天津大学
Tianjin University

Doubly charmed baryon weak decays in the light front quark model

柯红卫

2021.5. 3 南开大学

Hong-Wei Ke, et.al. , **arXiv:20xx.xxxxx**

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)**

提纲

1. 动机
2. 重子的顶角函数
3. 跃迁矩阵元
4. 数值结果
5. 新的进展

1. 动机

- 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}

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

$$\Lambda_b \to \Lambda_c \text{ weak decays}$$

$$\Sigma_b \to \Sigma_c \text{ and } \Omega_b \to \Omega_c \text{ weak decays}$$

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)**

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

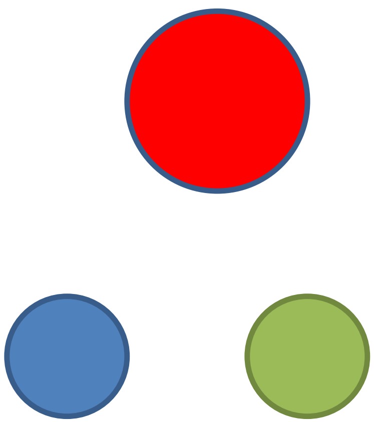
Weak Decays of Doubly Heavy Baryons: the $1/2 \to 1/2$ case

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

2019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. 重子的顶角函数



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)

(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 diaquark

$\Lambda_{b(c)}$ 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

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

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

$$
\left\langle \lambda_1 \left| \mathcal{R}^{\dagger}_M(x_1,k_{1\perp},m_1) \right| s_1 \right\rangle \left\langle 00; \frac{1}{2}s_1 \left| \frac{1}{2}S_z \right.\right\rangle = \frac{1}{\sqrt{2(p_1\cdot \bar{P}+m_1M_0)}} \bar{u}(p_1,\lambda_1)\Gamma u(\bar{P},S_z)
$$

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

$$\Psi^{SS_z}_{\Sigma_c}(\tilde{p}_1,\tilde{p}_2,\lambda_1,m) = \frac{A_2}{\sqrt{6(p_1\cdot\bar{P}+m_1M_0)}}\bar{u}(p_1,\lambda_1)[-\gamma_5\not{\epsilon}^*(p_2,m)]u(\bar{P},S_z)\varphi(x,k_\perp)$$

$$A_2 = \sqrt{\frac{12(M_0m_1+p_1\cdot\bar{P})}{12M_0m_1+4p_1\cdot\bar{P}+8p_1\cdot p_2\,p_2\cdot\bar{P}/m_2^2}}$$

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 spir $S = 1/2$ and momentum P

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

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

$$
\langle \frac{1}{2}s_1; 1m | \frac{1}{2}S_z \rangle = A_1 \bar{u}(p_1,s_1) \frac{-\gamma_5 \not{\epsilon}^*(\bar{P},m)}{\sqrt{3}} u(\bar{P},S_z)
$$

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

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

(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

$$\Psi_0^{SS_z}(\tilde{p}_i,\lambda_i) = A_0 \bar{u}(p_3,\lambda_3)[(\bar{\not{P}}+M_0)\gamma_5]v(p_2,\lambda_2)\bar{u}_Q(p_1,\lambda_1)u(\bar{P},S)\varphi(x_i,k_{i\perp}),$$

and for Σ_Q

$$\Psi_1^{SS_z}(\tilde{p}_i,\lambda_i) = A_1 \bar{u}(p_3,\lambda_3)[(\bar{\not{P}}+M_0)\gamma_{\perp\alpha}]v(p_2,\lambda_2)\bar{u}_Q(p_1,\lambda_1)\gamma_{\perp\alpha}\gamma_5 u(\bar{P},S)\varphi(x_i,k_{i\perp}),$$

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

S. Tawfiq, P. J. O'Donnell and J. G. Korner, Phys. Rev. D **58**, 054010 (1998) doi:10.1103/PhysRevD.58.054010 [hep-ph/9803246].

$$
\begin{aligned}
A_0 &= \frac{1}{4\sqrt{P^+ M_0^3 (m_1+e_1)(m_2+e_2)(m_3+e_3)}}, \\
A_1 &= \frac{1}{4\sqrt{3P^+ M_0^3 (m_1+e_1)(m_2+e_2)(m_3+e_3)}},
\end{aligned}
$$

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

天津大学

对于Ξ_{cc}、Ξ_c、Ξ_c'

$$|\Xi_{cc}(P,S,S_z)\rangle = \int\{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\,2(2\pi)^3\delta^3(\tilde{P}-\tilde{p}_1-\tilde{p}_2-\tilde{p}_3)$$

$$\times\sum_{\lambda_1,\lambda_2,\lambda_3}\Psi^{SS_z}(\tilde{p}_i,\lambda_i)\mathcal{C}^{\alpha\beta\gamma}\mathcal{F}_{ccu}\,|\,c_\alpha(p_1,\lambda_1)c_\beta(p_2,\lambda_2)u_\gamma(p_3,\lambda_3)\rangle,$$

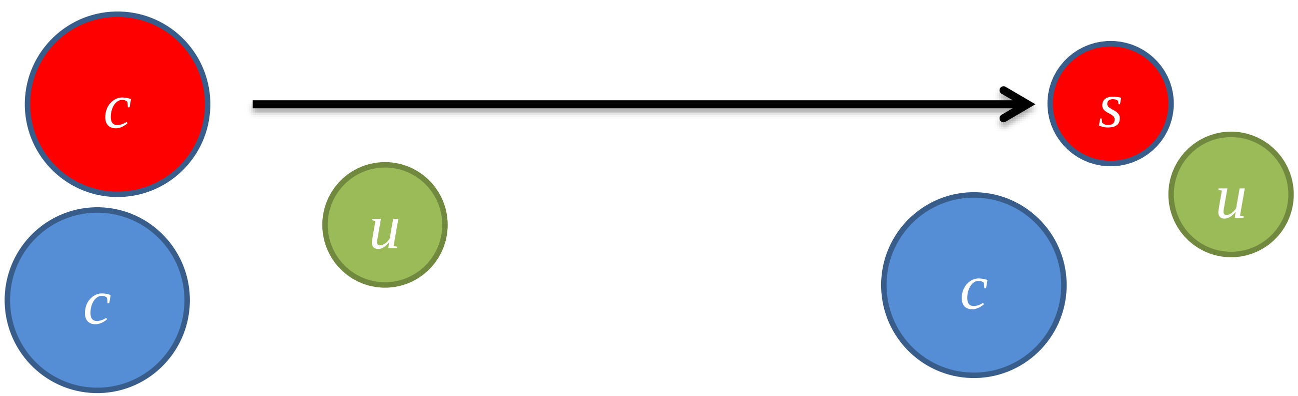
$$|\Xi_c^{(\prime)}(P,S,S_z)\rangle = \int\{d^3\tilde{p}_1\}\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\,2(2\pi)^3\delta^3(\tilde{P}-\tilde{p}_1-\tilde{p}_2-\tilde{p}_3)$$

$$\times\sum_{\lambda_1,\lambda_2,\lambda_3}\Psi^{(\prime)SS_z}(\tilde{p}_i,\lambda_i)\mathcal{C}^{\alpha\beta\gamma}\mathcal{F}_{csu}\,|\,s_\alpha(p_1,\lambda_1)c_\beta(p_2,\lambda_2)u_\gamma(p_3,\lambda_3)\rangle.$$

3. 跃迁矩阵元

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

对于$\Xi_{cc} \to \Xi_c$（Ξ_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

三个角动量耦合基矢的变换：Racah 系数

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

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

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

W. Wang, F. S. Yu and Z. X. Zhao, Eur. Phys. J. C **77**, no. 11, 781 (2017) doi:10.1140/epjc/s10052-017-5360-1 [arXiv:1707.02834 [hep-ph]].

于是

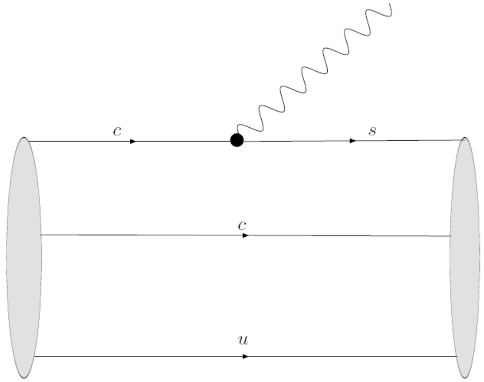
$$\Psi_{ccu}^{SS_z}(\tilde{p}_i, \lambda_i) = \sqrt{2}[-\frac{\sqrt{3}}{2}\Psi_0^{SS_z}(\tilde{p}_i, \lambda_i) + \frac{1}{2}\Psi_1^{SS_z}(\tilde{p}_i, \lambda_i)],$$

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

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

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

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



$$\langle \Xi_c(P', S_z') \mid \bar{s}\gamma^\mu(1-\gamma_5)c \mid \Xi_{cc}(P, S_z)\rangle = \frac{\sqrt{6}}{4}\langle \Xi_c(P', S_z') \mid \bar{s}\gamma^\mu(1-\gamma_5)c \mid \Xi_{cc}(P, S_z)\rangle_0$$

$$+\frac{\sqrt{6}}{4}\langle \Xi_c(P', S_z') \mid \bar{c}\gamma^\mu(1-\gamma_5)b \mid \Xi_{cc}(P, S_z)\rangle_1$$

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

$$= \int \frac{\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\phi^*_{\Xi_c}(x', k'_\perp)\phi_{\Xi_{cc}}(x, k_\perp)Tr[(\bar{\not{P}}' - M'_0)\gamma_5(\not{p}_2 + m_2)(\bar{\not{P}} + M_0)\gamma_5(\not{p}_3 - m_3)]}{16\sqrt{p_1^+ p_1'^+ \bar{P}^+ \bar{P}'^+ M_0^3 (m_1+e_1)(m_2+e_2)(m_3+e_3)(m'_1+e'_1)(m'_2+e'_2)(m'_3+e'_3)}}$$

$$\times \bar{u}(\bar{P}', S'_z)(\not{p}'_1 + m'_1)\gamma^\mu(1-\gamma_5)(\not{p}_1 + m_1)u(\bar{P}, S_z).$$

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

$$= \frac{\int\{d^3\tilde{p}_2\}\{d^3\tilde{p}_3\}\phi^*_{\Xi_c}(x', k'_\perp)\phi_{\Xi_{cc}}(x, k_\perp)Tr[\gamma_\perp^\alpha(\bar{\not{P}}' + M'_0)\gamma_5(\not{p}_2 + m_2)(\bar{\not{P}} + M_0)\gamma_5\gamma_\perp^\beta(\not{p}_3 - m_3)]}{48\sqrt{p_1^+ p_1'^+ \bar{P}^+ \bar{P}'^+ M_0^3 (m_1+e_1)(m_2+e_2)(m_3+e_3)(m'_1+e'_1)(m'_2+e'_2)(m'_3+e'_3)}}$$

$$\times \bar{u}(\bar{P}', S'_z)\gamma_{\perp\alpha}\gamma_5(\not{p}'_1 + m'_1)\gamma^\mu(1-\gamma_5)(\not{p}_1 + m_1)\gamma_{\perp\beta}\gamma_5 u(\bar{P}, S_z).$$

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

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

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

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

$$f_1^s = \int \frac{dx_2 d^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[(\bar{\not{P}}'-M_0')\gamma_5(\not{p}_2+m_2)(\bar{\not{P}}+M_0)\gamma_5(\not{p}_3-m_3)]}{\sqrt{M_0^3(m_1+e_1)(m_2+e_2)(m_3+e_3)(m_1'+e_1')(m_2'+e_2')(m_3'+e_3')}}$$
$$\times\frac{\phi^*_{\Xi_c}(x',k_\perp')\phi_{\Xi_{cc}}(x,k_\perp)}{16\sqrt{x_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not{P}}+M_0)\gamma^+(\bar{\not{P}}'+M_0')(\not{p}_1'+m_1')\gamma^+(\not{p}_1+m_1)]}{8P^+P'^+},$$

$$\frac{f_2^s}{M_{\Xi_{cc}}} = \frac{-i}{q_\perp^i}\int \frac{dx_2 d^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[(\bar{\not{P}}'-M_0')\gamma_5(\not{p}_2+m_2)(\bar{\not{P}}+M_0)\gamma_5(\not{p}_3-m_3)]}{\sqrt{M_0^3(m_1+e_1)(m_2+e_2)(m_3+e_3)(m_1'+e_1')(m_2'+e_2')(m_3'+e_3')}}$$
$$\times\frac{\phi^*_{\Xi_c}(x',k_\perp')\phi_{\Xi_{cc}}(x,k_\perp)}{16\sqrt{x_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not{P}}+M_0)\sigma^{i+}(\bar{\not{P}}'+M_0')(\not{p}_1'+m_1')\gamma^+(\not{p}_1+m_1)]}{8P^+P'^+},$$

$$g_1^s = \int \frac{dx_2 d^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[(\bar{\not{P}}'-M_0')\gamma_5(\not{p}_2+m_2)(\bar{\not{P}}+M_0)\gamma_5(\not{p}_3-m_3)]}{\sqrt{M_0^3(m_1+e_1)(m_2+e_2)(m_3+e_3)(m_1'+e_1')(m_2'+e_2')(m_3'+e_3')}}$$
$$\times\frac{\phi^*_{\Xi_c}(x',k_\perp')\phi_{\Xi_{cc}}(x,k_\perp)}{16\sqrt{x_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not{P}}+M_0)\gamma^+\gamma_5(\bar{\not{P}}'+M_0')(\not{p}_1'+m_1')\gamma^+\gamma_5(\not{p}_1+m_1)]}{8P^+P'^+},$$

$$\frac{g_2^s}{M_{\Xi_{cc}}} = \frac{i}{q_\perp^i}\int \frac{dx_2 d^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[(\bar{\not{P}}'-M_0')\gamma_5(\not{p}_2+m_2)(\bar{\not{P}}+M_0)\gamma_5(\not{p}_3-m_3)]}{\sqrt{M_0^3(m_1+e_1)(m_2+e_2)(m_3+e_3)(m_1'+e_1')(m_2'+e_2')(m_3'+e_3')}}$$
$$\times\frac{\phi^*_{\Xi_c}(x',k_\perp')\phi_{\Xi_{cc}}(x,k_\perp)}{16\sqrt{x_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not{P}}+M_0)\sigma^{i+}\gamma_5(\bar{\not{P}}'+M_0')(\not{p}_1'+m_1')\gamma^+\gamma_5(\not{p}_1+m_1)]}{8P^+P'^+},$$

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

$$\begin{aligned}
f_1^v &= \int \frac{dx_2 d^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[\gamma_\perp^\alpha(\bar{\not P}' + M_0')\gamma_5(\not p_2 + m_2)(\bar{\not 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_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not P} + M_0)\gamma^+(\bar{\not 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^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[\gamma_\perp^\alpha(\bar{\not P}' + M_0')\gamma_5(\not p_2 + m_2)(\bar{\not 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_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not P} - M_0)\sigma^{i+}(\bar{\not 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^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[\gamma_\perp^\alpha(\bar{\not P}' + M_0')\gamma_5(\not p_2 + m_2)(\bar{\not 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_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not P} - M_0)\gamma^+\gamma_5(\bar{\not 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^2k_{2\perp}^2}{2(2\pi)^3}\frac{dx_3 d^2k_{3\perp}^2}{2(2\pi)^3}\frac{\mathrm{Tr}[\gamma_\perp^\alpha(\bar{\not P}' + M_0')\gamma_5(\not p_2 + m_2)(\bar{\not 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_1x_1'}}\frac{\mathrm{Tr}[(\bar{\not P} - M_0)\sigma^{i+}\gamma_5(\bar{\not 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}$$

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

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

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

四、数值结果

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

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

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

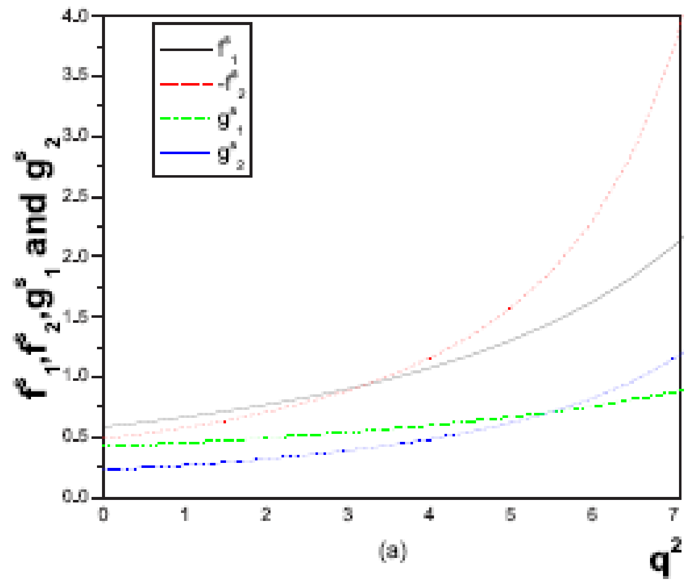
Since these form factors $f_i^{s(v)}$ $(i = 1, 2)$ and $g_i^{s(v)}$ $(i = 1, 2)$ are evaluated in the frame $q^+ = 0$ i.e. $q^2 = -q_\perp^2 \leq 0$ (the space-like region) one needs to extend them into the time-like region. In Ref.[31] a tl

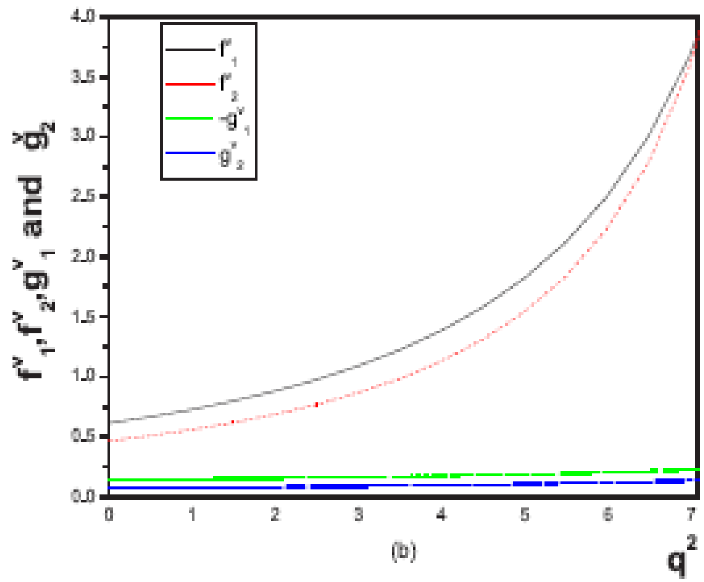
$$F(q^2) = \frac{F(0)}{\left(1 - \frac{q^2}{M^2_{\Xi_{cc}}}\right)\left[1 - a\left(\frac{q^2}{M^2_{\Xi_{cc}}}\right) + b\left(\frac{q^2}{M^2_{\Xi_{cc}}}\right)^2\right]},$$

[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


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
(a)
q2


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
(b)
q2

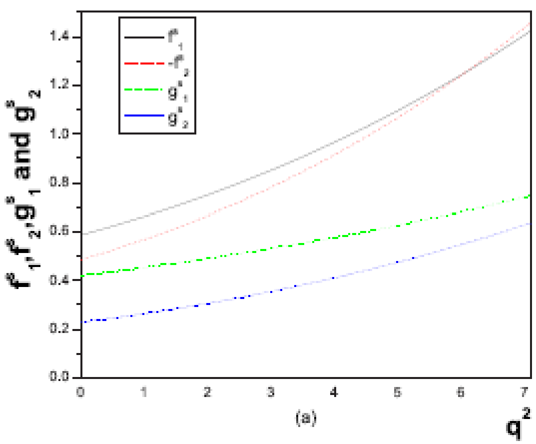
we suggest a polynomial to parameterize these form factors

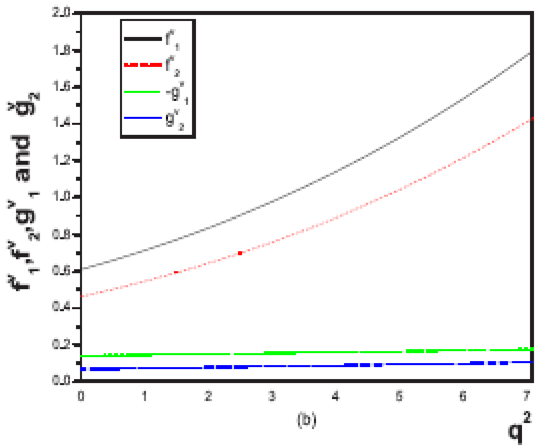
$$F(q^2) = F(0)\left[1 + a'\left(\frac{q^2}{M^2_{\Xi_{cc}}}\right) + b'\left(\frac{q^2}{M^2_{\Xi_{cc}}}\right)^2 + c'\left(\frac{q^2}{M^2_{\Xi_{cc}}}\right)^3\right]$$

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

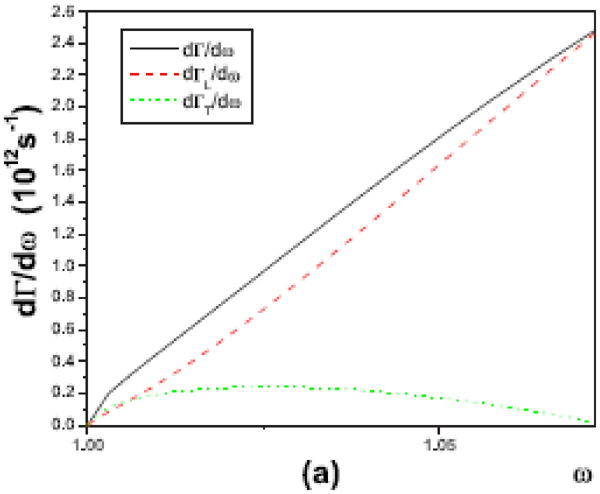
F	$F(0)$	a'	b'	c'
f_1^s	0.586	1.57	1.59	0.704
f_2^s	-0.484	2.06	2.42	1.17
g_1^s	0.420	0.983	0.692	0.258
g_2^s	0.228	1.90	2.07	0.960
f_1^v	0.610	2.04	2.27	1.06
f_2^v	0.463	2.14	2.49	1.19
g_1^v	-0.140	0.422	0.0931	0.00632
g_2^v	0.0673	0.925	0.245	-0.0862

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

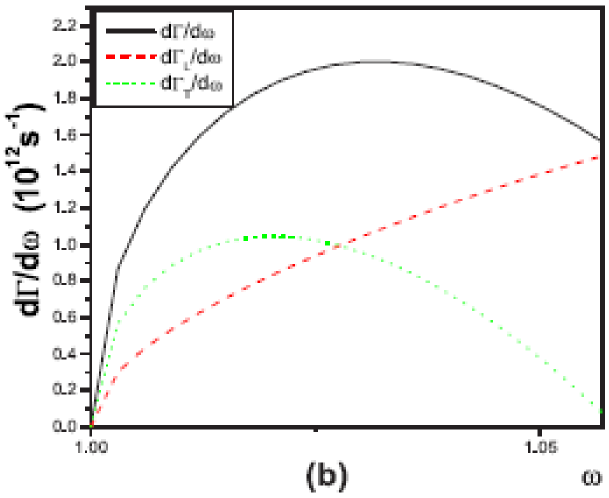

f^s_1
-f^s_2
g^s_1
g^s_2
f^s_1,f^s_2,g^s_1 and g^s_2
(a)
q^2


f^v_1
f^v_2
-g^v_1
g^v_2
f^v_1,f^v_2,g^v_1 and g^v_2
(b)
q^2

2. 半轻衰变



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



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

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

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

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

$$\Gamma(\Xi_{cc}' \to \Xi_c l \bar{\nu}_l) = 0.193 \times 10^{-12}\mathrm{s}^{-1}$$ R=1.42

W. Wang, F.S. Yu, Z.X. Zhao, Eur. Phys. J. C **77**(11), 781 (2017). https://doi.org/10.1140/epjc/s10052-017-5360-1. arXiv:1707.02834 [hep-ph]

3. 非轻衰变

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

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

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

W. Wang, F.S. Yu, Z.X. Zhao, Eur. Phys. J. C 77(11), 781 (2017). https://doi.org/10.1140/epjc/s10052-017-5360-1. arXiv:1707.02834 [hep-ph]

天津大学

五、 新的进展

最近Belle测量了 $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ 的分支比，格点QCD也有计算结果

Measurements of the branching fractions of semileptonic decays $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$ and asymmetry parameter of $\Xi_c^0 \to \Xi^- \pi^+$ decay

Belle Collaboration • Y.B. Li (Fudan U.) et al. (Mar 11, 2021)

e-Print: 2103.06496 [hep-ex]

$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (1.72 \pm 0.10 \pm 0.12 \pm 0.50)\%$

之前平均 $\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e)$ is $(2.34 \pm 1.59)\%$

$\Xi_c \to \Xi$ Form Factors and $\Xi_c \to \Xi \ell^+ \nu_\ell$ Decay Rates From Lattice QCD

Qi-An Zhang (Shanghai Jiao Tong U. and Tsung-Dao Lee Inst., Shanghai), Jun Hua (Shanghai Jiaotong U., INPAC and Tsung-Dao Lee Inst., Shanghai), Fei Huang (Shanghai Jiaotong U., INPAC and Tsung-Dao Lee Inst., Shanghai), Renbo Li (Nanjing Normal U.), Yuanyuan Li (Nanjing Normal U.) Show All(10)

Mar 11, 2021

7 pages

e-Print: 2103.07064 [hep-lat]

$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = 2.38(0.30)(0.33)\%$

理论计算

Z. X. Zhao, Chin. Phys. C **42**, 093101 (2018), doi:10.1088/1674-1137/42/9/093101 [arXiv:1803.02292 [hep-ph]]. — 5.39×10^{-2}

Y. L. Liu and M. Q. Huang, J. Phys. G **37**, 115010 (2010), doi:10.1088/0954-3899/37/11/115010 [arXiv:1102.4245 [hep-ph]].

K. Azizi, Y. Sarac and H. Sundu, Eur. Phys. J. A **48**, 2 (2012), doi:10.1140/epja/i2012-12002-1 [arXiv:1107.5925 [hep-ph]].

C. Q. Geng, Y. K. Hsiao, C. W. Liu and T. H. Tsai, Phys. Rev. D **97**, no.7, 073006 (2018), doi:10.1103/PhysRevD.97.073006 [arXiv:1801.03276 [hep-ph]]. — $(3.38^{+2.19}_{-2.26}) \times 10^{-2}$

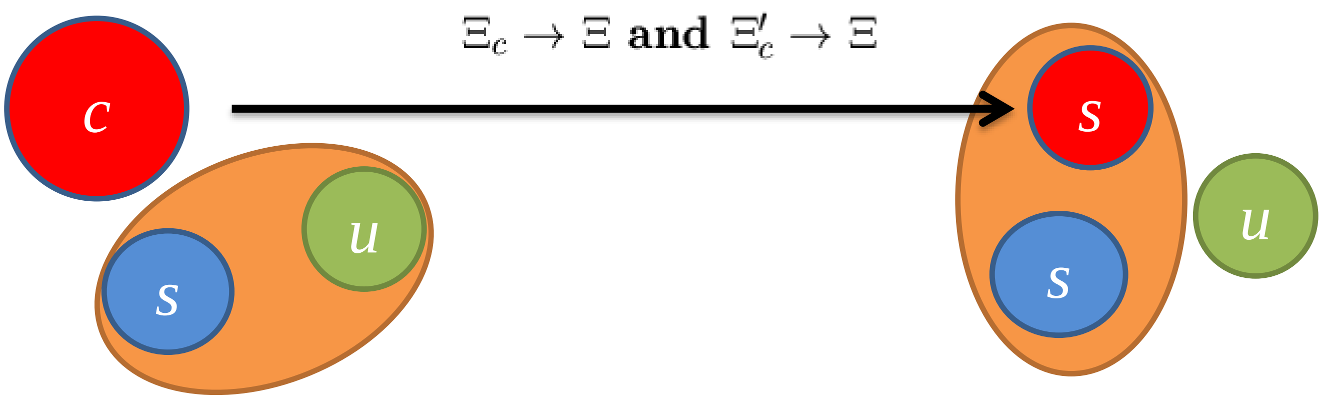
C. Q. Geng, C. W. Liu, T. H. Tsai and S. W. Yeh, Phys. Lett. B **792**, 214-218 (2019), doi:10.1016/j.physletb.2019.03.056 [arXiv:1901.05610 [hep-ph]].

C. Q. Geng, C. W. Liu and T. H. Tsai, [arXiv:2012.04147 [hep-ph]]. — $(3.49 \pm 0.95)\%$,

Semi-leptonic form factors of $\Xi_c \to \Xi$ in QCD sum rules

Zhen-Xing Zhao (Neimunggu U.) (Mar 17, 2021)

e-Print: 2103.09436 [hep-ph]



初态su对有确定的自旋，末态ss对有确定的自旋

谢谢大家！