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Weak decays of triply heavy baryons in light front approach

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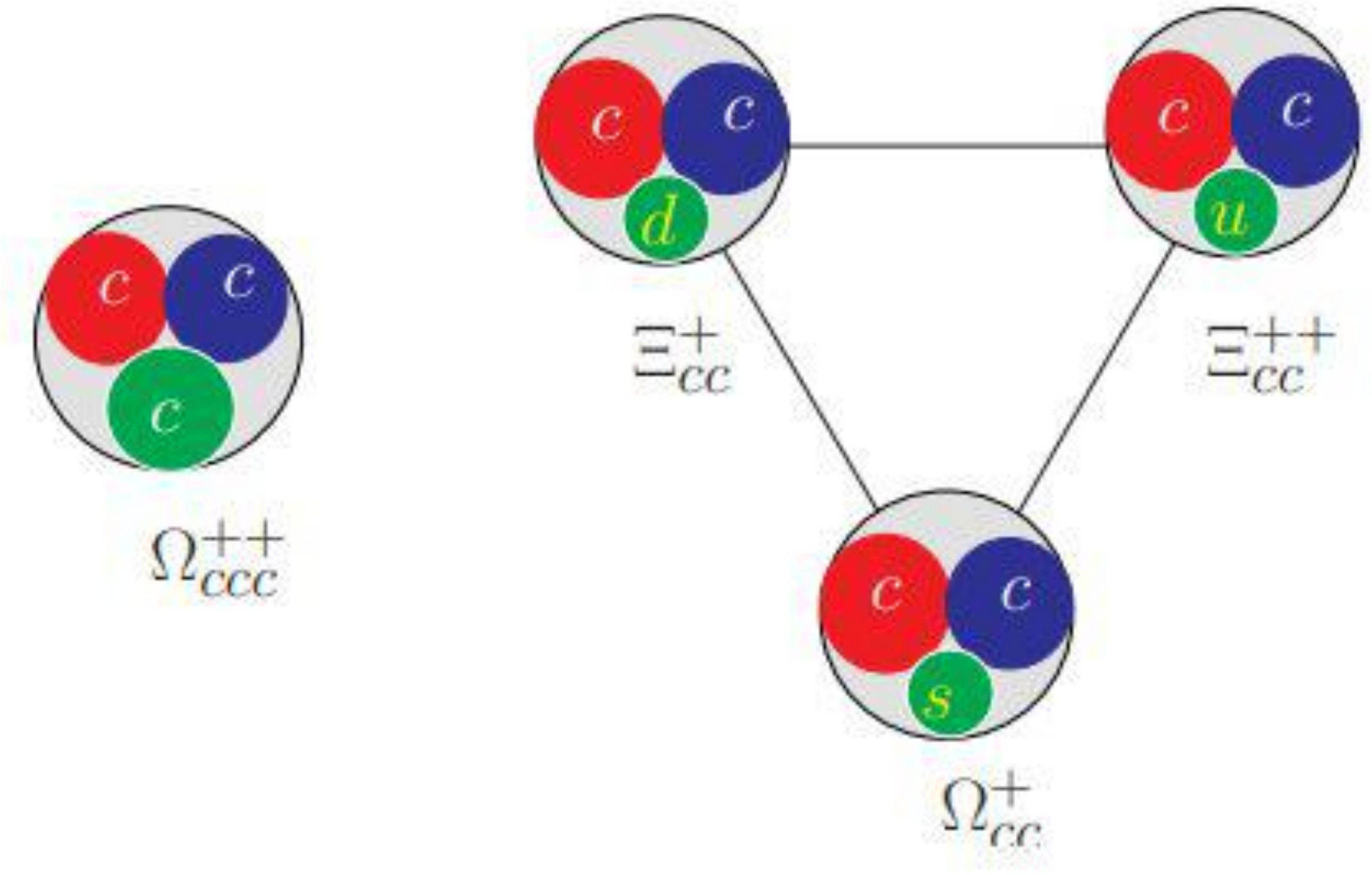
Introduction



$$c \to d/s$$

$$\Omega_{ccc}^{++} \to \Omega_{cc}^{+}/\Xi_{cc}^{+}$$

LFQM

quark-diquark assumption

$$\Lambda_b \to \Lambda_c$$

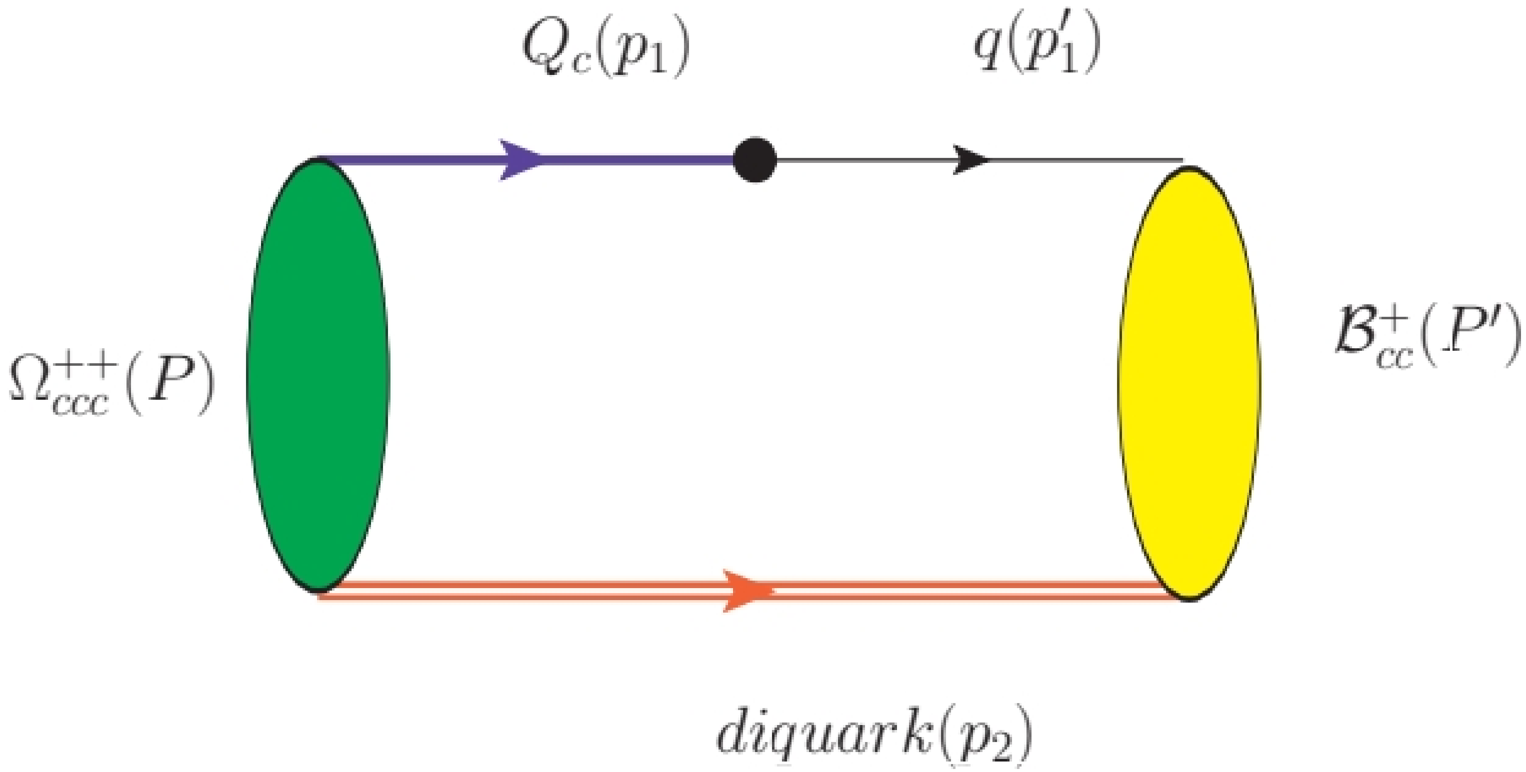
$$\Sigma_b \to \Sigma_c$$

Theoretical framework

$$\mathcal{H}_{\rm eff}(c \to d/s\ \ell^+\nu_l) = \frac{G_F}{\sqrt{2}}\Big(V_{cd}^*[\bar{d}\gamma_\mu(1-\gamma_5)c][\bar{\nu}_l\gamma^\mu(1-\gamma_5)l] + V_{cs}^*[\bar{s}\gamma_\mu(1-\gamma_5)c][\bar{\nu}_l\gamma^\mu(1-\gamma_5)l]\Big),$$

$$\mathcal{H}_{\rm eff}(c \to d\bar{s}u/s\bar{d}u) = \sum_{i=1,2}\frac{G_F}{\sqrt{2}}C_i(V_{cs}V_{ud}^*O_i^{s\bar{d}u} + V_{cd}V_{us}^*O_i^{d\bar{s}u} + V_{cs}V_{us}^*O_i^{s\bar{s}u} + V_{cd}V_{ud}^*O_i^{d\bar{d}u}) + h.c.,$$

$$i\mathcal{M}(\Omega_{ccc}^{++} \to \mathcal{B}_{cc}^+\ \ell^+\nu_l) = \frac{G_F}{\sqrt{2}}V_{cq}^*\langle\mathcal{B}_{cc}^+|\bar{q}\gamma_\mu(1-\gamma_5)c|\Omega_{ccc}^{++}\rangle\bar{\nu}_l\gamma^\mu(1-\gamma_5)l,\ \mathcal{B}_{cc}^+ = \Xi_{cc}^+/\ \Omega_{cc}^+,\ q = d/s.$$


$Q_c(p_1)$
$q(p_1')$
$\Omega_{ccc}^{++}(P)$
$\mathcal{B}_{cc}^{+}(P')$
$diquark(p_2)$

$$\Psi^{SS_z}(\tilde{p}_1, \tilde{p}_2, \lambda_1, \lambda_2) = \frac{1}{\sqrt{2(p_1 \cdot \bar{P} + m_1 M_0)}} \bar{u}(p_1, \lambda_1) \Gamma_A^{\alpha}(p_2, \lambda_2) u_{\alpha}(\bar{P}, S_z) \phi(x, k_\perp),$$

$$\begin{aligned}
&\langle \mathcal{B}_{cc}^{+}(P', S' = \frac{1}{2}, S'_z) | \bar{q} \gamma^\mu (1 - \gamma_5) Q_c | \Omega_{ccc}^{++}(P, S = \frac{3}{2}, S_z) \rangle \\
= &\int \{d^3 p_2\} \frac{\phi'(x', k'_\perp) \phi(x, k_\perp)}{2\sqrt{p_1^+ p_1'^+ (p_1 \cdot \bar{P} + m_1 M_0)(p'_1 \cdot \bar{P}' + m'_1 M'_0)}} \\
&\times \sum_{\lambda_2} \bar{u}(\bar{P}', S'_z) \left[\bar{\Gamma}'_A (\not{p}'_1 + m'_1) \gamma^\mu (1 - \gamma_5)(\not{p}_1 + m_1) \Gamma_A^\alpha \right] u_\alpha(\bar{P}, S_z),
\end{aligned}$$

$$
\begin{aligned}
\mathtt{f}_1(q^2) &= \frac{-M^2}{2s_-^2 s_+^2}\{4M[H_1 s_- - H_2 M] - 2H_3(s_- - 2MM') + H_4(s_- s_+)\},\\
\mathtt{f}_2(q^2) &= \frac{-M\bar{M}}{s_-^3 s_+^2}\{s_-[H_1 M(s_- - 2MM') + H_4(s_- + MM')s_+] + 4H_2M^2(2s_+ - 3MM')\\
&\quad -2H_3[M^4 - 2M^3M' + 2M^2(6M'^2 - q^2) + 2MM'(q^2 - M'^2) + (M'^2 - q^2)^2]\},\\
\mathtt{f}_3(q^2) &= \frac{M^3\bar{M}}{s_-^3 s_+^2}\{s_-(H_4 s_+ - 2H_1 M) + 20H_2M^2 - 4H_3(2s_+ - 3MM')\},\\
\mathtt{f}_4(q^2) &= \frac{1}{2s_-^2 s_+}\{s_-[H_1 M + H_4 s_+] + 2H_2M^2 - 2H_3[s_- + MM']\},
\end{aligned}
$$

$$
\begin{aligned}
\mathtt{g}_1(q^2) &= \frac{-M^2}{2s_-^2 s_+^2}\{4M[H_1 s_+ - H_2 M] - 2H_3(s_+ + 2MM') + H_4(s_- s_+)\},\\
\mathtt{g}_2(q^2) &= \frac{M\bar{M}}{s_+^3 s_-^2}\{s_+[H_1 M(s_+ + 2MM') + H_4(s_+ - MM')s_+] + 4H_2M^2(2s_- + 3MM')\\
&\quad -2H_3[M^4 + 2M^3M' + 2M^2(6M'^2 - q^2) - 2MM'(q^2 - M'^2) + (M'^2 - q^2)^2]\},\\
\mathtt{g}_3(q^2) &= \frac{-M^3\bar{M}}{s_+^3 s_-^2}\{s_+(H_4 s_- - 2H_1 M) + 20H_2M^2 - 4H_3(2s_- + 3MM')\},\\
\mathtt{g}_4(q^2) &= \frac{1}{2s_+^2 s_-}\{s_+[H_1 M + H_4 s_-] + 2H_2M^2 - 2H_3[s_+ - MM']\},
\end{aligned}
$$

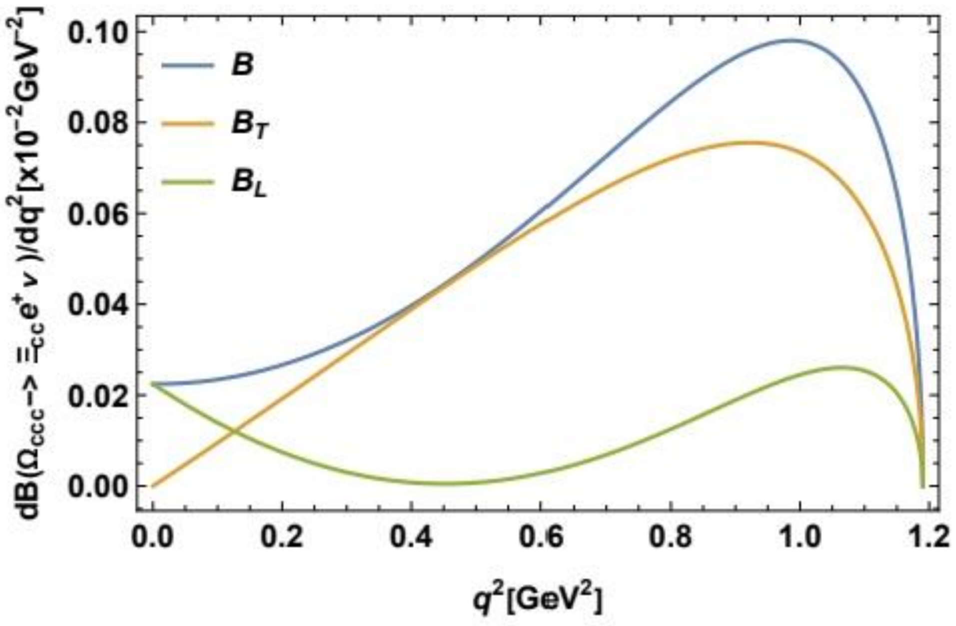
Numerical results

TABLE I: Numerical results for form factors at $q^2 = 0$ in Ω_{ccc}^{++} decays.

channel	$f_1(0)$	$f_2(0)$	$f_3(0)$	$f_4(0)$	$g_1(0)$	$g_2(0)$	$g_3(0)$	$g_4(0)$
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+}$	0.869	-7.183	8.996	0.373	-2.739	6.525	-7.626	-0.942
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+}$	1.113	-11.995	14.628	0.739	-9.221	12.362	-13.067	-1.557

TABLE II: Numerical results of decay width and branching fraction in Ω_{ccc}^{++} semi-leptonic decays.

channel	$\Gamma(\times 10^{-14}\text{GeV})$	$\Gamma_T(\times 10^{-14}\text{GeV})$	$\Gamma_L(\times 10^{-14}\text{GeV})$	Γ_L/Γ_T	Branching fraction (%) [52]
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} e^{+} \nu_e$	0.28	0.23	0.053	0.24	0.069
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \mu^{+} \nu_\mu$	0.27	0.22	0.048	0.22	0.067
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} e^{+} \nu_e$	7.78	6.33	1.45	0.23	1.93
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \mu^{+} \nu_\mu$	7.43	6.08	1.30	0.21	1.84


dB(Ωccc-> Ξcc e+ ν)/dq2[x10-2GeV-2]
B
BT
BL
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.2
0.4
0.6
0.8
1.0
1.2
q2[GeV2]

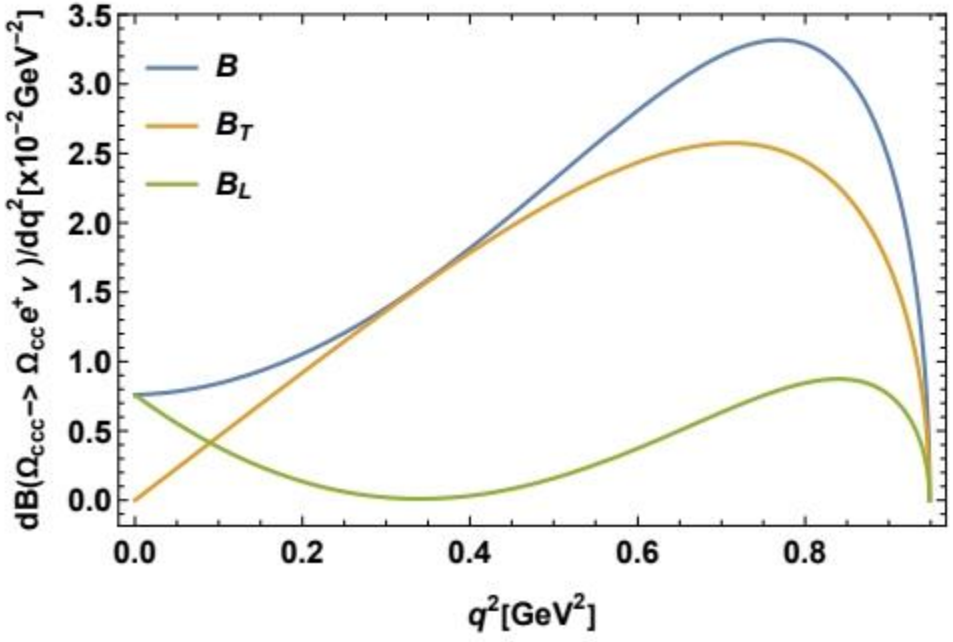

dB(Ωccc-> Ωcc e+ ν)/dq2[x10-2GeV-2]
B
BT
BL
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
q2[GeV2]

TABLE III: Numerical results of decay width and branching fraction in Ω_{ccc}^{++} nonleptonic decays.

channel	Γ(GeV)	Branching fraction (%)	Branching fraction $(N_c = 2)$(%)	Branching fraction $(N_c = \infty)$(%)
$\Omega_{ccc}^{++} \to \Xi_{cc}^{+} K^{+}$	1.613×10^{-17}	4.00×10^{-6}	3.42×10^{-6}	5.31×10^{-6}
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} K^{+}$	9.152×10^{-16}	2.27×10^{-4}	1.94×10^{-4}	3.01×10^{-4}
$\Gamma(\Omega_{ccc}^{++} \to \Xi_{cc}^{+} \pi^{+}$	9.202×10^{-16}	2.28×10^{-4}	1.95×10^{-4}	3.03×10^{-4}
$\Omega_{ccc}^{++} \to \Omega_{cc}^{+} \pi^{+}$	5.522×10^{-14}	1.370%	1.17%	1.82%

$$\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\pi^{+})}\right)_{SU(3)}=\frac{|V_{cd}V_{us}|^2}{|V_{cs}V_{ud}|^2}=0.0026,$$

$$\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}K^{+})}\right)_{SU(3)}=\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}\pi^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\pi^{+})}\right)_{SU(3)}=\frac{|V_{cd}|^2}{|V_{cs}|^2}=0.050,$$

$$\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}\pi^{+})}\right)_{SU(3)}=\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\pi^{+})}\right)_{SU(3)}=\frac{|V_{us}|^2}{|V_{ud}|^2}=0.053,$$

$$\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}\ell^{+}\nu_l)}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\ell^{+}\nu_l)}\right)_{LFQM}=0.036,\quad\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\pi^{+})}\right)_{LFQM}=0.00029,$$

$$\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}K^{+})}\right)_{LFQM}=0.018,\quad\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}\pi^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\pi^{+})}\right)_{LFQM}=0.018,$$

$$\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Xi_{cc}^{+}\pi^{+})}\right)_{LFQM}=0.017,\quad\left(\frac{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}K^{+})}{\Gamma(\Omega_{ccc}^{++}\to\Omega_{cc}^{+}\pi^{+})}\right)_{LFQM}=0.017.$$

Summary

- 借助螺旋度振幅，计算了衰变宽度。
- 预测了半轻衰变的分支比：$\mathcal{B}(\Omega_{ccc}^{++} \to \Xi_{cc}^{+} e^{+} \nu_e) = 0.069\%$，$\mathcal{B}(\Omega_{ccc}^{++} \to \Omega_{cc}^{+} e^{+} \nu_e) = 1.93\%$。
- 在非轻衰变过程中存在着相当大的SU（3）对称性破缺效应，其主要来源于末态重子和介子的质量差。
- 我们发现$\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\pi^{+}$有一个相当大的分支分数：$\mathcal{B}(\Omega_{ccc}^{++} \to \Omega_{cc}^{+}\pi^{+}) = 1.37\%$。

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谢 谢 聆 听!

请各位老师和同学批评指正！