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Doubly charmed baryon weak decays in the light front quark model

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Hong-Wei Ke, Ning Hao and Xue-Qian Li, **arXiv:1904.05705 Eur.Phys.J. C79 , 540(2019)**

Hong-Wei Ke , Ning Hao and Xue-Qian Li, arXiv:1711.02518, **J.Phys. G46 (2019) , 115003**

Hong-Wei Ke, Xue-Qian Li and Zheng-Tao Wei, **Phys.Rev.D77:014020,2008**

Hong-Wei Ke, Xu-Hao Yuan, Xue-Qian Li, Zheng-Tao Wei and Yan-Xi Zhang, **Phys.Rev.D86, 114005 (2012)**



Outline

- 1. Motivation**
- 2. Vertex function of baryons**
- 3. Transition matrix element**
- 4. Numerical Results**
- 5. Summary**



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1. Motivation

Determining the CKM parameter V_{cs} as a compensation to the measurements on mesons

Investigating the non-perturbative QCD effects in the heavy baryon system

Serve as an ideal laboratory to explore new physics

its characters and inner structure of Ξ_{cc}



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Hai-Yang Cheng *et al.* 在light-front quark model 下研究了介子和pentaquark的衰变

Phys. Rev. D 69, 074025 (2004)

JHEP0411:072,2004

Phys.Rev. D70 (2004) 034007

我们推广该方法到重味重子的衰变研究，重子的结构是heavy-quark-light-diquark

$\Lambda_b \rightarrow \Lambda_c$ weak decays

$\Sigma_b \rightarrow \Sigma_c$ and $\Omega_b \rightarrow \Omega_c$ weak decays

Hong-Wei Ke, Xue-Qian Li and Zheng-Tao Wei, Phys.Rev.D77:014020,2008

Hong-Wei Ke, Xu-Hao Yuan, Xue-Qian Li, Zheng-Tao Wei and Yan-Xi Zhang, Phys.Rev.D86, 114005 (2012)



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我们的推广被用于doubly charmed baryon的衰变研究

arXiv:1703.09086 [pdf, other] hep-ph

Discovery Potentials of Doubly Charmed Baryons

Authors: Fu-Sheng Yu, Hua-Yu Jiang, Run-Hui Li, Cai-Dian Lü, Wei Wang, Zhen-Xing Zhao

arXiv:1707.02834 [pdf, ps, other] hep-ph

doi [10.1140/epjc/s10052-017-5360-1](https://doi.org/10.1140/epjc/s10052-017-5360-1)

Weak Decays of Doubly Heavy Baryons: the $1/2 \rightarrow 1/2$ case

Authors: Wei Wang, Fu-Sheng Yu, Zhen-Xing Zhao

今年我们用了three-quark picture 在light-front quark model中计算重子的弱衰变

Hong-Wei Ke, Ning Hao and Xue-Qian Li, arXiv:1904.05705 Eur.Phys.J. C79 , 540(2019)



2. Vertex function of baryons

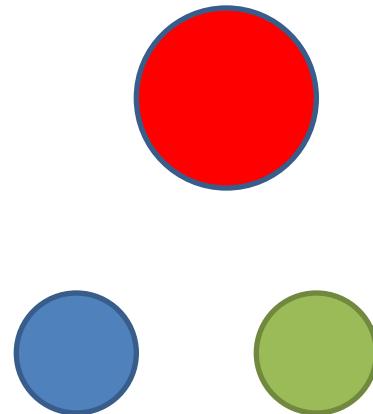
重子的内部结构和自旋

Λ_b 和 Λ_c 重夸克+自旋为0 **ud** subsystem

Σ_b 和 Σ_c 重夸克+自旋为1 **ud(uu,dd)** subsystem

Ξ_b 和 Ξ_c 重夸克+自旋为0 **us (ds)** subsystem

Ξ_b' 和 Ξ_c' 重夸克+自旋为1 **us (ds)** subsystem



J. KÄorner and P. Kroll, Phys. Lett. B 293, 201 1992

D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Rev.D 73, 094002 (2006)

Ξ_{cc} 轻夸克+自旋为1 **cc** subsystem

R.~Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 119, 112001 (2017)

R.~Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 121, 162002 (2018)



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(1) 在quark-diquark图像下的vertex function

In the heavy quark limit the heavy quark decouples from light quarks in baryons, and the two light quarks tend to form a diquark

$\Lambda_{b(c)}$ is composed of one heavy quark $b(c)$ and a light 0^+ diquark [ud].

$\Sigma_{b(c)}$ consists of a light 1^+ diquark[ud] and one heavy quark $b(c)$.

diquark当成了点粒子



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$$\begin{aligned} |\Lambda_Q(P, S, S_z)\rangle &= \int \{d^3 p_1\} \{d^3 p_2\} 2(2\pi)^3 \delta^3(\tilde{P} - \tilde{p}_1 - \tilde{p}_2) \\ &\quad \times \sum_{\lambda_1} \Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1) C_{\beta\gamma}^\alpha F^{bc} |Q_\alpha(p_1, \lambda_1)[q_{1b}^\beta q_{2c}^\gamma](p_2)\rangle \end{aligned}$$

$$\Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1) = \left\langle \lambda_1 \left| \mathcal{R}_M^\dagger(x_1, k_{1\perp}, m_1) \right| s_1 \right\rangle \left\langle 00; \frac{1}{2}s_1 \left| \frac{1}{2}S_z \right\rangle \phi(x, k_\perp) \right.$$

$$\left. \left\langle \lambda_1 \left| \mathcal{R}_M^\dagger(x_1, k_{1\perp}, m_1) \right| s_1 \right\rangle \left\langle 00; \frac{1}{2}s_1 \left| \frac{1}{2}S_z \right\rangle \right\rangle = \frac{1}{\sqrt{2(p_1 \cdot \bar{P} + m_1 M_0)}} \bar{u}(p_1, \lambda_1) \Gamma u(\bar{P}, S_z)$$



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$$\begin{aligned} |\Sigma_Q(P, S, S_z)\rangle &= \int \{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\} 2(2\pi)^3\delta^3(\tilde{P} - \tilde{p}_1 - \tilde{p}_2) \\ &\times \sum_{\lambda_1} \Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1) C_{\beta\gamma}^\alpha F^{bc} |Q_\alpha(p_1, \lambda_1)[q_{1b}^\beta q_{2c}^\gamma](p_2)\rangle, \end{aligned}$$

$$\Psi_{\Sigma_c}^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1, m) = \frac{A_2}{\sqrt{6(p_1 \cdot \bar{P} + m_1 M_0)}} \bar{u}(p_1, \lambda_1) [-\gamma_5 \not{d}(p_2, m)] u(\bar{P}, S_z) \varphi(x, k_\perp)$$



$$A_2 = \sqrt{\frac{12(M_0 m_1 + p_1 \cdot \bar{P})}{12M_0 m_1 + 4p_1 P + 8p_1 \cdot p_2 p_2 \cdot P / m_2^2}}$$

Hong-Wei Ke, Xu-Hao Yuan, Xue-Qian Li, Zheng-Tao Wei and Yan-Xi Zhang,
Phys.Rev.D86, 114005 (2012)

C.~K.~Chua, 在Phys. Rev.\D 99, 014023 (2019) [arXiv:1811.09265 [hep-ph]]中
比我们多了一项



Another scheme for axial vector diquark

The wavefunction of Σ_Q with a total spin $S = 1/2$ and momentum P

$$|\Sigma_Q(P, S, S_z)\rangle = \int \{d^3\tilde{p}_1\} \{d^3\tilde{p}_2\} 2(2\pi)^3 \delta^3(\tilde{P} - \tilde{p}_1 - \tilde{p}_2) \\ \times \sum_{\alpha, \beta, \gamma} \Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1, m) C_{\beta\gamma}^{\alpha} F^{ij} |Q_{\alpha}(p_1, \lambda_1)[q_{1i}^{\beta} q_{2j}^{\gamma}(m)](p_2)\rangle$$

$$\Psi_{\Sigma_c}^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1, m) = \left\langle \lambda_1 \left| \mathcal{R}_M^{\dagger}(x_1, k_{1\perp}, m) \right| s_1 \right\rangle \left\langle \frac{1}{2}s_1; 1m \left| \frac{1}{2}S_z \right. \right\rangle \varphi(x, k_{\perp})$$

$$\left\langle \frac{1}{2}s_1; 1m \left| \frac{1}{2}S_z \right. \right\rangle = A_1 \bar{u}(p_1, s_1) \frac{-\gamma_5 \cancel{v}(\bar{P}, m)}{\sqrt{3}} u(\bar{P}, S_z)$$

$$A_1 = \frac{1}{\sqrt{2(M_0 m_1 + p_1 \cdot \bar{P})}}$$



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(2) 在three-quark图像下的vertex function

$$|\mathcal{B}_Q(P, S, S_z)\rangle = \int \{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\} 2(2\pi)^3\delta^3(\tilde{P} - \tilde{p}_1 - \tilde{p}_2 - \tilde{p}_3) \\ \times \sum_{\lambda_1, \lambda_2, \lambda_3} \Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \tilde{p}_3, \lambda_1, \lambda_2, \lambda_3) C^{\alpha\beta\gamma} F_{Qdu} | Q_\alpha(p_1, \lambda_1) u_\beta(p_2, \lambda_2) d_\gamma(p_3, \lambda_3) \rangle$$

The spin and spatial wave function for Λ_Q is

$$\Psi_0^{SS_z}(\tilde{p}_i, \lambda_i) = A_0 \bar{u}(p_3, \lambda_3)[(\bar{P} + M_0)\gamma_5] v(p_2, \lambda_2) \bar{u}_Q(p_1, \lambda_1) u(\bar{P}, S) \varphi(x_i, k_{i\perp}),$$

and for Σ_Q

$$\Psi_1^{SS_z}(\tilde{p}_i, \lambda_i) = A_1 \bar{u}(p_3, \lambda_3)[(\bar{P} + M_0)\gamma_{\perp\alpha}] v(p_2, \lambda_2) \bar{u}_Q(p_1, \lambda_1) \gamma_{\perp\alpha} \gamma_5 u(\bar{P}, S) \varphi(x_i, k_{i\perp}),$$

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$$A_0 = \frac{1}{4\sqrt{P^+ M_0^3 (m_1 + e_1)(m_2 + e_2)(m_3 + e_3)}},$$

$$A_1 = \frac{1}{4\sqrt{3P^+ M_0^3 (m_1 + e_1)(m_2 + e_2)(m_3 + e_3)}},$$

$$\varphi(x_1, x_2, x_3, k_{1\perp}, k_{2\perp}, k_{3\perp}) = \frac{e_1 e_2 e_3}{x_1 x_2 x_3 M_0} \varphi(\vec{k}_1, \beta_1) \varphi(\frac{\vec{k}_2 - \vec{k}_3}{2}, \beta_{23})$$



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对于 Ξ_{cc} 、 Ξ_c 、 Ξ_c'

$$|\Xi_{cc}(P, S, S_z)\rangle = \int \{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\} 2(2\pi)^3\delta^3(\tilde{P} - \tilde{p}_1 - \tilde{p}_2 - \tilde{p}_3) \\ \times \sum_{\lambda_1, \lambda_2, \lambda_3} \Psi^{SS_z}(\tilde{p}_i, \lambda_i) \mathcal{C}^{\alpha\beta\gamma} \mathcal{F}_{ccu} | c_\alpha(p_1, \lambda_1) c_\beta(p_2, \lambda_2) u_\gamma(p_3, \lambda_3) \rangle,$$

$$|\Xi_c^{(')}(P, S, S_z)\rangle = \int \{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\} 2(2\pi)^3\delta^3(\tilde{P} - \tilde{p}_1 - \tilde{p}_2 - \tilde{p}_3) \\ \times \sum_{\lambda_1, \lambda_2, \lambda_3} \Psi^{(')SS_z}(\tilde{p}_i, \lambda_i) \mathcal{C}^{\alpha\beta\gamma} \mathcal{F}_{csu} | s_\alpha(p_1, \lambda_1) c_\beta(p_2, \lambda_2) u_\gamma(p_3, \lambda_3) \rangle.$$



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3. the transition matrix elements

对于 $\Lambda_b \rightarrow \Lambda_c$ 衰变, 轻夸克是可近似为旁观者





对于 $\Xi_{cc} \rightarrow \Xi_c (\Xi_c')$ 衰变, cu 可近似为旁观者



Ξ_c us (ds) subsystem自旋为0
 Ξ_c' us (ds) subsystem自旋为1
 Ξ_{cc} cc subsystem自旋为1



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三个角动量耦合基矢的变换：Racah 系数

$$[c^1 c^2]_1[u] = \frac{\sqrt{2}}{2} \left(-\frac{\sqrt{3}}{2} [c^2][c^1 u]_0 + \frac{1}{2} [c^2][c^1 u]_1 \right.$$

$$\left. -\frac{\sqrt{3}}{2} [c^1][c^2 u]_0 + \frac{1}{2} [c^1][c^2 u]_1 \right)$$

$$[su]_0[c] = -\frac{1}{2} [s][cu]_0 + \frac{\sqrt{3}}{2} [s][cu]_1$$

$$[su]_1[c] = \frac{\sqrt{3}}{2} [s][cu]_0 + \frac{1}{2} [s][cu]_1$$



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于是

$$\Psi_{ccu}^{SS_z}(\tilde{p}_i, \lambda_i) = \sqrt{2} \left[-\frac{\sqrt{3}}{2} \Psi_0^{SS_z}(\tilde{p}_i, \lambda_i) + \frac{1}{2} \Psi_1^{SS_z}(\tilde{p}_i, \lambda_i) \right],$$

$$\Psi_{csu}^{SS_z}(\tilde{p}_i, \lambda_i) = -\frac{1}{2} \Psi_0^{SS_z}(\tilde{p}_i, \lambda_i) + \frac{\sqrt{3}}{2} \Psi_1^{SS_z}(\tilde{p}_i, \lambda_i),$$

$$\Psi_{csu}'^{SS_z}(\tilde{p}_i, \lambda_i) = \frac{\sqrt{3}}{2} \Psi_0^{SS_z}(\tilde{p}_i, \lambda_i) + \frac{1}{2} \Psi_1^{SS_z}(\tilde{p}_i, \lambda_i),$$

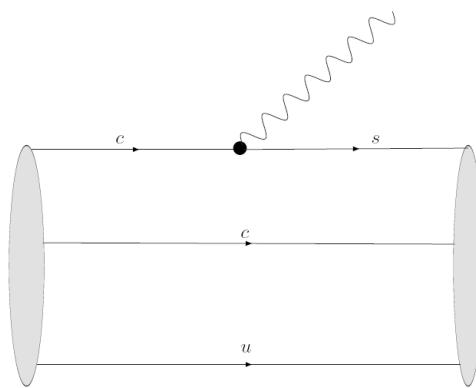


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The form factors for the weak transition $\Xi_{cc} \rightarrow \Xi_c$ are defined

$$\begin{aligned} & \langle \Xi_c(P', S', S'_z) | \bar{s} \gamma_\mu (1 - \gamma_5) c | \Xi_{cc}(P, S, S_z) \rangle \\ = & \bar{u}_{\Xi_c}(P', S'_z) \left[\gamma_\mu f_1(q^2) + i \sigma_{\mu\nu} \frac{q^\nu}{M_{\Xi_{cc}}} f_2(q^2) + \frac{q_\mu}{M_{\Xi_{cc}}} f_3(q^2) \right] u_{\Xi_{cc}}(P, S_z) \\ - & \bar{u}_{\Xi_c}(P', S'_z) \left[\gamma_\mu g_1(q^2) + i \sigma_{\mu\nu} \frac{q^\nu}{M_{\Xi_{cc}}} g_2(q^2) + \frac{q_\mu}{M_{\Xi_{cc}}} g_3(q^2) \right] \gamma_5 u_{\Xi_{cc}}(P, S_z) \end{aligned}$$





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$$\begin{aligned} & \langle \Xi_c(P', S'_z) | \bar{s}\gamma^\mu(1 - \gamma_5)c | \Xi_{cc}(P, S_z) \rangle = \frac{\sqrt{6}}{4} \langle \Xi_c(P', S'_z) | \bar{s}\gamma^\mu(1 - \gamma_5)c | \Xi_{cc}(P, S_z) \rangle_0 \\ & \quad + \frac{\sqrt{6}}{4} \langle \Xi_c(P', S'_z) | \bar{c}\gamma^\mu(1 - \gamma_5)b | \Xi_{cc}(P, S_z) \rangle_1 \\ & \langle \Xi_c(P', S'_z) | \bar{s}\gamma^\mu(1 - \gamma_5)c | \Xi_{cc}(P, S_z) \rangle_0 \\ &= \int \frac{\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\phi_{\Xi_c}^*(x', k'_\perp)\phi_{\Xi_{cc}}(x, k_\perp)Tr[(\bar{P}' - M'_0)\gamma_5(\not{p}_2 + m_2)(\bar{P} + M_0)\gamma_5(\not{p}_3 - m_3)]}{16\sqrt{p_1^+ p_1'^+ \bar{P}^+ \bar{P}'^+} M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)} \\ & \quad \times \bar{u}(\bar{P}', S'_z)(\not{p}'_1 + m'_1)\gamma^\mu(1 - \gamma_5)(\not{p}_1 + m_1)u(\bar{P}, S_z). \\ & \langle \Xi_c(P', S'_z) | \bar{s}\gamma^\mu(1 - \gamma_5)c | \Xi_{cc}(P, S_z) \rangle_1 \\ &= \frac{\int \{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\phi_{\Xi_c}^*(x', k'_\perp)\phi_{\Xi_{cc}}(x, k_\perp)Tr[\gamma_\perp^\alpha(\bar{P}' + M'_0)\gamma_5(\not{p}_2 + m_2)(\bar{P} + M_0)\gamma_5\gamma_\perp^\beta(\not{p}_3 - m_3)]}{48\sqrt{p_1^+ p_1'^+ \bar{P}^+ \bar{P}'^+} M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)} \\ & \quad \times \bar{u}(\bar{P}', S'_z)\gamma_{\perp\alpha}\gamma_5(\not{p}'_1 + m'_1)\gamma^\mu(1 - \gamma_5)(\not{p}_1 + m_1)\gamma_{\perp\beta}\gamma_5u(\bar{P}, S_z). \end{aligned}$$



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$$\langle \Xi_c(P', S', S'_z) \mid \bar{s}\gamma_\mu(1 - \gamma_5)c \mid \Xi_{cc}(P, S, S_z) \rangle_0$$

the form factors are denoted to f_i^s , g_i^s

$$\langle \Xi_c(P', S'_z) \mid \bar{s}\gamma^\mu(1 - \gamma_5)c \mid \Xi_{cc}(P, S_z) \rangle_1$$

the form factors are denoted to f_i^v , g_i^v

对于 $\langle \Xi_c(P', S', S'_z) \mid \bar{s}\gamma_\mu(1 - \gamma_5)c \mid \Xi_{cc}(P, S, S_z) \rangle$

$$f_1 = \frac{\sqrt{6}}{4} f_1^s + \frac{\sqrt{6}}{4} f_1^v, g_1 = \frac{\sqrt{6}}{4} g_1^s + \frac{\sqrt{6}}{4} g_1^v,$$

$$f_2 = \frac{\sqrt{6}}{4} f_2^s + \frac{\sqrt{6}}{4} f_2^v, g_2 = \frac{\sqrt{6}}{4} g_2^s + \frac{\sqrt{6}}{4} g_2^v.$$



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$$\begin{aligned}
f_1^s &= \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[(\bar{P}' - M'_0) \gamma_5 (\not{p}_2 + m_2)(\bar{P} + M_0) \gamma_5 (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{16\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} + M_0) \gamma^+(\bar{P}' + M'_0)(\not{p}'_1 + m'_1) \gamma^+(\not{p}_1 + m_1)]}{8P^+ P'^+}, \\
\frac{f_2^s}{M_{\Xi_{cc}}} &= \frac{-i}{q_\perp^i} \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[(\bar{P}' - M'_0) \gamma_5 (\not{p}_2 + m_2)(\bar{P} + M_0) \gamma_5 (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{16\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} + M_0) \sigma^{i+}(\bar{P}' + M'_0)(\not{p}'_1 + m'_1) \gamma^+(\not{p}_1 + m_1)]}{8P^+ P'^+}, \\
g_1^s &= \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[(\bar{P}' - M'_0) \gamma_5 (\not{p}_2 + m_2)(\bar{P} + M_0) \gamma_5 (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{16\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} + M_0) \gamma^+ \gamma_5 (\bar{P}' + M'_0)(\not{p}'_1 + m'_1) \gamma^+ \gamma_5 (\not{p}_1 + m_1)]}{8P^+ P'^+}, \\
\frac{g_2^s}{M_{\Xi_{cc}}} &= \frac{i}{q_\perp^i} \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[(\bar{P}' - M'_0) \gamma_5 (\not{p}_2 + m_2)(\bar{P} + M_0) \gamma_5 (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{16\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} + M_0) \sigma^{i+} \gamma_5 (\bar{P}' + M'_0)(\not{p}'_1 + m'_1) \gamma^+ \gamma_5 (\not{p}_1 + m_1)]}{8P^+ P'^+},
\end{aligned}$$



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$$\begin{aligned}
f_1^v &= \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[\gamma_\perp^\alpha (\bar{P}' + M'_0) \gamma_5 (\not{p}_2 + m_2) (\bar{P} + M_0) \gamma_5 \gamma_\perp^\beta (\not{p}_3 - m_3)]]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{48\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} + M_0) \gamma^+ (\bar{P}' + M'_0) \gamma_{\perp\alpha} \gamma_5 (\not{p}'_1 + m'_1) \gamma^+ (\not{p}_1 + m_1) \gamma_{\perp\beta} \gamma_5]}{8P^+ P'^+}, \\
\frac{f_2^v}{M_{\Xi_{cc}}} &= \frac{-i}{q_\perp^i} \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[\gamma_\perp^\alpha (\bar{P}' + M'_0) \gamma_5 (\not{p}_2 + m_2) (\bar{P} + M_0) \gamma_5 \gamma_\perp^\beta (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{48\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} - M_0) \sigma^{i+} (\bar{P}' - M'_0) \gamma_{\perp\alpha} \gamma_5 (\not{p}'_1 + m'_1) \gamma^+ (\not{p}_1 + m_1) \gamma_{\perp\beta} \gamma_5]}{8P^+ P'^+}, \\
g_1^v &= \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[\gamma_\perp^\alpha (\bar{P}' + M'_0) \gamma_5 (\not{p}_2 + m_2) (\bar{P} + M_0) \gamma_5 \gamma_\perp^\beta (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{48\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} - M_0) \gamma^+ \gamma_5 (\bar{P}' - M'_0) \gamma_{\perp\alpha} \gamma_5 (\not{p}'_1 + m'_1) \gamma^+ (\not{p}_1 + m_1) \gamma_{\perp\beta} \gamma_5]}{8P^+ P'^+}, \\
\frac{g_2^v}{M_{\Xi_{cc}}} &= \frac{i}{q_\perp^i} \int \frac{dx_2 d^2 k_{2\perp}^2}{2(2\pi)^3} \frac{dx_3 d^2 k_{3\perp}^2}{2(2\pi)^3} \frac{\text{Tr}[\gamma_\perp^\alpha (\bar{P}' + M'_0) \gamma_5 (\not{p}_2 + m_2) (\bar{P} + M_0) \gamma_5 \gamma_\perp^\beta (\not{p}_3 - m_3)]}{\sqrt{M_0^3(m_1 + e_1)(m_2 + e_2)(m_3 + e_3)(m'_1 + e'_1)(m'_2 + e'_2)(m'_3 + e'_3)}} \\
&\quad \times \frac{\phi_{\Xi_c}^*(x', k'_\perp) \phi_{\Xi_{cc}}(x, k_\perp)}{48\sqrt{x_1 x'_1}} \frac{\text{Tr}[(\bar{P} - M_0) \sigma^{i+} \gamma_5 (\bar{P}' - M'_0) \gamma_{\perp\alpha} \gamma_5 (\not{p}'_1 + m'_1) \gamma^+ (\not{p}_1 + m_1) \gamma_{\perp\beta} \gamma_5]}{8P^+ P'^+}
\end{aligned}$$



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For the transition $\langle \Xi_c'(P', S', S'_z) \mid \bar{Q}'\gamma_\mu(1 - \gamma_5)Q \mid \Xi_{cc}(P, S, S_z) \rangle$

$$f'_1 = -\frac{3\sqrt{2}}{4}f_1^s + \frac{\sqrt{2}}{4}f_1^v, g'_1 = -\frac{3\sqrt{2}}{4}g_1^s + \frac{\sqrt{2}}{4}g_1^v,$$
$$f'_2 = -\frac{3\sqrt{2}}{4}f_2^s + \frac{\sqrt{2}}{4}f_2^v, g'_2 = -\frac{3\sqrt{2}}{4}g_2^s + \frac{\sqrt{2}}{4}g_2^v.$$



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四、Numerical Results

the reciprocal of β is related to the electrical radium of two constituents.

$$\beta_{qq^{(\prime)}} \approx \sqrt{2}\beta_{q\bar{q}^{(\prime)}}$$

for a compact $qq^{(\prime)}$ system

$$\beta_{qq^{(\prime)}} = 2.9\beta_{q\bar{q}^{(\prime)}}$$

根据这些，我们可以估计

$$\beta_{c[c\bar{c}]} \approx 2.9\beta_{c\bar{c}}, \beta_{s[c\bar{c}]} \approx \sqrt{2}\beta_{c\bar{s}}, \beta_{[cu]} \approx \sqrt{2}\beta_{c\bar{u}}$$

Q. Chang, X. N. Li, X. Q. Li, F. Su and Y. D. Yang, Phys. Rev. D 98, no. 11, 114018 (2018)
doi:10.1103/PhysRevD.98.114018 [arXiv:1810.00296 [hep-ph]].



1. 形状因子

Since these form factors $f_i^{s(v)}$ ($i = 1, 2$) and $g_i^{s(v)}$ ($i = 1, 2$) are evaluated in the frame $q^+ = 0$ i.e. $q^2 = -q_\perp^2 \leq 0$ (the space-like region) one needs to extend them into the time-like region. In Ref.[31] a tl

$$F(q^2) = \frac{F(0)}{\left(1 - \frac{q^2}{M_{\Xi_{cc}}^2}\right) \left[1 - a \left(\frac{q^2}{M_{\Xi_{cc}}^2}\right) + b \left(\frac{q^2}{M_{\Xi_{cc}}^2}\right)^2\right]},$$

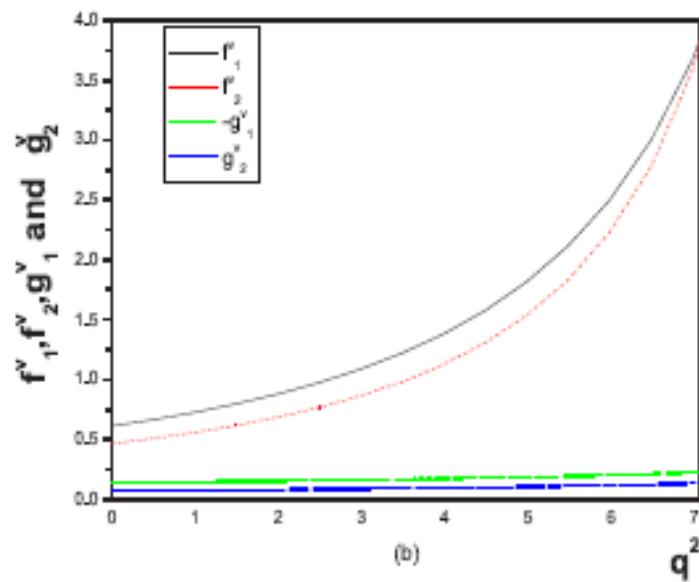
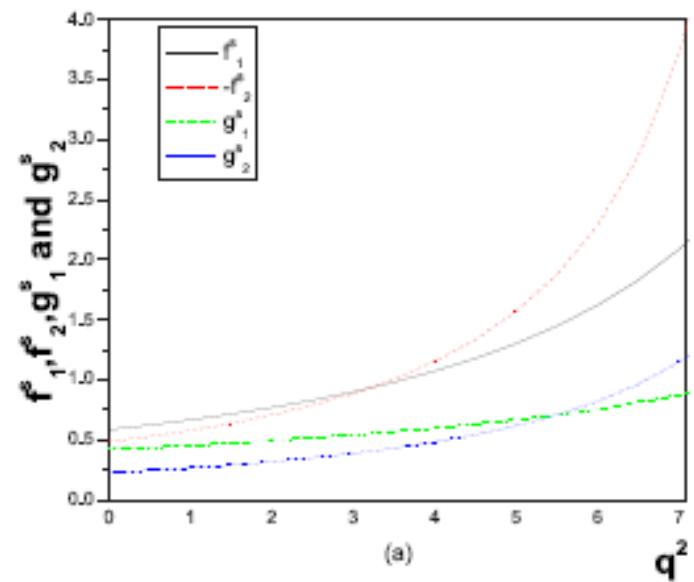
[31] H. Y. Cheng, C. K. Chua and C. W. Hwang, Phys. Rev. D 70, 034007 (2004)
doi:10.1103/PhysRevD.70.034007 [hep-ph/0403232].

TABLE II: The form factors given in the three-parameter form.

F	$F(0)$	a	b
f_1^s	0.586	0.640	-0.194
f_2^s	-0.484	1.23	-0.222
g_1^s	0.420	-0.0142	0.0748
g_2^s	0.228	1.02	-0.101
f_1^v	0.610	1.18	-0.0492
f_2^v	0.463	1.32	-0.0642
g_1^v	-0.140	-0.501	0.274
g_2^v	0.0673	0.00936	0.327



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we suggest a polynomial to parameterize these form factors

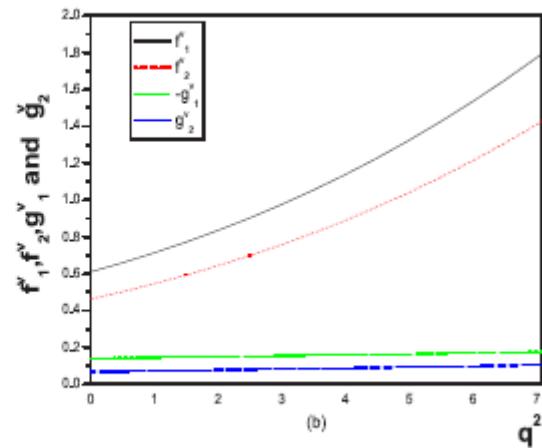
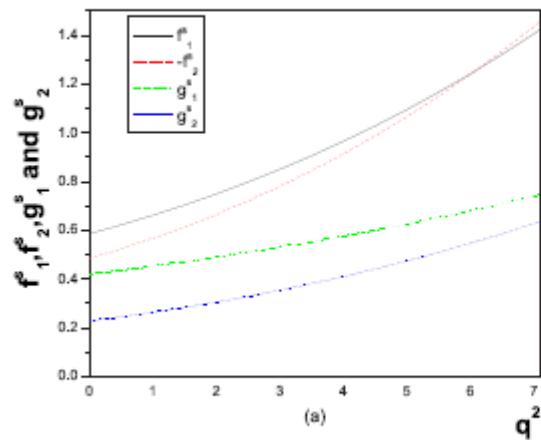
$$F(q^2) = F(0) \left[1 + a' \left(\frac{q^2}{M_{\Xi_{cc}}^2} \right) + b' \left(\frac{q^2}{M_{\Xi_{cc}}^2} \right)^2 + c' \left(\frac{q^2}{M_{\Xi_{cc}}^2} \right)^3 \right]$$

TABLE III: The form factors given in the ploynomial form.

F	$F(0)$	a'	b'	c'
f_1^s	0.586	1.57	1.59	0.704
f_2^s	-0.484	2.06	2.42	1.17
g_1^s	0.420	0.983	0.692	0.258
g_2^s	0.228	1.90	2.07	0.960
f_1^v	0.610	2.04	2.27	1.06
f_2^v	0.463	2.14	2.49	1.19
g_1^v	-0.140	0.422	0.0931	0.00632
g_2^v	0.0673	0.925	0.245	-0.0862



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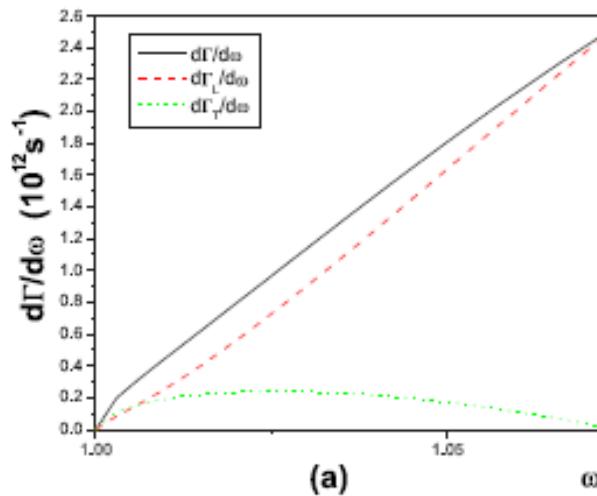




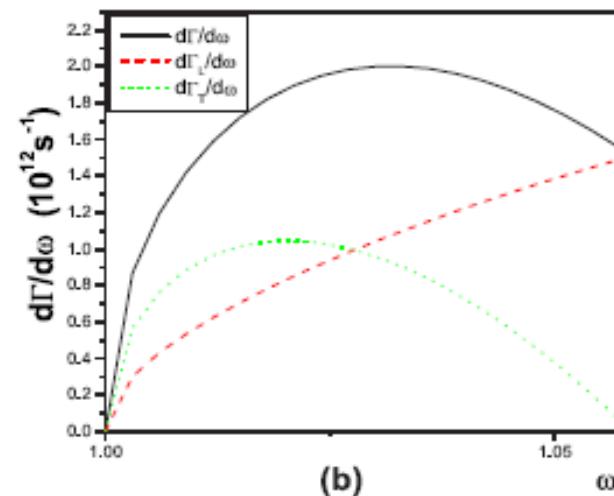
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2. 半轻衰变



(a)



(b)

$$\Xi_{cc} \rightarrow \Xi_c l \bar{\nu}_l$$

$$\Xi'_{cc} \rightarrow \Xi_c l \bar{\nu}_l$$



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mode	Γ	Γ_L	Γ_T	R
$\Xi_{cc} \rightarrow \Xi_c l \bar{\nu}_l$	0.100 ± 0.015	0.0879 ± 0.0114	0.0123 ± 0.0019	7.14 ± 0.61
$\Xi_{cc} \rightarrow \Xi'_c l \bar{\nu}_l$	0.0995 ± 0.0091	0.0569 ± 0.0060	0.0426 ± 0.0062	1.34 ± 0.07

(in unit 10^{12}s^{-1})

$$\Gamma(\Xi_{cc} \rightarrow \Xi_c l \bar{\nu}_l) = 0.173 \times 10^{-12}\text{s}^{-1} \quad R=9.99$$

$$\Gamma(\Xi'_{cc} \rightarrow \Xi_c l \bar{\nu}_l) = 0.193 \times 10^{-12}\text{s}^{-1} \quad R=1.42$$



3. 半轻衰变

$$\begin{aligned} & \langle \Xi_c^{(\prime)}(P', S'_z) M \mid \mathcal{H} \mid \Xi_{cc}(P, S_z) \rangle \\ = & \frac{G_F V_{cs} V_{qq'}^*}{\sqrt{2}} \langle M \mid \bar{q}' \gamma^\mu (1 - \gamma_5) q \mid 0 \rangle \langle \Xi_c^{(\prime)}(P', S'_z) \mid \bar{s} \gamma^\mu (1 - \gamma_5) c \mid \Xi_{cc}(P, S_z) \rangle \end{aligned}$$

mode	our results	predictions in Ref.[8]	mode	our results	predictions in Ref.[8]
$\Xi_{cc} \rightarrow \Xi_c \pi$	13.6 ± 1.8	23.9	$\Xi_{cc} \rightarrow \Xi'_c \pi$	7.68 ± 0.92	16.7
$\Xi_{cc} \rightarrow \Xi_c \rho$	11.0 ± 1.5	-	$\Xi_{cc} \rightarrow \Xi'_c \rho$	13.9 ± 1.2	-
$\Xi_{cc} \rightarrow \Xi_c K$	1.03 ± 0.14	-	$\Xi_{cc} \rightarrow \Xi'_c K$	0.492 ± 0.059	-
$\Xi_{cc} \rightarrow \Xi'_c K^*$	0.414 ± 0.055	1.81	$\Xi_{cc} \rightarrow \Xi'_c K^*$	0.623 ± 0.052	2.84

(in unit 10^{10}s^{-1})



五、Summary

1. 我们在three-quark的图像下研究了doubly charmed baryon的弱衰变

$$\langle \Xi_c(P', S', S'_z) | \bar{s}\gamma_\mu(1 - \gamma_5)c | \Xi_{cc}(P, S, S_z) \rangle$$

$$\langle \Xi'_c(P', S', S'_z) | \bar{Q}'\gamma_\mu(1 - \gamma_5)Q | \Xi_{cc}(P, S, S_z) \rangle$$

2. 我们计算了形状因子，建议多项式拟合

3. 我们计算了半轻和非轻的衰变



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谢谢大家！