0.62}$	–
$\Lambda_c^+ \to \Sigma^+ K^{*0}$	C', E_1	–	–	$2.10^{+1.37}_{-0.86}$	3.5 ± 1.0
$\Lambda_c^+ \to p \phi$	C	1.78×10^{-3}	$1.44^{+1.14}_{-0.66}$	$1.37^{+1.13}_{-0.65}$	1.06 ± 0.14
$\Lambda_c^+ \to p \omega$	C, C', E_1, E_2, B	1.48×10^{-3}	$1.28^{+0.46}_{-0.37}$	$1.26^{+0.45}_{-0.37}$	0.83 ± 0.11
$\Lambda_c^+ \to p \rho^0$	C, C', E_1, E_2, B	1.81×10^{-3}	$2.79^{+1.89}_{-1.29}$	$2.72^{+1.87}_{-1.27}$	1.52 ± 0.44
$\Lambda_c^+ \to n \rho^+$	T, C', E_2, B	7.14	$8.50^{+9.57}_{-4.72}$	$26.39^{+13.71}_{-8.86}$	–
Decay modes	Topology	$\mathcal{B}R_{\rm SD}(\times 10^{-4})$	$\mathcal{B}R_{\rm LD}(\times 10^{-4})$	$\mathcal{B}R_{\rm tot}(\times 10^{-4})$	$\mathcal{B}R_{\rm exp}$
$\Lambda_c^+ \to p K^{*0}$	C, C'	9.28×10^{-4}	$0.53^{+3.67}_{-0.38}$	$0.55^{+3.71}_{-0.39}$	–
$\Lambda_c^+ \to n K^{*+}$	T, C'	3.66	$0.44^{+1.64}_{-0.30}$	$5.08^{+1.95}_{-0.66}$	–

1 Model Parameter, 8 Remarkable Results !

3/4 **Final-state rescattering mechanism in bottom-baryon decays**

$\Lambda_b^0 \to p\pi^-, pK^-, p\rho^-, pK^{*-}$ and $\Lambda\phi$, within the framework of re-scattering mechanism.

$$\mathcal{F}(\Lambda, m_k) = \frac{\Lambda^4}{(k^2 - m_k^2)^2 + \Lambda^4}$$

Advantage :no additional phase.

Model parameter set to 1.0 for charm triangle diagrams and 0.5 for charmless ones.

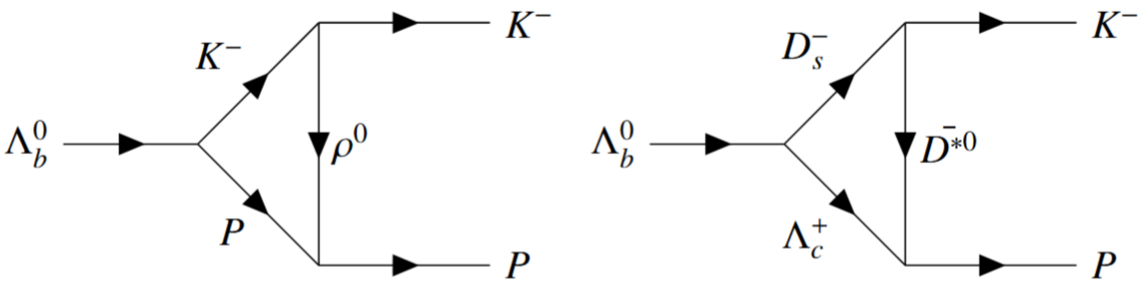
determined by $p\pi^-, pK^-$

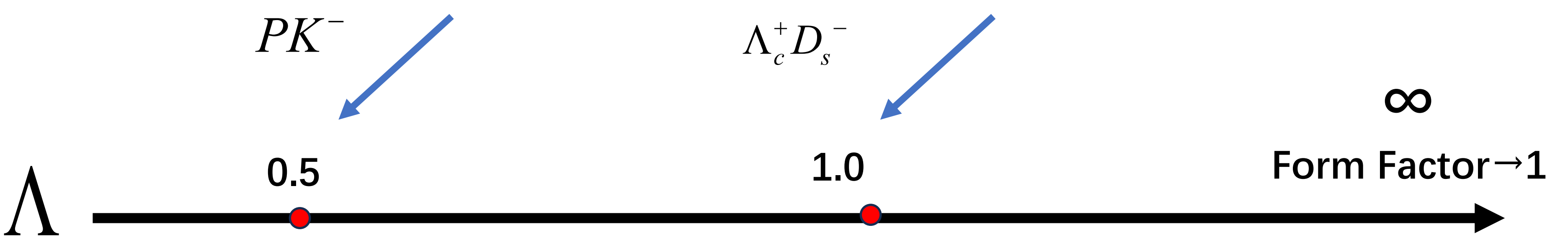
Z.D.Duan, J.P.Wang, R.H.Li, C.D.LÜ and F.S.Yu 2025

10.1007/JHEP09(2025)160

3/4 **Final-state rescattering mechanism in bottom-baryon decays**

charmless charm





$$\mathcal{F}(\Lambda, m_k) = \frac{\Lambda^4}{(k^2 - m_k^2)^2 + \Lambda^4}$$

3/4 Final-state rescattering mechanism in bottom-baryon decays

	BR(10^{-5})	Direct CP
$\Lambda_b^0 \to pK^{*-}$		
FSI (this work)	$1.35^{+1.36}_{-0.71}$	$0.02^{+0.04}_{-0.04}$
PQCD [17]	0.302	0.057
QCDF [27]	0.101	0.311
GFA [31]	0.286	0.197
$\Lambda_b^0 \to p\rho^-$		
FSI (this work)	$1.34^{+0.53}_{-0.19}$	$-0.24^{+0.07}_{-0.03}$
PQCD [17]	1.513	−0.020
QCDF [27]	0.747	−0.319
GFA [31]	1.1	−0.038
$\Lambda_b^0 \to \Lambda\phi$		
FSI (this work)	$0.31^{+0.43}_{-0.19}$	$-0.005^{+0.02}_{-0.01}$
PQCD [14]	0.69	−0.01
QCDF [27]	0.0633	0.016
GFA [31]	0.177	0.014

The use of the world average value of $\mathcal{B}(B^0 \to K_S^0\phi) = (3.65\,^{+0.35}_{-0.30}) \times 10^{-6}$ [15] gives the final result of

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\phi)/10^{-6} = 5.18 \pm 1.04\,(\text{stat}) \pm 0.35\,(\text{syst})\,^{+0.50}_{-0.43}\,(\mathcal{B}(B^0 \to K_S^0\phi)) \pm 0.44\,(f_d/f_{\Lambda_b^0}).$$

LHCb arXiv:1603.02870

A possible explanation for this result is the cancellation of CP asymmetries among the partial waves in the $\Lambda_b^0 \to pK^*(892)^-$ decay [27, 28].

LHCb arXiv:2508.17836

This Work

4/4

$(\Lambda_b^0 \to pk^-\pi^0)$
$\Lambda(1520)\pi^0$
$(\Lambda_b^0 \to pk^-\pi^+\pi^-)$
$\Lambda(1520)f_0(980)$
$\Lambda(1520)\rho^0$
$\Lambda(1520)f_0(500)$
$(\Lambda_b^0 \to pk^-k^+k^-)$
$\Lambda(1520)\phi$
$\Lambda(1520)f_0(980)$
$(\Lambda_b^0 \to pk^-k^+\pi^-)$
$\Lambda(1520)k^{*0}$
$\Lambda(1520)\kappa(700)$
$(\Xi_b^- \to pk^-k^-)$
$\Lambda(1520)k^-$

NEW: $f_0(980) \quad I^G(J^{PC}) = 0^+(0^{++})$

NEW: $\Lambda(1520) \quad I(J^P) = 0(3/2^-)$

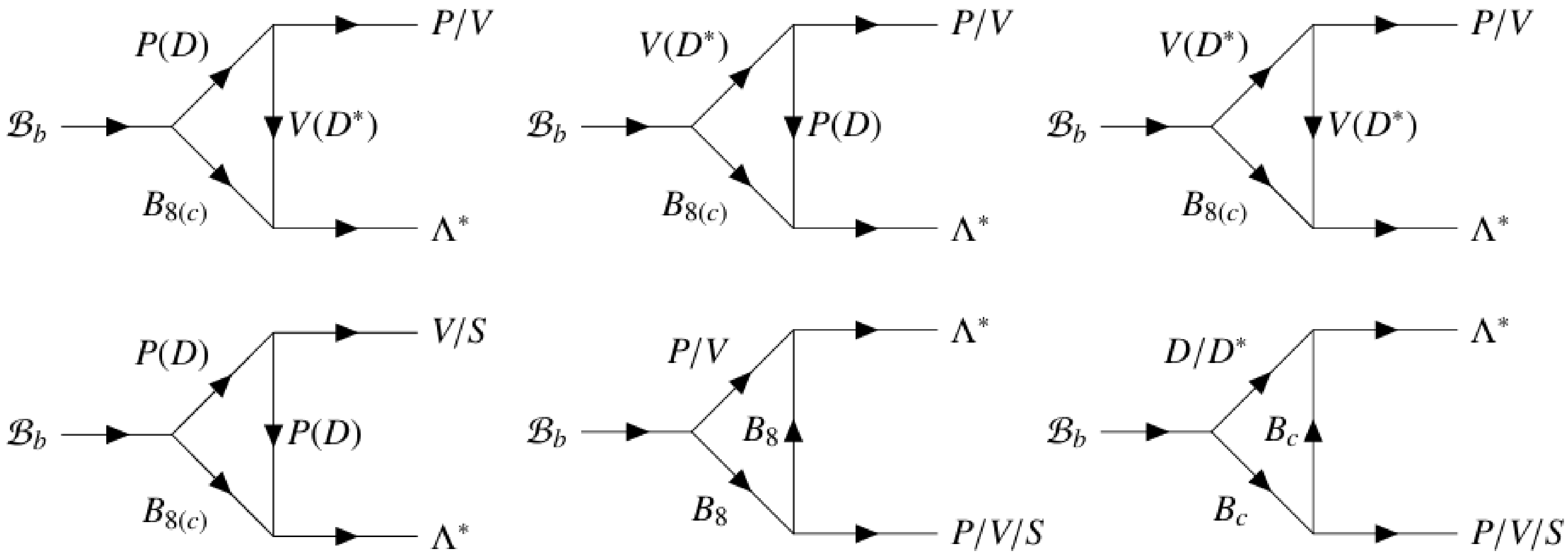
~~NEW~~: $\mathcal{F}(\Lambda, m_k) = \dfrac{\Lambda^4}{(k^2 - m_k^2)^2 + \Lambda^4}$

1.0 for charm triangle diagrams and 0.5 for charmless.

To appear

Introduction

4/4



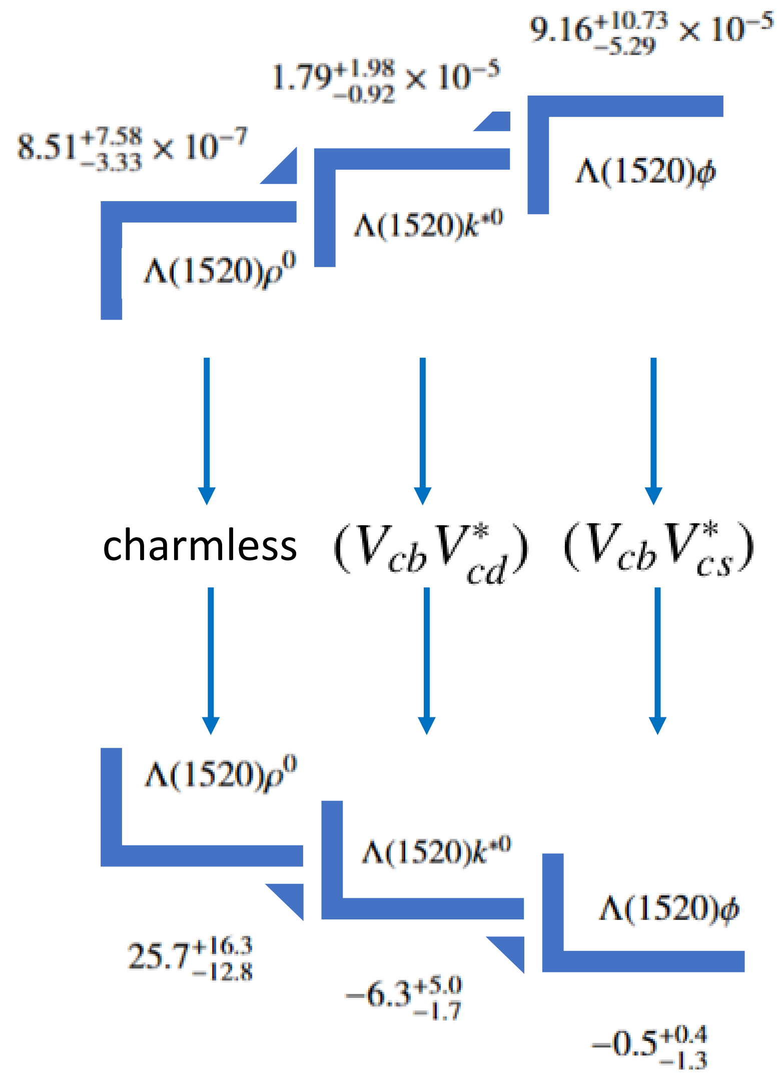
$$\mathcal{M}[P,B_8;V]=\int\frac{d^4p}{(2\pi)^4}(+i)\frac{g_{VB\Lambda}}{m_k^2}\frac{g_{PPV}}{\sqrt{2}}\bar{u}^{\sigma}(p_4,s_4)\sigma_{\mu\nu}k^{\nu}k_{\sigma}(\not{p}_2+m_2)(A+B\gamma_5)u(p,s)(-g^{\mu\alpha}+\frac{k^{\mu}k^{\alpha}}{m_k^2})$$

$$(p_1+p_3)_{\alpha}\mathcal{P}^3\mathcal{F}$$

Branching ratio and CP violation

Table 10: Branching ratio and direct CP violation for the various reactions

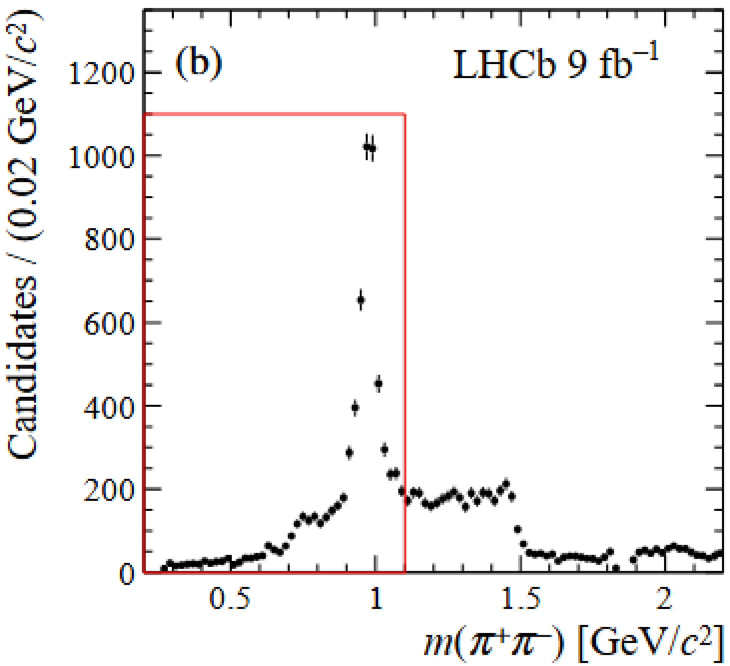
	BR	Direct CP(10^{-2})
$(\Lambda_b^0 \to pk^-\pi^0)$		
$\Lambda(1520)\pi^0$	$6.90^{+12.47}_{-4.31} \times 10^{-9}$	$17.4^{+6.9}_{-7.3}$
$(\Lambda_b^0 \to pk^-\pi^+\pi^-)$		
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\Lambda(1520)\rho^0$	$8.51^{+7.58}_{-3.33} \times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520)f_0(500)$	$9.28^{+11.50}_{-5.42} \times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$
$(\Lambda_b^0 \to pk^-k^+k^-)$		
$\Lambda(1520)\phi$	$9.16^{+10.73}_{-5.29} \times 10^{-5}$	$-0.5^{+0.4}_{-1.3}$
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$(\Lambda_b^0 \to pk^-k^+\pi^-)$		
$\Lambda(1520)k^{*0}$	$1.79^{+1.98}_{-0.92} \times 10^{-5}$	$-6.3^{+5.0}_{-1.7}$
$\Lambda(1520)\kappa(700)$	$1.64^{+1.87}_{-0.93} \times 10^{-7}$	$24.2^{+17.3}_{-17.8}$
$(\Xi_b^- \to pk^-k^-)$		
$\Lambda(1520)k^-$	$1.79^{+2.03}_{-1.02} \times 10^{-6}$	$-3.4^{+7.9}_{-6.7}$



Branching ratio and CP violation

Table 10: Branching ratio and direct *CP* violation for the various reactions

	BR	Direct CP(10^{-2})
$(\Lambda_b^0 \to pk^-\pi^0)$		
$\Lambda(1520)\pi^0$	$6.90^{+12.47}_{-4.31} \times 10^{-9}$	$17.4^{+6.9}_{-7.3}$
$(\Lambda_b^0 \to pk^-\pi^+\pi^-)$		
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\Lambda(1520)\rho^0$	$8.51^{+7.58}_{-3.33} \times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520)f_0(500)$	$9.28^{+11.50}_{-5.42} \times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$
$(\Lambda_b^0 \to pk^-k^+k^-)$		
$\Lambda(1520)\phi$	$9.16^{+10.73}_{-5.29} \times 10^{-5}$	$-0.5^{+0.4}_{-1.3}$
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$(\Lambda_b^0 \to pk^-k^+\pi^-)$		
$\Lambda(1520)k^{*0}$	$1.79^{+1.98}_{-0.92} \times 10^{-5}$	$-6.3^{+5.0}_{-1.7}$
$\Lambda(1520)\kappa(700)$	$1.64^{+1.87}_{-0.93} \times 10^{-7}$	$24.2^{+17.3}_{-17.8}$
$(\Xi_b^- \to pk^-k^-)$		
$\Lambda(1520)k^-$	$1.79^{+2.03}_{-1.02} \times 10^{-6}$	$-3.4^{+7.9}_{-6.7}$



Branching ratio and CP violation

Table 10: Branching ratio and direct CP violation for the various reactions

	BR	Direct CP(10^{-2})
($\Lambda_b^0 \to pk^-\pi^0$)		
$\Lambda(1520)\pi^0$	$6.90^{+12.47}_{-4.31} \times 10^{-9}$	$17.4^{+6.9}_{-7.3}$
($\Lambda_b^0 \to pk^-\pi^+\pi^-$)		
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\Lambda(1520)\rho^0$	$8.51^{+7.58}_{-3.33} \times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520)f_0(500)$	$9.28^{+11.50}_{-5.42} \times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$
($\Lambda_b^0 \to pk^-k^+k^-$)		
$\Lambda(1520)\phi$	$9.16^{+10.73}_{-5.29} \times 10^{-5}$	$-0.5^{+0.4}_{-1.3}$
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
($\Lambda_b^0 \to pk^-k^+\pi^-$)		
$\Lambda(1520)k^{*0}$	$1.79^{+1.98}_{-0.92} \times 10^{-5}$	$-6.3^{+5.0}_{-1.7}$
$\Lambda(1520)\kappa(700)$	$1.64^{+1.87}_{-0.93} \times 10^{-7}$	$24.2^{+17.3}_{-17.8}$
($\Xi_b^- \to pk^-k^-$)		
$\Lambda(1520)k^-$	$1.79^{+2.03}_{-1.02} \times 10^{-6}$	$-3.4^{+7.9}_{-6.7}$

$\Xi_b \to \Lambda(1520)k^-$:
$BR = (0.76 \pm 0.09 \pm 0.08 \pm 0.30) \times 10^{-6}$,
$A_{CP} = -5 \pm 9(stat) \pm 8(syst) \times 10^{-2}$.

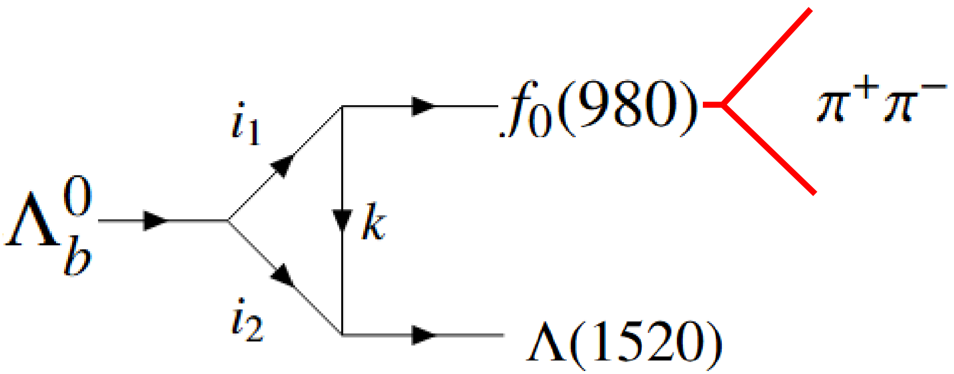
LHCb:2021

10.1103/PhysRevD.104.052010

Discussions

Extend the previous calculation of the primary decay to include the full decay chain, taking into account interference between different channels.

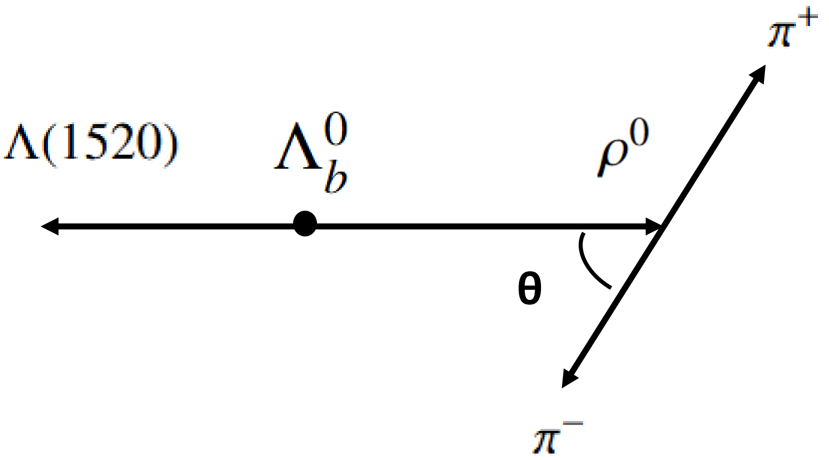
$(\Lambda_b^0 \to pk^-\pi^+\pi^-)$		
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47}\times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\Lambda(1520)\rho^0$	$8.51^{+7.58}_{-3.33}\times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520)f_0(500)$	$9.28^{+11.50}_{-5.42}\times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$
$(\Lambda_b^0 \to pk^-k^+k^-)$		
$\Lambda(1520)\phi$	$9.16^{+10.73}_{-5.29}\times 10^{-5}$	$-0.5^{+0.4}_{-1.3}$
$\Lambda(1520)f_0(980)$	$6.01^{+6.98}_{-3.47}\times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$(\Lambda_b^0 \to pk^-k^+\pi^-)$		
$\Lambda(1520)k^{*0}$	$1.79^{+1.98}_{-0.92}\times 10^{-5}$	$-6.3^{+5.0}_{-1.7}$
$\Lambda(1520)\kappa(700)$	$1.64^{+1.87}_{-0.93}\times 10^{-7}$	$24.2^{+17.3}_{-17.8}$



Decay Channel	Direct CPV (10^{-2})
$\Lambda_b^0 \to pK^-\pi^+\pi^-$	$10.8^{+0.1}_{-4.7}$
$\Lambda_b^0 \to pK^-K^+K^-$	$0.1^{+0.1}_{-0.1}$
$\Lambda_b^0 \to pK^-K^+\pi^-$	$-4.6^{+5.6}_{-0.4}$

Discussions

$(\Lambda_b^0 \to p k^- \pi^+ \pi^-)$			
$\Lambda(1520) f_0(980)$	S	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\Lambda(1520)\rho^0$	V	$8.51^{+7.58}_{-3.33} \times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520) f_0(500)$	S	$9.28^{+11.50}_{-5.42} \times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$
$(\Lambda_b^0 \to p k^- k^+ k^-)$			
$\Lambda(1520)\phi$	V	$9.16^{+10.73}_{-5.29} \times 10^{-5}$	$-0.5^{+0.4}_{-1.3}$
$\Lambda(1520) f_0(980)$	S	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$(\Lambda_b^0 \to p k^- k^+ \pi^-)$			
$\Lambda(1520) k^{*0}$	V	$1.79^{+1.98}_{-0.92} \times 10^{-5}$	$-6.3^{+5.0}_{-1.7}$
$\Lambda(1520)\kappa(700)$	S	$1.64^{+1.87}_{-0.93} \times 10^{-7}$	$24.2^{+17.3}_{-17.8}$



$$aCos^2\theta + bCos\theta + c$$

Discussions

$$A = \frac{a}{c}, B = \frac{b}{c}, C = 1 \qquad a_{CP}^{A} = \frac{A - \bar{A}}{|A| + |\bar{A}|}, a_{CP}^{B} = \frac{B - \bar{B}}{|B| + |\bar{B}|}$$

Table 12: CPV of different Coefficients

	B	$\bar{B}$	A	$\bar{A}$	$a_{CP}^{B}(10^{-2})$	$a_{CP}^{A}(10^{-2})$
$\Lambda_b^0 \to pk^-\pi^+\pi^-$	$-1.05^{+0.63}_{-0.81}$	$1.36^{+1.05}_{-0.82}$	$0.66^{+1.86}_{-0.53}$	$0.42^{+1.79}_{-0.39}$	$-100.0^{+0.0}_{-0.0}$	$21.8^{+40.9}_{-15.3}$
$\Lambda_b^0 \to pk^-k^+k^-$	$0.11^{+0.02}_{-0.02}$	$0.10^{+0.00}_{-0.03}$	$0.08^{+0.09}_{-0.04}$	$0.07^{+0.06}_{-0.03}$	$2.7^{+23.5}_{-5.7}$	$6.1^{+8.6}_{-7.1}$
$\Lambda_b^0 \to pk^-k^+\pi^-$	$0.04^{+0.09}_{-0.10}$	$0.09^{+0.00}_{-0.13}$	$4.29^{+0.00}_{-1.07}$	$5.56^{+4.64}_{-3.27}$	$-19.0^{+32.8}_{-24.0}$	$-12.9^{+29.8}_{-27.9}$

We recommend that experimentalists focus their measurements on the channel highlighted in the red box!!

Discussions

$\Lambda(1520) f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\boxed{\Lambda(1520)\rho^0}$	$8.51^{+7.58}_{-3.33} \times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520) f_0(500)$	$9.28^{+11.50}_{-5.42} \times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$

$$\left|A_\rho e^{i\phi_\rho} + A_m e^{i\phi_m}\right|^2 = A_\rho^2 + A_m^2 + 2A_\rho A_m \cos(\phi_\rho - \phi_2)$$

$$\left|A_\rho e^{i(\phi_\rho+\pi)} + A_m e^{i\phi_m}\right|^2 = A_\rho^2 + A_m^2 - 2A_\rho A_m \cos(\phi_\rho - \phi_2)$$

Significant CPV =large phase difference between the process and its conjugate;

leads to opposite signs in their kinematic coefficients B.

Summary

- The calculation of 8 channels was performed while keeping the model framework and parameters unchanged, showing the reliability of the FSI.

- Analysis of the results was followed by further kinematic studies, Recommended observables that could reach 100% CPV.

- The FSI framework shows promise for extending to more calculations in future studies.

- Thank you!

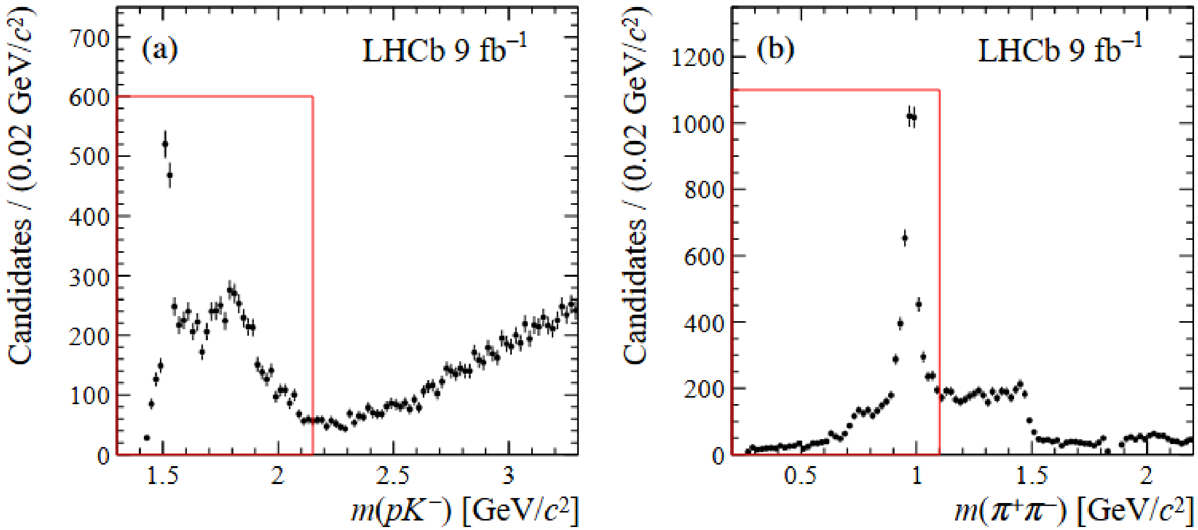
Backup

$$\frac{G_F}{\sqrt{2}} f_K [V_{ub} V_{us}^* a_1 - V_{tb} V_{ts}^* (a_4 + a_{10}) + R_{K^-} (-V_{tb} V_{ts}^* (a_6 + a_8))]$$

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \left\{ \begin{array}{ccc} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{array} \right\} .$$

a_1	$a_2(\times 10^{-2})$	$a_3(\times 10^{-3})$	$a_4(\times 10^{-3})$	$a_5(\times 10^{-3})$	$a_6(\times 10^{-3})$	$a_7(\times 10^{-4})$	$a_8(\times 10^{-4})$	$a_9(\times 10^{-4})$	$a_{10}(\times 10^{-4})$
1.03	10.3	3.60	-22.8	-2.29	-29.8	12.2	7.57	-82.2	-8.20

Backup



$\Lambda(1520) f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$
$\Lambda(1520)\rho^0$	$8.51^{+7.58}_{-3.33} \times 10^{-7}$
$\Lambda(1520) f_0(500)$	$9.28^{+11.50}_{-5.42} \times 10^{-7}$

Backup

$$P = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} + \frac{\eta_c}{\sqrt{12}} & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{6}} + \frac{\eta_c}{\sqrt{12}} & K^0 & D^- \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta + \frac{\eta_c}{\sqrt{12}} & D_s^- \\ D^0 & D^+ & D_s^+ & \frac{-3\eta_c}{\sqrt{12}} \end{pmatrix},$$

$$V = \begin{pmatrix} \frac{\rho_0}{\sqrt{2}} + \frac{\omega'}{\sqrt{6}} + \frac{J/\psi}{\sqrt{12}} & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & -\frac{\rho_0}{\sqrt{2}} + \frac{\omega'}{\sqrt{6}} + \frac{J/\psi}{\sqrt{12}} & K^{*0} & D^{*-} \\ K^{*-} & \bar{K}^{*0} & -\sqrt{\frac{2}{3}}\omega' + \frac{J/\psi}{\sqrt{12}} & D_s^{*-} \\ D^{*0} & D^{*+} & D_s^{*+} & -\frac{3J/\psi}{\sqrt{12}} \end{pmatrix}.$$

$$\boxed{\mathcal{F}(\Lambda, m_k) = \frac{\Lambda^4}{(k^2 - m_k^2)^2 + \Lambda^4}}$$

0.5 VS 1.0

Backup

$$\mathcal{H}_j^{\frac{1}{2}}(\Lambda_b^0 \to pk^-k^+\pi^-) = \int [\mathcal{H}^{\frac{1}{2}}_{j,j-\frac{1}{2}}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})\frac{i}{q^2 - m^2_{k^{*0}} + im_{k^{*0}}\Gamma_{k^{*0}}} d^1_{0,j-\frac{1}{2}}(\theta)\mathcal{H}(k^{*0} \to k^+\pi^-)$$

$$+ \mathcal{H}^{\frac{1}{2}}_{j,j-\frac{1}{2}}(\Lambda_b^0 \to \Lambda(1520) + \kappa(700))\frac{i}{q^2 - m^2_\kappa + im_\kappa\Gamma_\kappa}\mathcal{H}(\kappa(700) \to k^+\pi^-)]dq.$$

Cross check:

$$A_{cp}^{total} = \frac{\sum_M \Gamma(\Lambda_b \to \Lambda(1520) + M) \times \Gamma(M \to final - state) \times A^M_{CP}}{\sum_M \Gamma(\Lambda_b \to \Lambda(1520) + M) \times \Gamma(p \to final - state)}.$$

Backup

Table 12: CPV of different Coefficients

	B	$\bar{B}$	A	$\bar{A}$	$a^{B}_{CP}(10^{-2})$	$a^{A}_{CP}(10^{-2})$
$\Lambda_b^0 \to pk^-\pi^+\pi^-$	$-1.05^{+0.63}_{-0.81}$	$1.36^{+1.05}_{-0.82}$	$0.66^{+1.86}_{-0.53}$	$0.42^{+1.79}_{-0.39}$	$-100.0^{+0.0}_{-0.0}$	$21.8^{+40.9}_{-15.3}$
$\Lambda_b^0 \to pk^-k^+k^-$	$0.11^{+0.02}_{-0.02}$	$0.10^{+0.00}_{-0.03}$	$0.08^{+0.09}_{-0.04}$	$0.07^{+0.06}_{-0.03}$	$2.7^{+23.5}_{-5.7}$	$6.1^{+8.6}_{-7.1}$
$\Lambda_b^0 \to pk^-k^+\pi^-$	$0.04^{+0.09}_{-0.10}$	$0.09^{+0.00}_{-0.13}$	$4.29^{+0.00}_{-1.07}$	$5.56^{+4.64}_{-3.27}$	$-19.0^{+32.8}_{-24.0}$	$-12.9^{+29.8}_{-27.9}$

1.Why does coefficient A vary significantly across different reactions?

2.Why does coefficient B vary significantly across different reactions?

$$a = -\chi_1(|\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{3}{2},1}|^2 + \mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{3}{2},-1}|^2 + \mathcal{H}(k^{*0})^{\frac{1}{2}}_{-\frac{1}{2},-1}|^2 + \mathcal{H}(k^{*0})^{-\frac{1}{2}}_{\frac{1}{2},1}|^2)$$
$$+ 2\chi_1(|\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{1}{2},0}|^2 + \mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{1}{2},0}|^2),$$

$$b = -2\chi_2(\mathrm{Re}(\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{1}{2},0})\,\mathrm{Re}(\mathcal{H}(\kappa(700))^{\frac{1}{2}}_{\frac{1}{2},0}) + \mathrm{Im}(\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{1}{2},0})\,\mathrm{Im}(\mathcal{H}(\kappa(700))^{\frac{1}{2}}_{\frac{1}{2},0})$$
$$+ \mathrm{Re}(\mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{1}{2},0})\,\mathrm{Re}(\mathcal{H}(\kappa(700))^{-\frac{1}{2}}_{-\frac{1}{2},0}) + \mathrm{Im}(\mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{1}{2},0})\,\mathrm{Im}(\mathcal{H}(\kappa(700))^{-\frac{1}{2}}_{-\frac{1}{2},0}))$$
$$+ \chi_2(\mathrm{Re}(\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{1}{2},0})\,\mathrm{Im}(\mathcal{H}(\kappa(700))^{\frac{1}{2}}_{\frac{1}{2},0}) - \mathrm{Im}(\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{1}{2},0})\,\mathrm{Re}(\mathcal{H}(\kappa(700))^{\frac{1}{2}}_{\frac{1}{2},0})$$
$$+ \mathrm{Re}(\mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{1}{2},0})\,\mathrm{Im}(\mathcal{H}(\kappa(700))^{-\frac{1}{2}}_{-\frac{1}{2},0}) - \mathrm{Im}(\mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{1}{2},0})\,\mathrm{Re}(\mathcal{H}(\kappa(700))^{|\frac{1}{2}}_{-\frac{1}{2},0})),$$

$$c = \chi_1(|\mathcal{H}(k^{*0})^{\frac{1}{2}}_{\frac{3}{2},1}|^2 + \mathcal{H}(k^{*0})^{-\frac{1}{2}}_{-\frac{3}{2},-1}|^2 + \mathcal{H}(k^{*0})^{\frac{1}{2}}_{-\frac{1}{2},-1}|^2 + \mathcal{H}(k^{*0})^{-\frac{1}{2}}_{\frac{1}{2},1}|^2)$$
$$+ \chi_3(|\mathcal{H}(\kappa(700))^{\frac{1}{2}}_{\frac{1}{2},0}|^2 + |\mathcal{H}(\kappa(700))^{-\frac{1}{2}}_{-\frac{1}{2},0}|^2),$$

Backup

Why are the uncertainties so large?

	BR	Direct CP(10^{-2})
($\Lambda_b^0 \to p k^- \pi^0$)		
$\Lambda(1520)\pi^0$	$6.90^{+12.47}_{-4.31} \times 10^{-9}$	$17.4^{+6.9}_{-7.3}$
($\Lambda_b^0 \to p k^- \pi^+ \pi^-$)		
$\Lambda(1520) f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
$\Lambda(1520)\rho^0$	$8.51^{+7.58}_{-3.33} \times 10^{-7}$	$25.7^{+16.3}_{-12.8}$
$\Lambda(1520) f_0(500)$	$9.28^{+11.50}_{-5.42} \times 10^{-7}$	$-1.0^{+1.1}_{-0.7}$
($\Lambda_b^0 \to p k^- k^+ k^-$)		
$\Lambda(1520)\phi$	$9.16^{+10.73}_{-5.29} \times 10^{-5}$	$-0.5^{+0.4}_{-1.3}$
$\Lambda(1520) f_0(980)$	$6.01^{+6.98}_{-3.47} \times 10^{-6}$	$2.9^{+3.8}_{-1.6}$
($\Lambda_b^0 \to p k^- k^+ \pi^-$)		
$\Lambda(1520) k^{*0}$	$1.79^{+1.98}_{-0.92} \times 10^{-5}$	$-6.3^{+5.0}_{-1.7}$
$\Lambda(1520)\kappa(700)$	$1.64^{+1.87}_{-0.93} \times 10^{-7}$	$24.2^{+17.3}_{-17.8}$
($\Xi_b^- \to p k^- k^-$)		
$\Lambda(1520) k^-$	$1.79^{+2.03}_{-1.02} \times 10^{-6}$	$-3.4^{+7.9}_{-6.7}$

	B	$\bar{B}$	A	$\bar{A}$	$a^B_{CP}(10^{-2})$	$a^A_{CP}(10^{-2})$
$\Lambda_b^0 \to p k^- \pi^+ \pi^-$	$-1.05^{+0.63}_{-0.81}$	$1.36^{+1.05}_{-0.82}$	$0.66^{+1.86}_{-0.53}$	$0.42^{+1.79}_{-0.39}$	$-100.0^{+0.0}_{-0.0}$	$21.8^{+40.9}_{-15.3}$
$\Lambda_b^0 \to p k^- k^+ k^-$	$0.11^{+0.02}_{-0.02}$	$0.10^{+0.00}_{-0.03}$	$0.08^{+0.09}_{-0.04}$	$0.07^{+0.06}_{-0.03}$	$2.7^{+23.5}_{-5.7}$	$6.1^{+8.6}_{-7.1}$
$\Lambda_b^0 \to p k^- k^+ \pi^-$	$0.04^{+0.09}_{-0.10}$	$0.09^{+0.00}_{-0.13}$	$4.29^{+0.00}_{-1.07}$	$5.56^{+4.64}_{-3.27}$	$-19.0^{+32.8}_{-24.0}$	$-12.9^{+29.8}_{-27.9}$

$$\boxed{\mathcal{F}(\Lambda, m_k) = \frac{\Lambda^4}{(k^2 - m_k^2)^2 + \Lambda^4}}$$

0.5 VS 1.0

Backup

$$\mathcal{L}_{SPP} = -\gamma_{SPP} S \partial_\mu P \partial^\mu P$$

$$\mathcal{L}_{SVV} = \frac{g_{SVV}}{m_V}(\partial^\alpha V^\beta \partial_\alpha V_\beta - \partial^\alpha V^\beta \partial_\beta V_\alpha) S$$

$$\mathcal{L}_{SB_8B_8} = -g_{SBB} \bar{B}_8 S B_8$$

$$\mathcal{L}^{1520}_{PB_8\Lambda} = \frac{f^{1520}_{PB_8\Lambda}}{m_P} \bar{B}_8 \gamma_5 \partial_\sigma P \Lambda^\sigma + h.c.$$

$$\mathcal{L}^{1520}_{VB_8\Lambda} = \frac{ig^{1520}_{VB_8\Lambda}}{m_V^2} \bar{B}_8 \sigma_{\mu\nu} \partial^\nu \partial_\sigma V^\mu \Lambda^\sigma + h.c.$$

$$\mathcal{L}^{1520}_{PB_{10}\Lambda} = \frac{f^{1520}_{PB_{10}\Lambda}}{m_P} \bar{\Lambda}^\sigma \gamma^\mu B_{10\sigma} \partial_\mu P$$

Backup

Table 2: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520)\pi^0(10^{-7})$ with different CKM factors

decay modes	$H_{-\frac{1}{2}}$ $(V_{ub}V_{us}^*)$	$H_{-\frac{1}{2}}$ $(V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2}}$ $(V_{tb}V_{ts}^*)$	$H_{\frac{1}{2}}$ $(V_{ub}V_{us}^*)$	$H_{\frac{1}{2}}$ $(V_{cb}V_{cs}^*)$	$H_{\frac{1}{2}}$ $(V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520)\pi^0)$	0.20 i	—	0.03 i	1.16 i	—	0.16 i
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520)\pi^0)$	1.26+10.07 i	—	-0.003+0.07 i	1.85+10.40 i	—	-0.008+0.03 i

Table 3: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520) + \rho(10^{-7})$ with different CKM factors

decay modes	$H_{\frac{3}{2},1}$ $(V_{ub}V_{us}^*)$	$H_{\frac{3}{2},1}$ $(V_{cb}V_{cs}^*)$	$H_{\frac{3}{2},1}$ $(V_{tb}V_{ts}^*)$	$H_{-\frac{3}{2},-1}$ $(V_{ub}V_{us}^*)$	$H_{-\frac{3}{2},-1}$ $(V_{cb}V_{cs}^*)$	$H_{-\frac{3}{2},-1}$ $(V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \rho)$	0.00	—	0.00	0.00	—	0.00
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \rho)$	0.36-3.56 i	—	0.01-0.02i	-20.61-4.58 i	—	-0.12-0.07 i
decay modes	$H_{\frac{1}{2},0}$ $(V_{ub}V_{us}^*)$	$H_{\frac{1}{2},0}$ $(V_{cb}V_{cs}^*)$	$H_{\frac{1}{2},0}$ $(V_{tb}V_{ts}^*)$	$H_{-\frac{1}{2},0}$ $(V_{ub}V_{us}^*)$	$H_{-\frac{1}{2},0}$ $(V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2},0}$ $(V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \rho)$	1.87	—	0.19	-0.15	—	-0.02
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \rho)$	130.12+31.69 i	—	0.66+0.48 i	-20.91+27.56 i	—	-0.09+0.10 i
decay modes	$H_{-\frac{1}{2},-1}$ $(V_{ub}V_{us}^*)$	$H_{-\frac{1}{2},-1}$ $(V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2},-1}$ $(V_{tb}V_{ts}^*)$	$H_{\frac{1}{2},1}$ $(V_{ub}V_{us}^*)$	$H_{\frac{1}{2},1}$ $(V_{cb}V_{cs}^*)$	$H_{\frac{1}{2},1}$ $(V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \rho)$	-4.54	—	-0.46	0.41	—	0.04
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \rho)$	-47.92-12.12i	—	-0.29-0.19 i	15.65-3.63 i	—	0.11+0.02 i

Backup

Table 4: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520) + f_0(980)(10^{-7})$ with different CKM factors

decay modes	$H_{-\frac{1}{2}}\ (V_{ub}V_{us}^*)$	$H_{-\frac{1}{2}}\ (V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2}}\ (V_{tb}V_{ts}^*)$	$H_{\frac{1}{2}}\ (V_{ub}V_{us}^*)$	$H_{\frac{1}{2}}\ (V_{cb}V_{cs}^*)$	$H_{\frac{1}{2}}\ (V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + f_0(980))$	—	—	-0.60	—	—	-0.31
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + f_0(980))$	-3.63-2.57 i	—	0.35+0.11i	-7.70-3.37 i	—	0.03+0.02 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + f_0(980))$	—	-2.63-1.36i	0.20-0.29i	—	-2.79+9.99 i	-0.18+0.67 i

Table 5: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520) + \phi(10^{-7})$ with different CKM factors

decay modes	$H_{\frac{3}{2},1}\ (V_{ub}V_{us}^*)$	$H_{\frac{3}{2},1}\ (V_{cb}V_{cs}^*)$	$H_{\frac{3}{2},1}\ (V_{tb}V_{ts}^*)$	$H_{-\frac{3}{2},-1}\ (V_{ub}V_{us}^*)$	$H_{-\frac{3}{2},-1}\ (V_{cb}V_{cs}^*)$	$H_{-\frac{3}{2},-1}\ (V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	—	—	0.00	—	—	0.00
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	5.71 - 0.98 i	—	0.14 + 0.03i	-1.17 + 0.61 i	—	-0.07 - 0.03 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	—	7.38 + 4.55 i	0.07 + 0.04i	—	2.42 + 0.92 i	-0.25 - 0.27 i
decay modes	$H_{\frac{1}{2},0}\ (V_{ub}V_{us}^*)$	$H_{\frac{1}{2},0}\ (V_{cb}V_{cs}^*)$	$H_{\frac{1}{2},0}\ (V_{tb}V_{ts}^*)$	$H_{-\frac{1}{2},0}\ (V_{ub}V_{us}^*)$	$H_{-\frac{1}{2},0}\ (V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2},0}\ (V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	—	—	-0.48	—	—	0.12
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	14.84 - 9.15 i	—	-0.15 + 0.07 i	-7.50 + 2.61 i	—	0.34 + 0.01 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	—	4.04 - 5.28 i	1.44 + 1.12 i	—	-21.70 - 0.05 i	0.08 - 1.54 i
decay modes	$H_{-\frac{1}{2},-1}\ (V_{ub}V_{us}^*)$	$H_{-\frac{1}{2},-1}\ (V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2},-1}\ (V_{tb}V_{ts}^*)$	$H_{\frac{1}{2},1}\ (V_{ub}V_{us}^*)$	$H_{\frac{1}{2},1}\ (V_{cb}V_{cs}^*)$	$H_{\frac{1}{2},1}\ (V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	—	—	1.51	—	—	-0.14
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	-8.56 + 0.66i	—	-0.22 - 0.01 i	14.90 - 3.32 i	—	0.04 + 0.02 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + \phi)$	—	17.16 + 9.68i	0.11 - 1.43i	—	15.30 + 18.29i	0.30 + 0.13 i

Backup

Table 6: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520) + f_0(500)(10^{-7})$ with different CKM factors

decay modes	$H_{-\frac{1}{2}}$ $(V_{ub}V_{us}^*)$	$H_{-\frac{1}{2}}$ $(V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2}}$ $(V_{tb}V_{ts}^*)$	$H_{\frac{1}{2}}$ $(V_{ub}V_{us}^*)$	$H_{\frac{1}{2}}$ $(V_{cb}V_{cs}^*)$	$H_{\frac{1}{2}}$ $(V_{tb}V_{ts}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + f_0(500))$	—	—	0.10	—	—	0.03
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + f_0(500))$	8.64-0.63 i	—	0.29+0.09i	2.08-1.95 i	—	-0.33-0.03 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + f_0(500))$	—	-0.87-0.44i	0.06-0.12 i	—	-0.71+3.95 i	-0.06+0.26 i

Table 7: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520) + k^{*0}(10^{-7})$ with different CKM factors

decay modes	$H_{\frac{3}{2},1}$ $(V_{ub}V_{ud}^*)$	$H_{\frac{3}{2},1}$ $(V_{cb}V_{cd}^*)$	$H_{\frac{3}{2},1}$ $(V_{tb}V_{td}^*)$	$H_{-\frac{3}{2},-1}$ $(V_{ub}V_{ud}^*)$	$H_{-\frac{3}{2},-1}$ $(V_{cb}V_{cd}^*)$	$H_{-\frac{3}{2},-1}$ $(V_{tb}V_{td}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	—	—	0.00	—	—	0.00
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	5.10 + 1.63 i	—	-0.97 - 0.36i	23.83+12.42 i	—	0.70+0.06 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	—	5.55+3.47 i	0.06+0.04i	—	1.27-0.08i	-0.20-0.21 i
decay modes	$H_{\frac{1}{2},0}$ $(V_{ub}V_{ud}^*)$	$H_{\frac{1}{2},0}$ $(V_{cb}V_{cd}^*)$	$H_{\frac{1}{2},0}$ $(V_{tb}V_{td}^*)$	$H_{-\frac{1}{2},0}$ $(V_{ub}V_{ud}^*)$	$H_{-\frac{1}{2},0}$ $(V_{cb}V_{cd}^*)$	$H_{-\frac{1}{2},0}$ $(V_{tb}V_{td}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	—	—	-0.56	—	—	0.09
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	-88.26 - 68.21 i	—	-3.76 + 0.03 i	11.91-18.78i	—	5.20+1.07 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	—	15.64+15.18i	1.88+1.09 i	—	-26.34+14.14 i	0.29-1.86 i
decay modes	$H_{-\frac{1}{2},-1}$ $(V_{ub}V_{ud}^*)$	$H_{-\frac{1}{2},-1}$ $(V_{cb}V_{cd}^*)$	$H_{-\frac{1}{2},-1}$ $(V_{tb}V_{td}^*)$	$H_{\frac{1}{2},1}$ $(V_{ub}V_{ud}^*)$	$H_{\frac{1}{2},1}$ $(V_{cb}V_{cd}^*)$	$H_{\frac{1}{2},1}$ $(V_{tb}V_{td}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	—	—	1.55	—	—	-0.14
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	44.59 + 33.59i	—	1.79 + 0.43 i	8.73 - 1.48 i	—	-2.53 - 1.13 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + k^{*0})$	—	19.03+6.61i	0.29-1.42i	—	14.29+26.01i	0.37+0.31 i

Backup

Table 8: Helicity amplitudes of $\Lambda_b^0 \to \Lambda(1520) + \kappa(700)(10^{-7})$ with different CKM factors

decay modes	$H_{-\frac{1}{2}}\,(V_{ub}V_{ud}^*)$	$H_{-\frac{1}{2}}\,(V_{cb}V_{cd}^*)$	$H_{-\frac{1}{2}}\,(V_{tb}V_{td}^*)$	$H_{\frac{1}{2}}\,(V_{ub}V_{ud}^*)$	$H_{\frac{1}{2}}\,(V_{cb}V_{cd}^*)$	$H_{\frac{1}{2}}\,(V_{tb}V_{td}^*)$
$\mathcal{S}(\Lambda_b^0 \to \Lambda(1520) + \kappa(700))$	—	—	-0.29	—	—	-0.68
$\mathcal{NC}(\Lambda_b^0 \to \Lambda(1520) + \kappa(700))$	-5.30-5.88 i	—	0.03-0.04i	-4.97-2.76 i	—	0.04+0.09 i
$\mathcal{C}(\Lambda_b^0 \to \Lambda(1520) + \kappa(700))$	—	-1.30-0.79i	0.04+0.13i	—	-3.23-5.41i	0.06-0.23 i

Table 9: Helicity amplitudes of $\Xi_b^- \to \Lambda(1520)K^-(10^{-7})$ with different CKM factors

decay modes	$H_{-\frac{1}{2}}\,(V_{ub}V_{us}^*)$	$H_{-\frac{1}{2}}\,(V_{cb}V_{cs}^*)$	$H_{-\frac{1}{2}}\,(V_{tb}V_{ts}^*)$	$H_{\frac{1}{2}}\,(V_{ub}V_{us}^*)$	$H_{\frac{1}{2}}\,(V_{cb}V_{cs}^*)$	$H_{\frac{1}{2}}\,(V_{tb}V_{ts}^*)$
$\mathcal{S}(\Xi_b^- \to \Lambda(1520)K^-)$	-5.61 i	—	-0.86 i	-21.14 i	—	-0.68 i
$\mathcal{NC}(\Xi_b^- \to \Lambda(1520)K^-)$	-1.06-1.30 i	—	-0.007+0.51 i	-1.64+12.51 i	—	-0.04+0.54 i
$\mathcal{C}(\Xi_b^- \to \Lambda(1520)K^-)$	—	-0.61-0.21i	0.19+0.09 i	—	4.37+2.99 i	0.16+0.04 i

Backup

$$
\begin{aligned}
\mathcal{A}(\Lambda_b \to \Lambda(1520)K^{*0}) = {} & \mathcal{S}(\Lambda_b \to \Lambda(1520)K^{*0}) + \mathcal{M}(\pi^-, p; K^-) + \mathcal{M}(\rho^-, p; K^-) + \mathcal{M}(\pi^-, p; K^{*-}) \\
& + \mathcal{M}(\rho^-, p; K^{*-}) + \mathcal{M}(D^-, \Lambda_c^+; D_s^-) + \mathcal{M}(D^{*-}, \Lambda_c^+; D_s^-) + \mathcal{M}(D^-, \Lambda_c^+; D_s^{*-}) \\
& + \mathcal{M}(D^{*-}, \Lambda_c^+; D_s^{*-}) + \mathcal{M}(\pi^-, p; \Sigma^+) + \mathcal{M}(\rho^-, p; \Sigma^+) + \mathcal{M}(D^-, \Lambda_c^+; \Xi_c^+) \\
& + \mathcal{M}(D^{*-}, \Lambda_c^+; \Xi_c^+) + \mathcal{M}(K^0, \Lambda; \eta) + \mathcal{M}(K^0, \Lambda; \phi) + \mathcal{M}(K^0, \Lambda; \omega) \\
& + \mathcal{M}(K^{*0}, \Lambda; \eta) + \mathcal{M}(K^{*0}, \Lambda; \phi) + \mathcal{M}(K^{*0}, \Lambda; \omega) + \mathcal{M}(\pi^0, n; \bar{K}^0) + \mathcal{M}(\eta, n; \bar{K}^0) \\
& + \mathcal{M}(\rho^0, n; \bar{K}^0) + \mathcal{M}(\phi, n; \bar{K}^0) + \mathcal{M}(\omega, n; \bar{K}^0) + \mathcal{M}(\pi^0, n; \bar{K}^{*0}) + \mathcal{M}(\eta, n; \bar{K}^{*0}) \\
& + \mathcal{M}(\rho^0, n; \bar{K}^{*0}) + \mathcal{M}(\phi, n; \bar{K}^{*0}) + \mathcal{M}(\omega, n; \bar{K}^{*0}) + \mathcal{M}(K^0, \Lambda; \Xi^0) + \mathcal{M}(K^{*0}, \Lambda; \Xi^0) \\
& + \mathcal{M}(\eta, n; \Lambda) + \mathcal{M}(\phi, n; \Lambda) + \mathcal{M}(\omega, n; \Lambda) + \mathcal{M}(\pi^0, n; \Sigma^0) + \mathcal{M}(\pi^0, n; \Sigma^{*0}) \\
& + \mathcal{M}(\rho^0, n; \Sigma^0)
\end{aligned} \tag{A.6}
$$

$$
\begin{aligned}
\mathcal{A}(\Lambda_b \to \Lambda(1520)K(700)) = {} & \mathcal{S}(\Lambda_b \to \Lambda(1520)K(700)) + \mathcal{M}(\pi^-, p; K^-) + +\mathcal{M}(D^-, \Lambda_c^+; D_s^-) \\
& + \mathcal{M}(\pi^-, p; \Sigma^+) + \mathcal{M}(\rho^-, p; \Sigma^+) + \mathcal{M}(D^-, \Lambda_c^+; \Xi_c^+) + \mathcal{M}(D^{*-}, \Lambda_c^+; \Xi_c^+) \\
& + \mathcal{M}(K^0, \Lambda; \eta) + \mathcal{M}(\pi^0, n; \bar{K}^0) + \mathcal{M}(\eta, n; \bar{K}^0) + \mathcal{M}(K^0, \Lambda; \Xi^0) + \mathcal{M}(K^{*0}, \Lambda; \Xi^0) \\
& + \mathcal{M}(\eta, n; \Lambda) + \mathcal{M}(\phi, n; \Lambda) + \mathcal{M}(\omega, n; \Lambda) + \mathcal{M}(\pi^0, n; \Sigma^0) + \mathcal{M}(\rho^0, n; \Sigma^0)
\end{aligned} \tag{A.7}
$$