# 重子电弱衰变中的末态重散射机制

## $\Lambda_b^0 \to p\pi^-, pK^-, p\rho^-, pK^{*-}, \Lambda\phi$衰变的$CP$破坏分析

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# 内容

# 2018年及以前研究重子衰变的一些文献

## References


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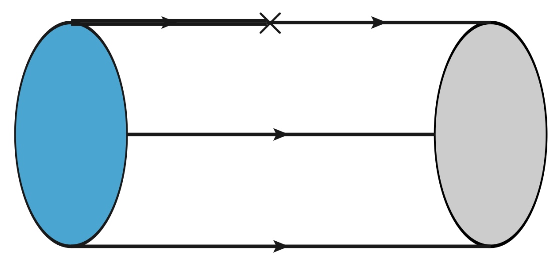
主要是基于SU(3)对称性的分析和形状因子的计算。



# Motivation


季 第09集

我提个问题 为什么要做这个
Here is the question. Why?

因为我们可以做到
Because we can.

# Motivation

## 我们对重子衰变的研究开始于寻找双重重子的需求

$$\Xi_{cc}^{++}, \Xi_{cc}^{+}, \Omega_{cc}^{+}, \Xi_{bc}^{+}, \Xi_{bc}^{0}, \Omega_{bc}^{0}, \Xi_{bb}^{0}, \Xi_{bb}^{-}, \Omega_{bb}^{-}$$

**Which one? Which decay channel?**

## 实验数据的积累推动理论研究的前进

***Accuracy improvement***

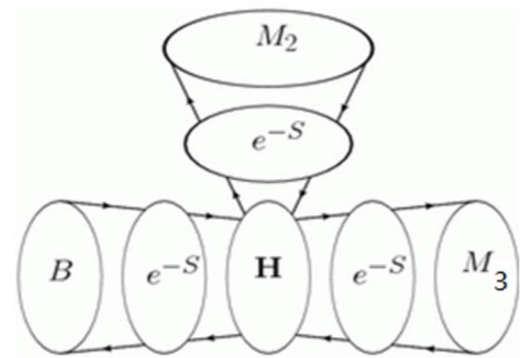
***CP* violations in baryon decays**

# 重子衰变的计算方案

## 重味介子衰变的计算依赖于“因子化方案”

### Two body nonleptonic B decays in pQCD

- Wave functions: universal inputs
- Sudakov factors: process independent functions
- Hard kernel: specific to decays




$$
\begin{aligned}
&\langle M_2(k_2)M_3(k_3)|C_iO_i|B(k_1)\rangle \\
&\sim \int_0^1 dx_1dx_2dx_3 \int d^2b_1d^2b_2d^2b_3\Phi_1(x_1,b_1)\Phi_2(x_2,b_2)\Phi_3(x_3,b_3) \\
&\times S_1(t,b_1)S_2(t,b_2)S_3(t,b_3)H(x_1,x_2,x_3,b_1,b_2,b_3,t)J(x_i)C(t)
\end{aligned}
$$

重子有三个价夸克，衰变动力学更复杂，没有被证明过的因子化方案。

# 重子衰变的计算方案

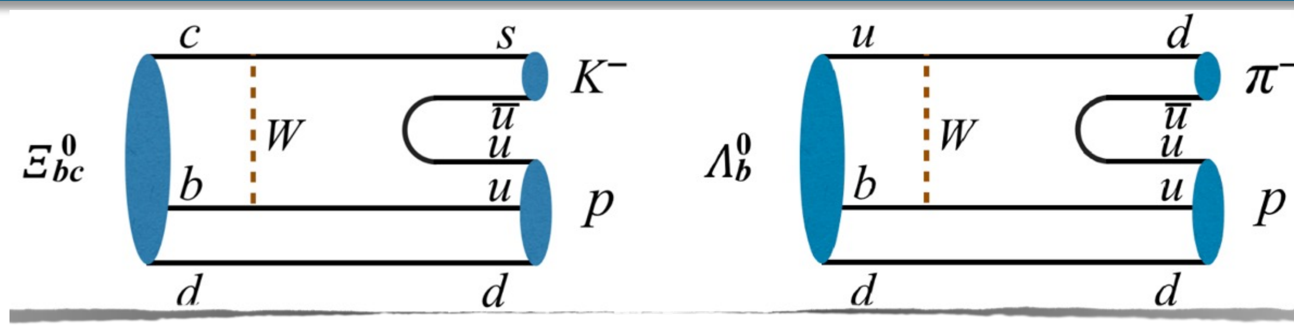
之前的理论研究基本都是形状因子的计算，没有系统的计算方案。

## 1 通过动力学机制的相似性进行估算

$\Xi_{bc}^0 \to pK^-$

VS

$\Lambda_b^0 \to p\pi^-$

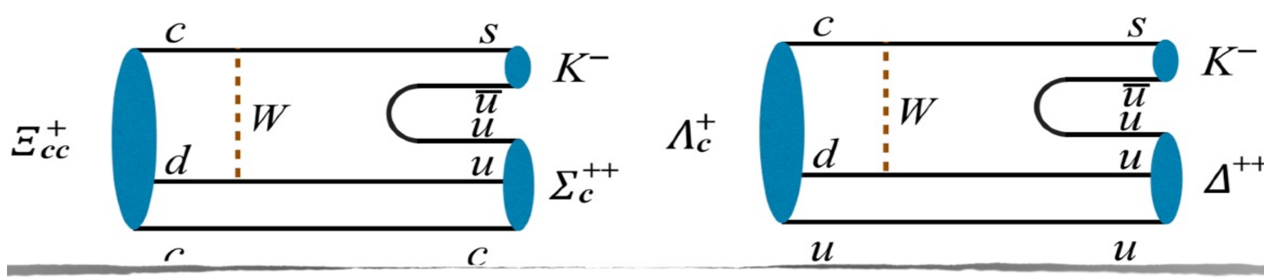



$$\mathcal{BR}(\Xi_{bc} \to p^+K^-) \approx 3.21 \times \mathcal{R}_f^2 \times \mathcal{R}_\tau \times 10^{-7}$$

$\Xi_{cc}^+ \to \Sigma_c^{++}(2520)K^-$

VS

$\Lambda_c^+ \to \Delta^{++}K^-$




$$\mathcal{BR}(\Xi_{cc}^+ \to \Sigma_c^{++}(2520)K^-) \in [0.36\%, 1.80\%]$$

**R.H. Li**, C.D. Lv, W. Wang, F.S. Yu, Z.T. Zou, PLB 757,232-235

# 重子衰变的计算方案

## 2 将PQCD因子化方法的框架进行拓展

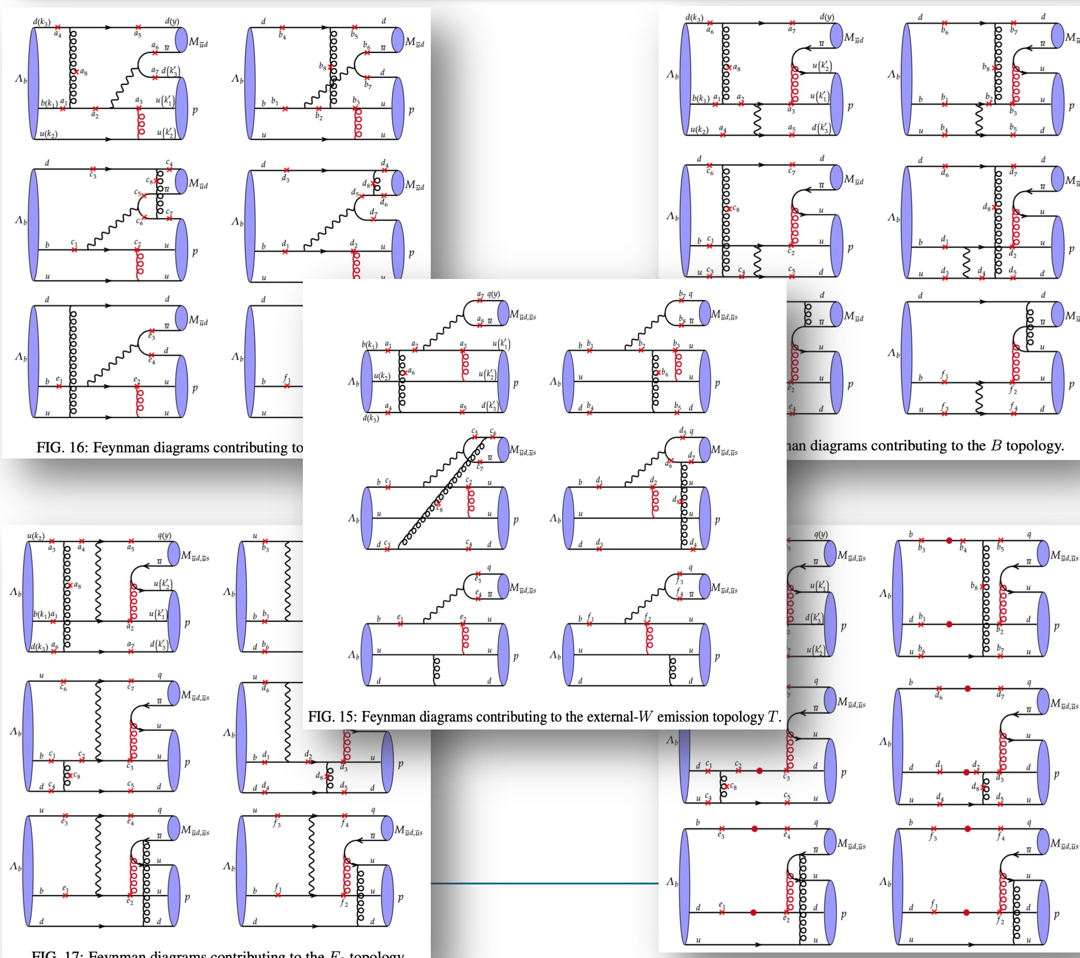


FIG. 16: Feynman diagrams contributing to

…an diagrams contributing to the $B$ topology.

FIG. 15: Feynman diagrams contributing to the external-$W$ emission topology $T$.

FIG. 17: Feynman diagrams contributing to the $E_2$ topology.

J.J. Han, J.X. Yu, Y. Li, H.n. Li, J.P. Wang, Z.J. Xiao, F.S. Yu,

- e-Print: 2506.07197;
- PRL 134 (2025) 22, 221801

# 重子衰变的计算方案

## 3 利用光锥求和规则方法计算部分衰变

An approach proposed by: A. Khodjamirian, Nucl. Phys. B 605, 558-578 (2001) for $B \to \pi\pi$

**To calculate a matrix element:**

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_{cs} V_{ud}^* \left(C_1 \mathcal{O}_1 + C_2 \mathcal{O}_2\right)$$

$$\langle \Xi^0(p-q) K^+(q) | \mathcal{O}_i(0) | \Lambda_c^+(p) \rangle$$
$$= i\, \bar{u}_{\Xi}(p-q)(A^i - B^i \gamma_5) u_{\Lambda_c}(p).$$

Y.J. Shi, Z.X. Zhao, PRD 110 (2024) 9, 096015

**One defines a correlation function:**

$$\Pi^{\mathcal{O}_i}(p,q,k) = i^2 \int d^4x\, e^{-i(p-q)\cdot x} \int d^4y\, e^{i(p-k)\cdot y}$$
$$\times \langle 0 | T \left\{ J_{\Xi}(y) \mathcal{O}_i(0) \bar{J}_{\Lambda_c}(x) \right\} \underline{|K^-(q)\rangle}$$

$$\left.\begin{aligned} J_{\Xi} &= \varepsilon_{ijk} \left(s_i^T C \gamma^\mu s_j\right) \gamma_\mu \gamma_5 Q_k, \\ J_{\Lambda_c} &= \varepsilon_{ijk} \left(u_i^T C \gamma_5 d_j\right) Q_k. \end{aligned}\right\}$$

Baryon currents

Firstly set Kaon as an initial state

# 重子衰变的计算方案

## 4　利用极点模型进行计算

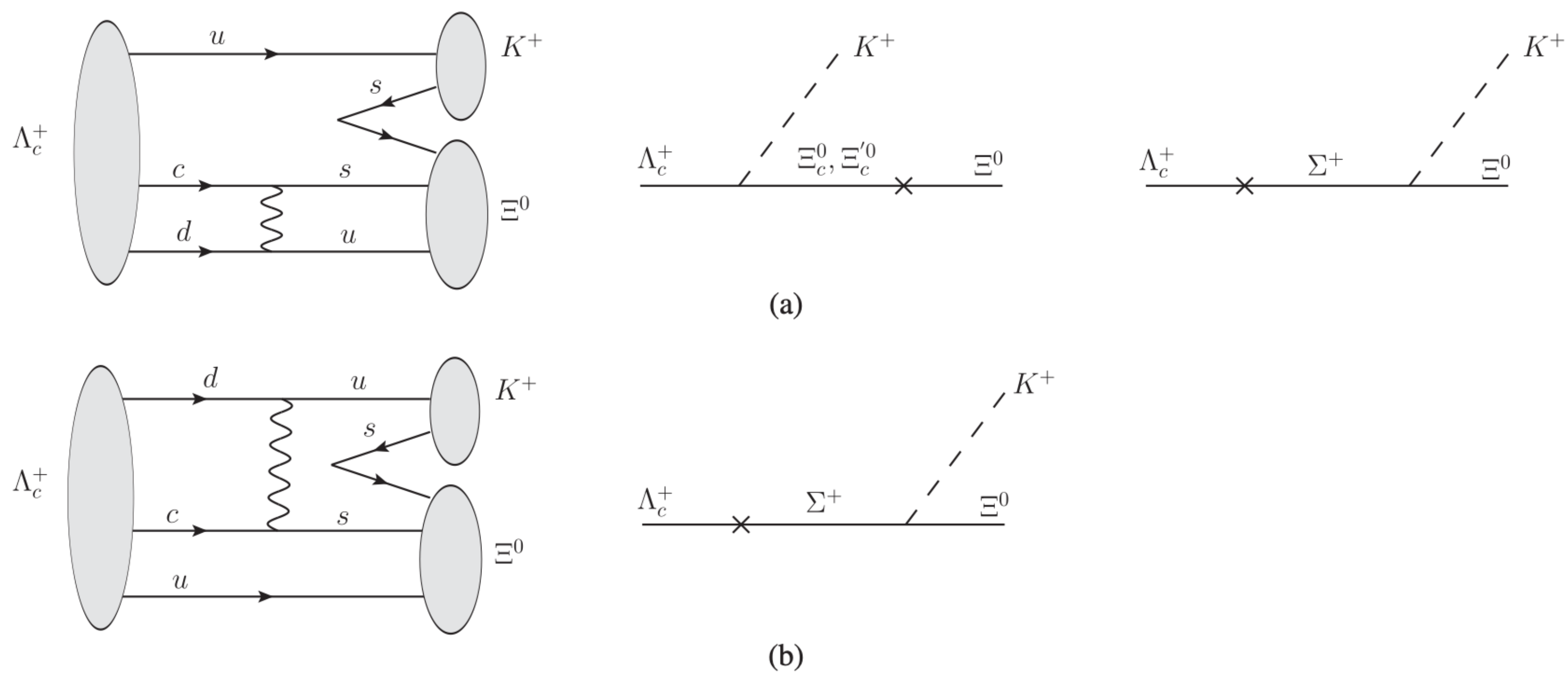



FIG. 1. $W$-exchange diagrams contributing to $\Lambda_c^+ \to \Xi^0 K^+$. The corresponding pole diagrams are also shown.

J. Zou, F. Xu, G. Meng and H. Y. Cheng, Phys. Rev. D 101, no.1, 014011 (2020)

# 重子衰变的计算方案

## 5 将末态相互作用机制推广到重子衰变中

对于衰变$B \to i$,有

$$\begin{aligned}\langle i;\mathrm{out}|Q|B;\mathrm{in}\rangle^* &= \sum_j \langle i;\mathrm{out}|\,j;\mathrm{in}\rangle\langle j;\mathrm{out}|Q|B;\mathrm{in}\rangle \\ &= \sum_j S_{ji}^*\langle j;\mathrm{out}|Q|B;\mathrm{in}\rangle.\end{aligned}$$

利用$S=1+iT$,有

$$2\,\mathcal{A}bs\,\langle i;\mathrm{out}|Q|B;\mathrm{in}\rangle = \sum_j T_{ji}^*\langle j;\mathrm{out}|Q|B;\mathrm{in}\rangle$$

H.Y. Cheng, C.K. Chua, A. Soni, PRD 71,014030

# 重子衰变的计算方案

对于一个两体末态衰变，振幅的虚部为

$$Abs\, M(p_B \to p_1 p_2) = \frac{1}{2}\sum_j \left(\Pi_{k=1}^{j}\int \frac{d^3\vec{q}_k}{(2\pi)^3 2E_k}\right)(2\pi)^4\delta^4(p_1+p_2-\sum_{k=1}^{j} q_k)$$
$$\times\, M(p_B \to \{q_k\})\, T^*(p_1 p_2 \to \{q_k\}).$$

Weak decay at short distance.

Strong interactions at long distance.

实部可以通过色散关系求得

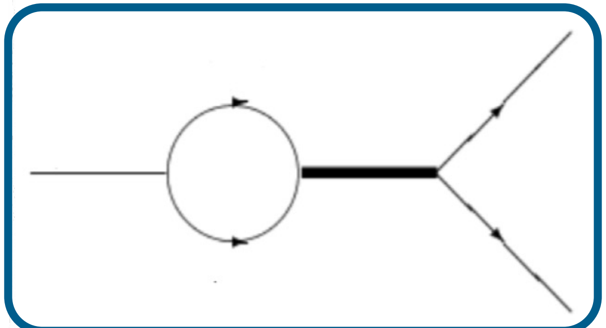
$$\mathcal{D}is\, A(m_B^2) = \frac{1}{\pi}\int_s^\infty \frac{\mathcal{A}bs\, A(s')}{s'-m_B^2} ds'$$

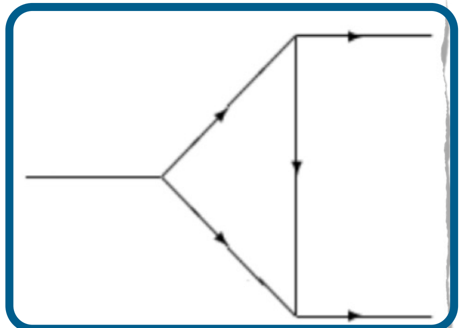
在计算分支比时，其不占主要贡献，被忽略

H.Y. Cheng, C.K. Chua, A. Soni, PRD 71,014030

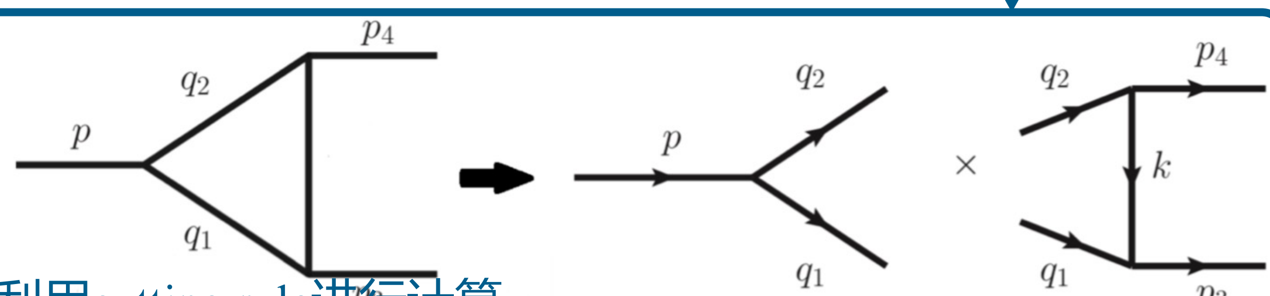
# 末态重散射机制的计算框架

将弱衰变处理成一个等效顶点，利用强子层次的手征拉氏量进行计算。可能会出现两种形式的贡献：





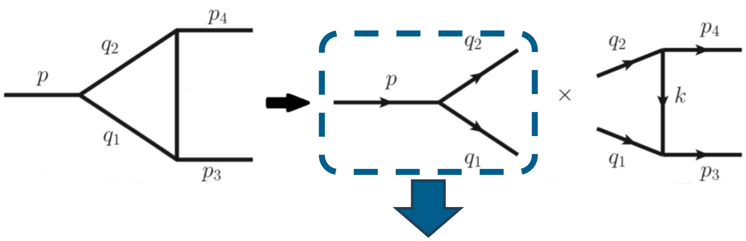
被离壳效应压低，忽略



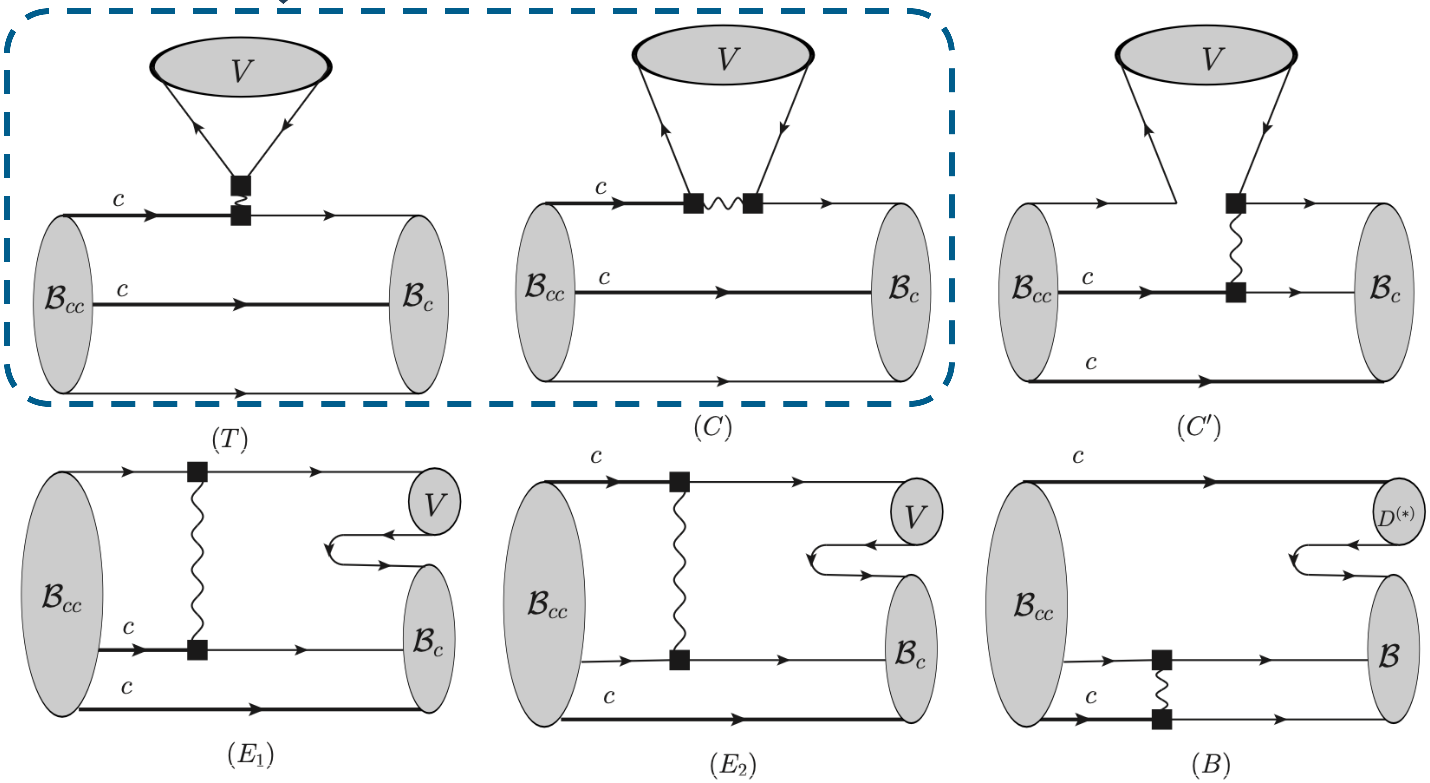

利用cutting rule进行计算

H.Y. Cheng, C.K. Chua, A. Soni, PRD 71,014030

# 末态重散射机制的计算框架

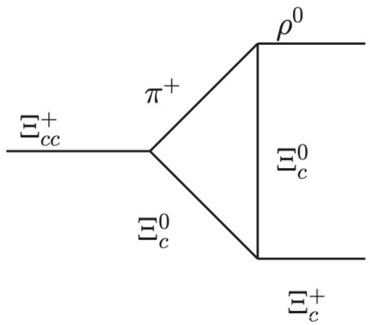



在目前的计算中弱顶点只考虑了T图和C图的贡献。原因：贡献大、容易计算




$$\frac{|C|}{|T|} \sim \frac{|C'|}{|C|} \sim \frac{|E_1|}{|C|} \sim \frac{|E_2|}{|C|} \sim \frac{|B|}{|C|} \sim \mathcal{O}\left(\frac{\Lambda_{QCD}}{m_Q}\right)$$

# 末态重散射机制的计算框架

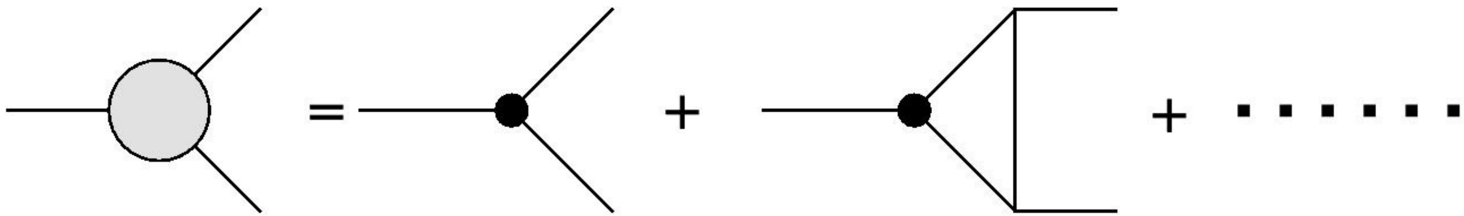



$$
\begin{aligned}
&\mathcal{A}bs\, M_b(\pi^+;\Xi_c^0;\Xi_c^0) \\
= \quad & i\int \frac{|\vec{p_2}|sin\theta d\theta d\varphi}{32\pi^2 m_{\Xi_{cc}^+}} \frac{G_F}{\sqrt{2}} V_{cs}^* V_{ud} a_1 f_\pi g_{\Xi_c^+\Xi_c^0\pi^+} \frac{F^2(t,m_{\Xi_c^0})}{t-m_{\Xi_c^0}^2} \epsilon_6^{*\nu} \\
& \times \overline{u}(p_5,s_z')\gamma_5(\not{p}_4+m_{\Xi_c^0})\left(f_{1\Xi_c^0\Xi_c^0\rho^0}\gamma_\nu + i\frac{f_{2\Xi_c^0\Xi_c^0\rho^0}}{2m_{\Xi_c^0}}\sigma_{\mu\nu}p_6^\mu\right) \\
& \times(\not{p}_3+m_{\Xi_c^0})\left[(m_{\Xi_{cc}^+}-m_{\Xi_c^0})f_1(m_\pi^2)+(m_{\Xi_{cc}^+}+m_{\Xi_c^0})g_1(m_\pi^2)\gamma_5\right]u(p_1,s_z)
\end{aligned}
$$

$$
F(t,m)=\left(\frac{\Lambda^2-m^2}{\Lambda^2-t}\right)^n \qquad \Lambda = m+\eta\Lambda_{\mathrm{QCD}}
$$

# 末态重散射机制的计算框架

## 对于包含T图贡献的衰变，短程的T图贡献占主导，其振幅形式为

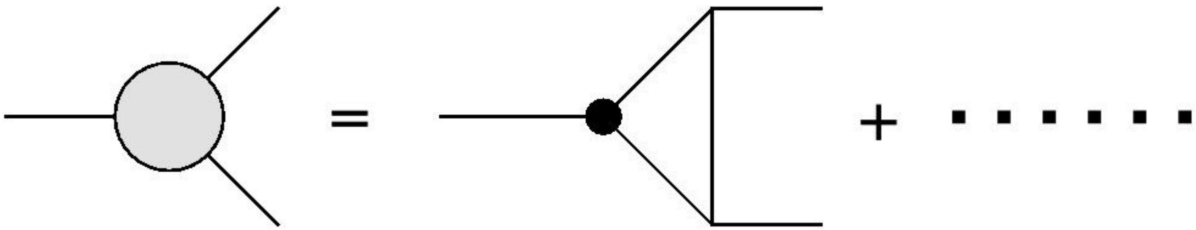


## 例:

$$
\begin{aligned}
&\mathcal{A}(\Xi_{cc}^{++} \to \Xi_c^{+} \rho^{+}) \\
&= T_{\rm SD}(\Xi_{cc}^{++} \to \Xi_c^{+} \rho^{+}) + i[\mathcal{M}(\Xi_{cc}^{++}, \pi^{+}, \Xi_c^{+}, \pi^{0}, \rho^{+}, \Xi_c^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \rho^{+}, \Xi_c^{+}, \rho^{0}, \rho^{+}, \Xi_c^{+}) \\
&+\mathcal{M}(\Xi_{cc}^{++}, \pi^{+}, \Xi_c^{\prime +}, \pi^{0}, \rho^{+}, \Xi_c^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \rho^{+}, \Xi_c^{\prime +}, \rho^{0}, \rho^{+}, \Xi_c^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \pi^{+}, \Xi_c^{+}, \Xi_c^{0}, \Xi_c^{+}, \rho^{+}) \\
&+\mathcal{M}(\Xi_{cc}^{++}, \rho^{+}, \Xi_c^{+}, \Xi_c^{0}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \pi^{+}, \Xi_c^{+}, \Xi_c^{\prime 0}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \rho^{+}, \Xi_c^{+}, \Xi_c^{\prime 0}, \Xi_c^{+}, \rho^{+}) \\
&+\mathcal{M}(\Xi_{cc}^{++}, \pi^{+}, \Xi_c^{\prime +}, \Xi_c^{0}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \rho^{+}, \Xi_c^{\prime +}, \Xi_c^{0}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \pi^{+}, \Xi_c^{\prime +}, \Xi_c^{\prime 0}, \Xi_c^{+}, \rho^{+}) \\
&+\mathcal{M}(\Xi_{cc}^{++}, \rho^{+}, \Xi_c^{\prime +}, \Xi_c^{\prime 0}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \bar{K}^{0}, \Sigma_c^{++}, K^{+}, \rho^{+}, \Xi_c^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \bar{K}^{*0}, \Sigma_c^{++}, K^{*+}, \rho^{+}, \Xi_c^{+}) \\
&+\mathcal{M}(\Xi_{cc}^{++}, \bar{K}^{0}, \Sigma_c^{++}, \Lambda_c^{+}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \bar{K}^{*0}, \Sigma_c^{++}, \Lambda_c^{+}, \Xi_c^{+}, \rho^{+}) + \mathcal{M}(\Xi_{cc}^{++}, \bar{K}^{0}, \Sigma_c^{++}, \Sigma_c^{+}, \Xi_c^{+}, \rho^{+}) \\
&+\mathcal{M}(\Xi_{cc}^{++}, \bar{K}^{*0}, \Sigma_c^{++}, \Sigma_c^{+}, \Xi_c^{+}, \rho^{+})]
\end{aligned}
$$

# 末态重散射机制的计算框架

对于不包含T图贡献的衰变，其振幅形式为



例：

$$
\begin{aligned}
&\mathcal{A}(\Xi_{cc} \to \Xi_c^+ \rho^0) \\
&= i\mathcal{A}bs \left[M_b(\pi^+; \Xi_c^0; \Xi_c^0) + M_b(\rho^+; \Xi_c^0; \Xi_c^0) + M_b(\pi^+; \Xi_c^0; \Xi_c'^0) + M_b(\rho^+; \Xi_c^0; \Xi_c'^0)\right. \\
&+ M_b(\pi^+; \Xi_c'^0; \Xi_c^0) + M_b(\rho^+; \Xi_c'^0; \Xi_c^0) + M_b(\pi^+; \Xi_c'^0; \Xi_c'^0) + M_b(\rho^+; \Xi_c'^0; \Xi_c'^0) \\
&+ M_c(\pi^+; \Xi_c^0; \pi^-) + M_c(\rho^+; \Xi_c^0; \rho^-) + M_c(\pi^+; {\Xi'}_c^0; \pi^-) + M_c(\rho^+; {\Xi'}_c^0; \rho^-) \\
&+ M_e(\overline{K}^0; \Sigma_c^+; \Lambda_c^+) + M_e(\overline{K}^{*0}; \Sigma_c^+; \Lambda_c^+) + M_e(\overline{K}^0; \Lambda_c^+; \Sigma_c^+) + M_e(\overline{K}^{*0}; \Lambda_c^+; \Sigma_c^+) \\
&\left.+ M_f(\bar{K}^0; \Lambda_c^+; K^0) + M_f(\bar{K}^{*0}; \Lambda_c^+; K^{*0}) + M_f(\bar{K}^0; \Sigma_c^+; K^0) + M_f(\bar{K}^{*0}; \Sigma_c^+; K^{*0})\right]
\end{aligned}
$$

# 在cutting rule算法下完成的工作

- Discovery Potentials of Doubly Charmed Baryons

  F.S. Yu, H.Y. Jiang, **R.H. Li**, C.D. Lv, W. Wang, Chin. Phys. C 42 (2018) 5, 051001

- Weak Decays of Doubly Heavy Baryons: $\mathcal{B}_{cc} \to \mathcal{B}D^{(*)}$

  **R.H. Li**, J.J. Hou, B. He, Y.R. Wang, Chin. Phys. C 45 (2021) 4, 043108

- Weak decays of doubly heavy baryons: $\mathcal{B}_{cc} \to \mathcal{B}_c V$

  L.J. Jiang, B. He, **R.H. Li**, Eur. Phys. J. C 78 (2018) 11, 961

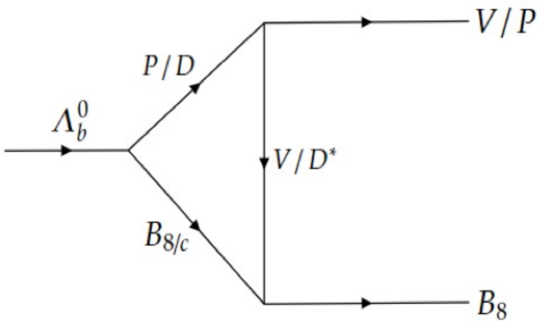
- Weak decays of bottom-charm baryons: $\mathcal{B}_{bc} \to \mathcal{B}_b P$

  J.J. Han, R.X. Zhang, H.Y. Jiang, Z.J. Xiao, F.S. Yu, Eur. Phys. J. C 81 (2021) 6, 539

- Rescattering mechanism of weak decays of double-charm baryons

  J.J. Han, H.Y. Jiang, W. Liu, Z.J. Xiao, F.S. Yu, Chin. Phys. C 45 (2021) 5, 053105

# 圈图算法for *CPV*




$$\mathcal{M}[P_8,B_8;V]=\int\frac{d^4k}{(2\pi)^4}\frac{4g_{P_8VV}}{f_{P_8}}\bar{u}(p_4,\lambda_4)(f_{1VB_8B_8}\gamma_\delta-\frac{if_{2VB_8B_8}}{m_2+m_4}\sigma_{\rho\delta}k^\rho)$$
$$\times(\not{p}_2+m_2)(A+B\gamma_5)u(p_i,\lambda_i)(-g^{\delta\nu}+\frac{k^\delta k^\nu}{m_k^2})\varepsilon^{\mu\nu\alpha\beta}\varepsilon^*_\beta(p_3,\lambda_3)k_\mu p_{3\alpha}$$
$$\times\frac{\mathcal{F}}{(p_1^2-m_1^2+i\varepsilon)(p_2^2-m_2^2+i\varepsilon)(k^2-m_k^2+i\varepsilon)}$$

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

# 在圈图算法下完成的工作

- Final-state rescattering mechanism of charmed baryon decays

  C.P. Jia, H.Y. Jiang, J.P. Wang, F.S. Yu, JHEP 11 (2024) 072

- Final-state rescattering mechanism of double-charm baryon decays: $\mathcal{B}_{cc} \to \mathcal{B}_c P$

  X.H. Hu, C.P. Jia, Y. Xing, F.S. Yu, Phys. Rev. D 111 (2025) 7, 076002

- Final-state rescattering mechanism of bottom-baryon decays

  Z.D. Duan, J.P. Wang, **R.H. Li**, C.D. Lv, F.S. Yu, e-Print: 2412.20458, accepted by JHEP

$$\boldsymbol{\Lambda_b^0 \to p\pi^-, pK^-, p\rho^-, pK^{*-}, \Lambda\phi}$$

# $\Lambda_b^0 \to p\pi^-, pK^-$的主要可观测量

$$BR\left[\Lambda_b^0 \to p\pi^-(pK^-)\right] = \frac{|p_c|}{8\pi M_{\Lambda_b}^2 \Gamma_{\Lambda_b^0}} \frac{1}{2}\left(\left|H_{+1/2}\right|^2 + \left|H_{-1/2}\right|^2\right)$$

$$a_{CP}^{dir} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$$

$$\alpha = \frac{\left|H_{+1/2}\right|^2 - \left|H_{-1/2}\right|^2}{\left|H_{+1/2}\right|^2 + \left|H_{-1/2}\right|^2}, \quad \beta = \frac{2\mathcal{I}m\left(H_{+1/2}H^*_{-1/2}\right)}{\left|H_{+1/2}\right|^2 + \left|H_{-1/2}\right|^2}, \quad \gamma = \frac{2\mathcal{R}e\left(H_{+1/2}H^*_{-1/2}\right)}{\left|H_{+1/2}\right|^2 + \left|H_{-1/2}\right|^2}$$

$$\langle\alpha\rangle = \frac{\alpha + \bar{\alpha}}{2}, \quad \langle\beta\rangle = \frac{\beta + \bar{\beta}}{2}, \quad \langle\gamma\rangle = \frac{\gamma + \bar{\gamma}}{2}$$

$$a_{CP}^{\alpha} = \frac{\alpha - \bar{\alpha}}{2}, \quad a_{CP}^{\beta} = \frac{\beta - \bar{\beta}}{2}, \quad a_{CP}^{\gamma} = \frac{\gamma - \bar{\gamma}}{2}$$

$$a_{CP}^{S} = \frac{|S|^2 - |\bar{S}|^2}{|S|^2 + |\bar{S}|^2}, \quad a_{CP}^{P} = \frac{|P|^2 - |\bar{P}|^2}{|P|^2 + |\bar{P}|^2}$$

$$\mathcal{H}_{+\frac{1}{2}} = \frac{1}{\sqrt{2}}(S + P), \quad \mathcal{H}_{-\frac{1}{2}} = \frac{1}{\sqrt{2}}(S - P).$$

# $\Lambda_b^0 \to p\pi^-, pK^-$的主要结果

| | BR($10^{-6}$) | $\alpha$ | Direct CP($10^{-2}$) | $a_{CP}^S$ | $a_{CP}^P$ |
|---|---|---|---|---|---|
| $\Lambda_b^0 \to pK^-$ | | | | | |
| FSI (This work) | $4.98^{+3.61}_{-1.98}$ | $0.97^{+0.02}_{-0.05}$ | $-9^{+2}_{-2}$ | $0.12^{+0.03}_{-0.04}$ | $-0.24^{+0.07}_{-0.09}$ |
| PQCD | 2.9 | 0.38 | $-5.8$ | $-0.05$ | $-0.23$ |
| QCDF | $2.17^{+0.98+0.60+0.33}_{-0.47-0.58-0.23}$ | $0.27^{+0.19}_{-0.14}$ | 10 | — | — |
| Bag model | 6.0 | 0.297 | $-19.6$ | — | — |
| GFA | $4.49^{+0.84}_{-0.39} \pm 0.26 \pm 0.59$ | — | $6.7^{+0.3}_{-0.2} \pm 0.3$ | — | — |
| Exp [LHCb 2025] | $5.5 \pm 1.0$ | — | $-1.1 \pm 0.7 \pm 0.4$ | — | — |
| $\Lambda_b^0 \to p\pi^-$ | | | | | |
| FSI (This work) | $4.28^{+0.66}_{-0.30}$ | $-0.75^{+0.18}_{-0.13}$ | $-2^{+6}_{-5}$ | $-0.22^{+0.15}_{-0.11}$ | $0.51^{+0.25}_{-0.25}$ |
| PQCD | 3.3 | $-0.81$ | 4.1 | 0.15 | $-0.07$ |
| QCDF | $4.30^{+0.27+1.18+0.69}_{-0.19-1.16-0.45}$ | $-0.98^{+0.00}_{-0.01}$ | $-0.337$ | — | — |
| Bag model | 5.0 | $-0.856$ | 1.4 | — | — |
| GFA | 4.25 | — | $-3.9 \pm 0.4$ | — | — |
| Exp [LHCb 2025] | $4.6 \pm 0.8$ | — | $0.2 \pm 0.8 \pm 0.4$ | — | — |

| | $\langle\alpha\rangle$ | $a_{CP}^{\alpha}$ | $\langle\beta\rangle$ | $a_{CP}^{\beta}$ | $\langle\gamma\rangle$ | $a_{CP}^{\gamma}$ |
|---|---|---|---|---|---|---|
| $\Lambda_b^0 \to pK^-$ | $0.20^{+0.02}_{-0.05}$ | $0.77^{+0.05}_{-0.07}$ | $-0.25^{+0.08}_{-0.10}$ | $0.50^{+0.05}_{-0.11}$ | $0.18^{+0.04}_{-0.06}$ | $-0.15^{+0.28}_{-0.21}$ |
| $\Lambda_b^0 \to p\pi^-$ | $-0.08^{+0.02}_{-0.01}$ | $-0.67^{+0.20}_{-0.15}$ | $0.49^{+0.14}_{-0.11}$ | $0.15^{+0.14}_{-0.17}$ | $-0.29^{+0.14}_{-0.11}$ | $0.44^{+0.05}_{-0.14}$ |

| Decay modes | $CPV(H_{-\frac{1}{2}})$ | $CPV(H_{\frac{1}{2}})$ |
|---|---|---|
| $\Lambda_b^0 \to pK^-$ | $-0.88^{+0.13}_{-0.07}$ | $0.02^{+0.02}_{-0.04}$ |
| $\Lambda_b^0 \to p\pi^-$ | $0.03^{+0.05}_{-0.03}$ | $-0.27^{+0.10}_{-0.05}$ |

# $\Lambda_b^0 \to p\rho^-, pK^{*-}, \Lambda\phi$的主要观测量

$$BR\left[\Lambda_b^0 \to BV\right] = \frac{|p_c|}{8\pi M_{\Lambda_b}^2 \Gamma_{\Lambda_b^0}} \frac{1}{2}\left(\left|H_{0,+1/2}\right|^2 + \left|H_{0,-1/2}\right|^2 + \left|H_{+1,+1/2}\right|^2 + \left|H_{-1,-1/2}\right|^2\right)$$

$$\alpha' = \frac{\left|H_{+1,+\frac{1}{2}}\right|^2 - \left|H_{-1,-\frac{1}{2}}\right|^2}{\left|H_{+1,+\frac{1}{2}}\right|^2 + \left|H_{-1,-\frac{1}{2}}\right|^2}, \quad \beta' = \frac{\left|H_{0,+\frac{1}{2}}\right|^2 - \left|H_{0,-\frac{1}{2}}\right|^2}{\left|H_{0,+\frac{1}{2}}\right|^2 + \left|H_{0,-\frac{1}{2}}\right|^2}, \quad \gamma' = \frac{\left|H_{+1,+\frac{1}{2}}\right|^2 + \left|H_{-1,-\frac{1}{2}}\right|^2}{\left|H_{0,+\frac{1}{2}}\right|^2 + \left|H_{0,-\frac{1}{2}}\right|^2}$$

$$P_L = \frac{\left|H_{+1,+\frac{1}{2}}\right|^2 - \left|H_{-1,-\frac{1}{2}}\right|^2 + \left|H_{0,+\frac{1}{2}}\right|^2 - \left|H_{0,-\frac{1}{2}}\right|^2}{\left|H_{+1,+\frac{1}{2}}\right|^2 + \left|H_{-1,-\frac{1}{2}}\right|^2 + \left|H_{0,+\frac{1}{2}}\right|^2 + \left|H_{0,-\frac{1}{2}}\right|^2}$$

$$\langle\alpha'\rangle = \frac{\alpha' + \bar{\alpha}'}{2}, \quad \langle\beta'\rangle = \frac{\beta' + \bar{\beta}'}{2}, \quad \langle\gamma'\rangle = \frac{\gamma' + \bar{\gamma}'}{2}, \quad \langle P_L\rangle = \frac{P_L + \bar{P}_L}{2}$$

$$a_{CP}^{\alpha'} = \frac{\alpha' - \bar{\alpha}'}{2}, \quad a_{CP}^{\beta'} = \frac{\beta' - \bar{\beta}'}{2}, \quad a_{CP}^{\gamma'} = \frac{\gamma' - \bar{\gamma}'}{2}, \quad a_{CP}^{P_L} = \frac{P_L - \bar{P}_L}{2}$$

# $\Lambda_b^0 \to p\rho^-, pK^{*-}, \Lambda\phi$的主要结果

| | BR($10^{-5}$) | Direct $CP$ | $\alpha'$ | $\beta'$ | $\gamma'$ | $P_L$ |
|---|---|---|---|---|---|---|
| $\Lambda_b^0 \to pK^{*-}$ | | | | | | |
| FSI (this work) | $1.35^{+1.36}_{-0.71}$ | $0.02^{+0.04}_{-0.04}$ | $0.60^{+0.03}_{-0.06}$ | $-0.85^{+0.03}_{-0.05}$ | $0.55^{+0.11}_{-0.12}$ | $-0.34^{+0.08}_{-0.10}$ |
| PQCD | 0.302 | 0.057 | $-0.999$ | $-0.92$ | 0.11 | — |
| QCDF | 0.101 | 0.311 | — | — | — | $-0.79$ |
| GFA | 0.286 | 0.197 | — | — | — | — |
| $\Lambda_b^0 \to p\rho^-$ | | | | | | |
| FSI (this work) | $1.34^{+0.53}_{-0.19}$ | $-0.24^{+0.07}_{-0.03}$ | $-0.26^{+0.37}_{-0.44}$ | $-0.71^{+0.14}_{-0.10}$ | $0.12^{+0.15}_{-0.04}$ | $-0.66^{+0.13}_{-0.11}$ |
| PQCD | 1.513 | $-0.020$ | $-0.71$ | $-0.98$ | 0.04 | — |
| QCDF | 0.747 | $-0.319$ | — | — | — | $-0.81$ |
| GFA | 1.1 | $-0.038$ | — | — | — | — |
| $\Lambda_b^0 \to \Lambda\phi$ | | | | | | |
| FSI (this work) | $0.31^{+0.43}_{-0.19}$ | $-0.005^{+0.02}_{-0.01}$ | $0.72^{+0.03}_{-0.06}$ | $-0.61^{+0.43}_{-0.13}$ | $3.10^{+4.2}_{-1.1}$ | $0.39^{+0.17}_{-0.18}$ |
| PQCD | 0.69 | $-0.01$ | — | $-0.71$ | — | $-0.79$ |
| QCDF | 0.0633 | 0.016 | — | — | — | $-0.80$ |
| GFA | 0.177 | 0.014 | — | — | — | — |

# $\Lambda_b^0 \to p\rho^-, pK^{*-}, \Lambda\phi$的主要结果

| | $\langle\alpha'\rangle$ | $a_{CP}^{\alpha'}$ | $\langle\beta'\rangle$ | $a_{CP}^{\beta'}$ | $\langle\gamma'\rangle$ | $a_{CP}^{\gamma'}$ | $\langle P_L\rangle$ | $a_{CP}^{P_L}$ |
|---|---|---|---|---|---|---|---|---|
| $\Lambda_b^0 \to pK^{*-}$ | $-0.04^{+0.02}_{-0.03}$ | $0.65^{+0.01}_{-0.04}$ | $-0.06^{+0.02}_{-0.03}$ | $-0.80^{+0.01}_{-0.02}$ | $0.03^{+0.08}_{-0.03}$ | $0.52^{+0.08}_{-0.09}$ | $-0.31^{+0.05}_{-0.07}$ | $-0.03^{+0.03}_{-0.03}$ |
| $\Lambda_b^0 \to p\rho^-$ | $0.01^{+0.10}_{-0.13}$ | $-0.28^{+0.27}_{-0.31}$ | $0.09^{+0.07}_{-0.05}$ | $-0.81^{+0.07}_{-0.05}$ | $-0.07^{+0.05}_{-0.11}$ | $0.20^{+0.22}_{-0.08}$ | $-0.72^{+0.11}_{-0.09}$ | $0.05^{+0.03}_{-0.02}$ |
| $\Lambda_b^0 \to \Lambda\phi$ | $0.02^{+0.04}_{-0.01}$ | $0.70^{+0.04}_{-0.10}$ | $0.01^{+0.05}_{-0.01}$ | $-0.62^{+0.37}_{-0.13}$ | $0.38^{+1.70}_{-0.31}$ | $2.72^{+2.53}_{-0.80}$ | $0.34^{+0.17}_{-0.15}$ | $0.05^{+0.06}_{-0.04}$ |

| Decay modes | $CPV(H_{0,-\frac{1}{2}})$ | $\mathrm{CPV}(H_{-1,-\frac{1}{2}})$ | $\mathrm{CPV}(H_{1,\frac{1}{2}})$ | $\mathrm{CPV}(H_{0,\frac{1}{2}})$ |
|---|---|---|---|---|
| $\Lambda_b^0 \to pK^{*-}$ | $0.03^{+0.06}_{-0.08}$ | $0.18^{+0.09}_{-0.07}$ | $0.03^{+0.04}_{-0.02}$ | $-0.28^{+0.12}_{-0.28}$ |
| $\Lambda_b^0 \to p\rho^-$ | $-0.23^{+0.09}_{-0.06}$ | $-0.53^{+0.18}_{-0.07}$ | $-0.51^{+0.24}_{-0.13}$ | $0.33^{+0.20}_{-0.17}$ |
| $\Lambda_b^0 \to \Lambda\phi$ | $-0.11^{+0.08}_{-0.25}$ | $-0.04^{+0.03}_{-0.02}$ | $0.05^{+0.08}_{-0.03}$ | $-0.09^{+0.06}_{-0.15}$ |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# Summary

- ✓ 重子衰变的研究引起越来越多的关注，理论上产生了多种计算方案，然而仍然有很长的路要走。

- ✓ 我们将末态相互作用的方法拓展到重子衰变中，并利用圈图计算的方法改进了计算方案。

- ✓ 我们对$\Lambda_b^0 \to p\pi^-, pK^-, p\rho^-, pK^{*-}, \Lambda\phi$进行了计算。我们对分支比、CP破坏、不对称参数、各螺旋度贡献的CP破坏、不对称参数的CP破坏、各分波贡献的CP破坏等量进行了计算。发现在将衰变贡献细化后，CP破坏显示出更丰富的图象。

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# THANK YOU

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