Semi-leptonic decays of doubly heavy baryons : spin-1/2 to spin-1/2 and spin-1/2 to spin-3/2 cases

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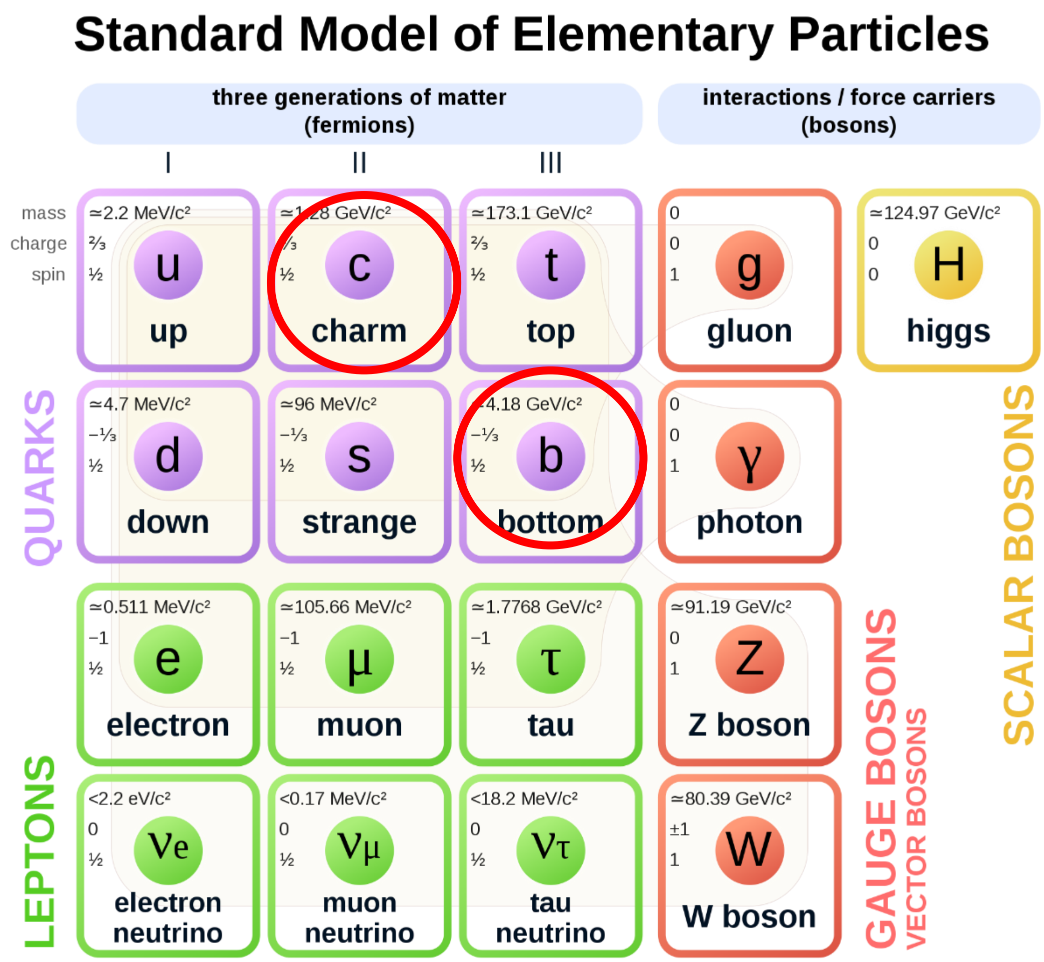
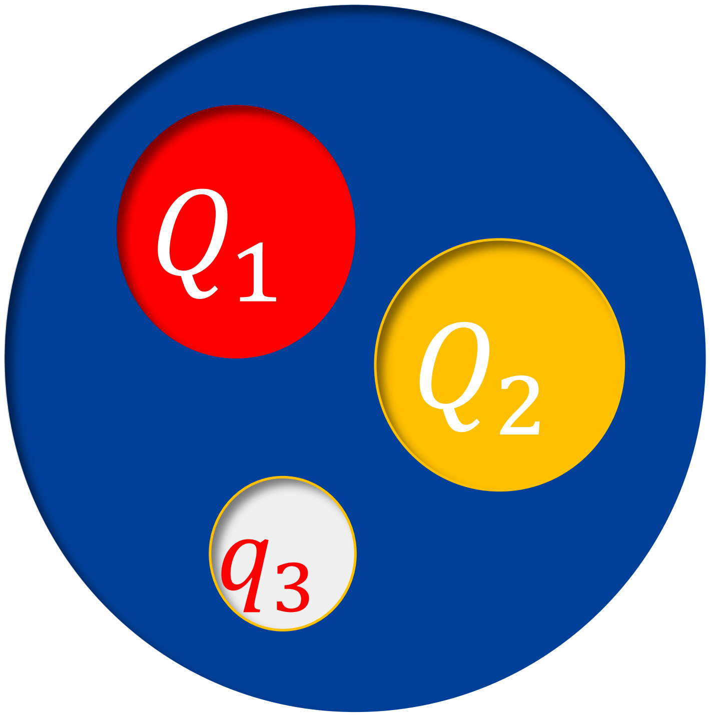
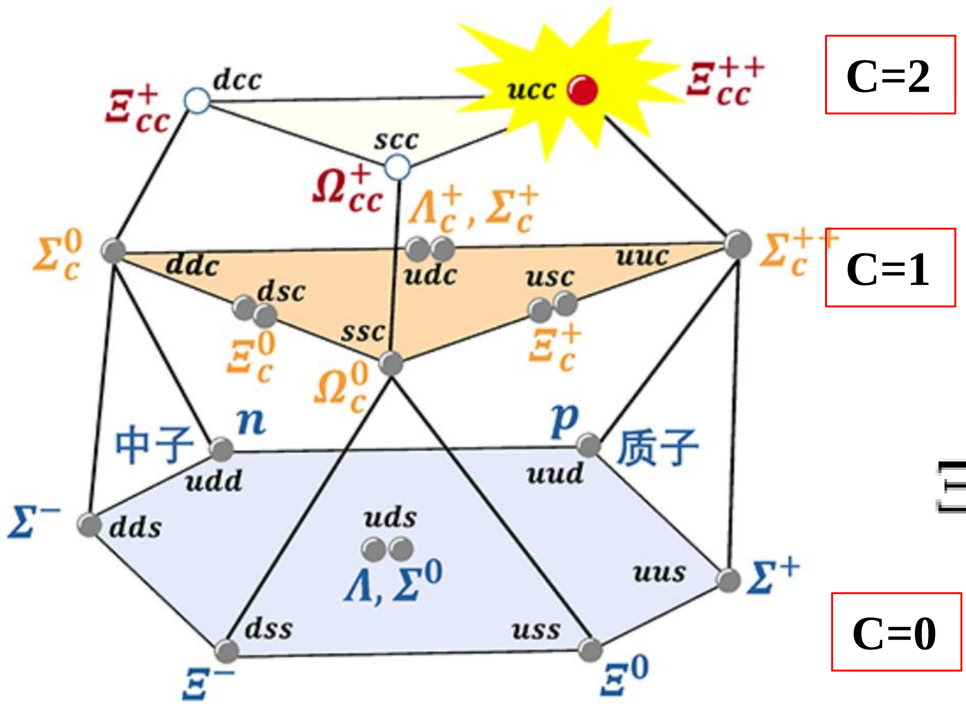
Quark model



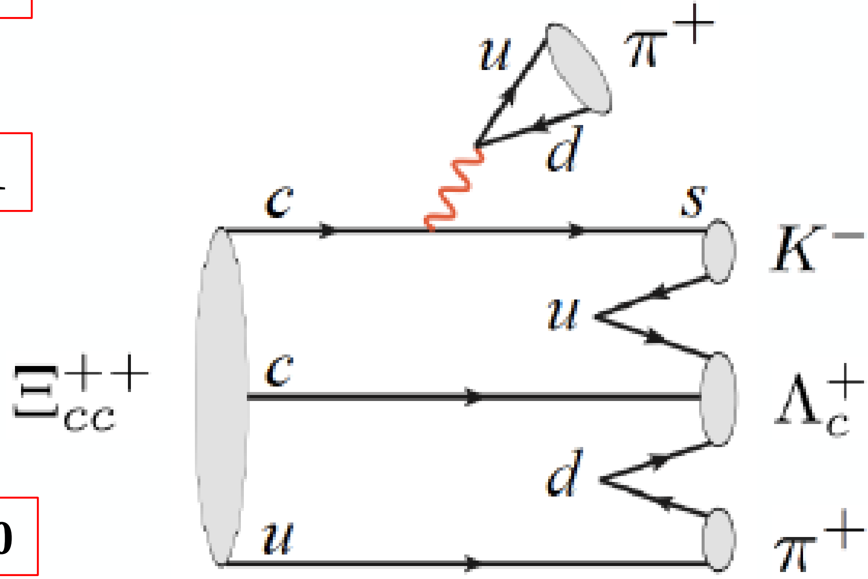


Doubly heavy baryons

Observation of Ξ_{cc}^{++}



$$\Xi_{cc}^{++} \to \Lambda_c^{+} K^{-} \pi^{+} \pi^{+}$$



Phys. Rev. Lett. 119. 112001

$$m_{\Xi_{cc}^{++}} = [3621.40 \pm 0.72(\mathrm{stat}) \pm 0.27(\mathrm{syst}) \pm 0.14(\Lambda_c^{+})]\mathrm{MeV/c^2}$$

$$\tau_{\Xi_{cc}^{++}} = [0.256^{+0.024}_{-0.022}(\mathrm{stat}) \pm 0.014(\mathrm{syst})]\mathrm{ps}$$

Phys. Rev. Lett. 121. 052002 (2018)

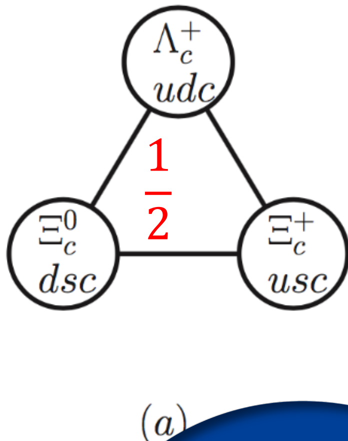
Theoretical framework

- Doubly heavy baryons decays

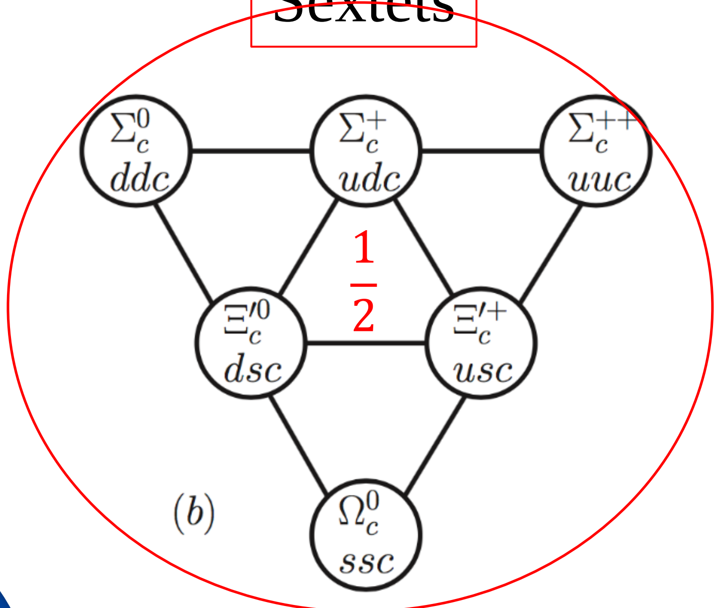
$\Xi_{QQ'}$

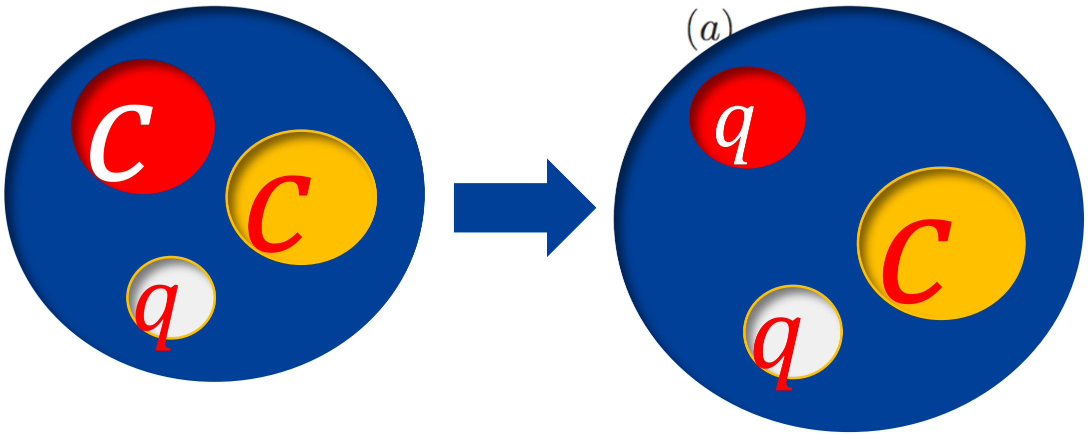
$Q, Q' = b, c$

Anti-triplets



Sextets



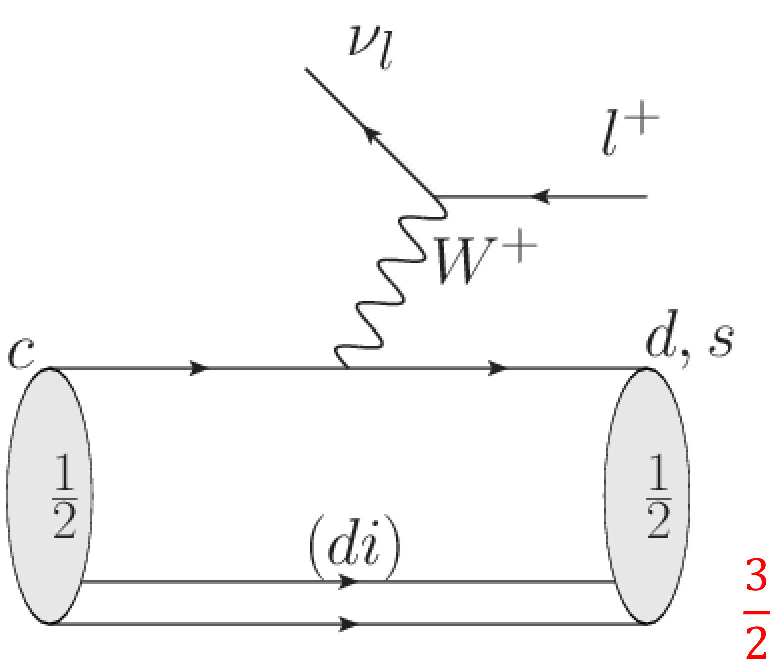


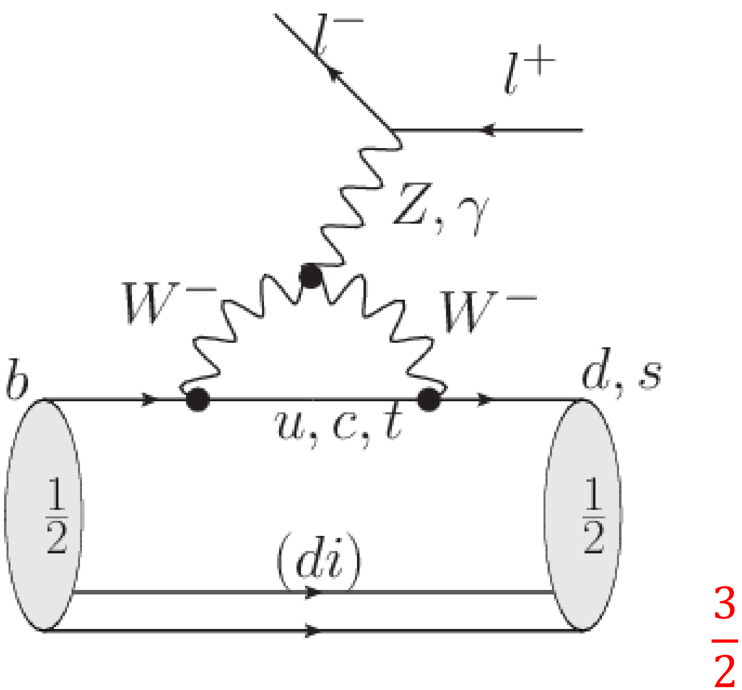
Excited states $\frac{3}{2}$

spin 1/2→ spin 1/2 or spin 3/2: V-A current and FCNC

$\frac{1}{2} \rightarrow \frac{1}{2}$ Charged current

$\frac{1}{2} \rightarrow \frac{1}{2}$ FCNC





$\frac{1}{2} \rightarrow \frac{3}{2}$ Charged current

$\frac{1}{2} \rightarrow \frac{3}{2}$ FCNC

The effective Hamiltonian

- The Hamiltonian for $c \to d, s\, l^+ \nu_l$

$$\frac{G_F}{\sqrt{2}}\left(V_{cs}^*[\bar{s}\gamma_\mu(1-\gamma_5)c][\bar{\nu}_l\gamma^\mu(1-\gamma_5)l] + V_{cd}^*[\bar{d}\gamma_\mu(1-\gamma_5)c][\bar{\nu}_l\gamma^\mu(1-\gamma_5)l]\right)$$

- The Hamiltonian for $b \to u, c l^- \bar{\nu}_l$

$$\frac{G_F}{\sqrt{2}}\left(V_{cb}[\bar{c}\gamma_\mu(1-\gamma_5)b][\bar{l}\gamma^\mu(1-\gamma_5)\nu_l] + V_{ub}[\bar{u}\gamma_\mu(1-\gamma_5)b][\bar{l}\gamma^\mu(1-\gamma_5)\nu_l]\right)$$

- The Hamiltonian for $b \to s l^+ l^-$

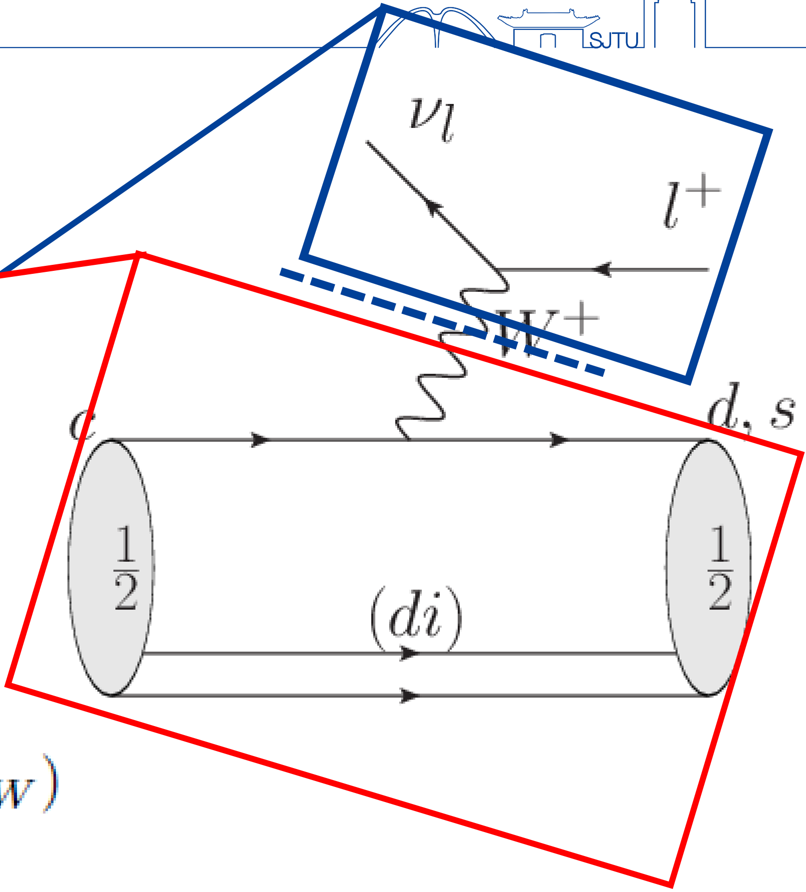
$$\mathcal{H}_{\rm eff}(b \to s l^+ l^-) = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu).$$

Helicity Amplitude

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{cd}^* \, [\bar{d}\gamma_\mu(1-\gamma_5)c][\bar{\nu}_l \gamma^\mu (1-\gamma_5) l]$$

$$\mathcal{M} = \langle \Lambda_c^+ l^+ \nu_l | \mathcal{H}_{eff} | \Xi_{cc}^{++} \rangle$$

$$= \frac{G_F}{\sqrt{2}} V_{cd}^* \langle \Lambda_c^+ | \bar{d}\gamma_\mu(1-\gamma_5)c | \Xi_{cc}^{++} \rangle \langle l^+ \nu_l | \bar{\nu}_l \gamma^\mu (1-\gamma_5) l | 0 \rangle$$



$$H^V_{\lambda', \lambda_W} \equiv \langle \mathcal{B}_f^{(*)}(\lambda') | \bar{q}\gamma^\mu Q | \mathcal{B}_i(\lambda) \rangle \epsilon^*_{W\mu}(\lambda_W)$$

$$H^A_{\lambda', \lambda_W} \equiv \langle \mathcal{B}_f^{(*)}(\lambda') | \bar{q}\gamma^\mu \gamma_5 Q | \mathcal{B}_i(\lambda) \rangle \epsilon^*_{W\mu}(\lambda_W)$$

Helicity Amplitude

$$H^V_{\frac{1}{2},0} = -i\frac{\sqrt{Q_-}}{\sqrt{q^2}}\left((M+M')f_1 - \frac{q^2}{M}f_2\right),$$

$$H^V_{\frac{1}{2},1} = i\sqrt{2Q_-}\left(-f_1 + \frac{M+M'}{M}f_2\right),$$

$$H^A_{\frac{1}{2},0} = -i\frac{\sqrt{Q_+}}{\sqrt{q^2}}\left((M-M')g_1 + \frac{q^2}{M}g_2\right),$$

$$H^A_{\frac{1}{2},1} = i\sqrt{2Q_+}\left(-g_1 - \frac{M-M'}{M}g_2\right),$$

Physical form factors

For b quark decay

$$F(q^2) = \frac{F(0)}{1 - \frac{q^2}{m_{fit}^2} + \delta(\frac{q^2}{m_{fit}^2})^2}$$

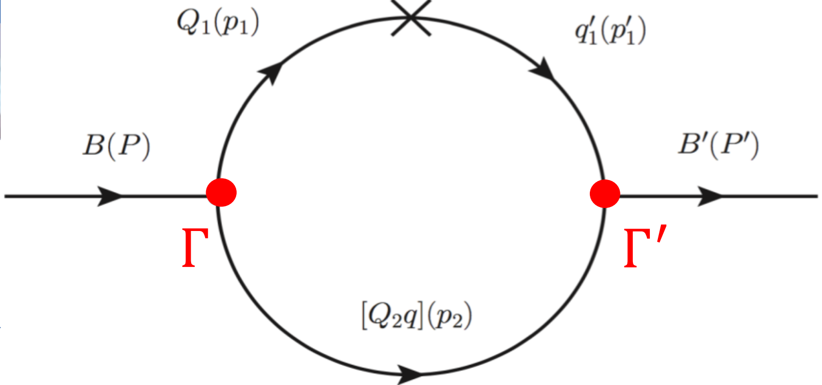
For c quark decay

$$F(q^2) = \frac{F(0)}{1 - \frac{q^2}{m_{pole}^2}}$$

$$\frac{d\Gamma_L}{dq^2} = \frac{G_F^2|V_{CKM}|^2}{(2\pi)^3}\frac{q^2 p}{24M^2}(|H_{\frac{1}{2},0}|^2 + |H_{-\frac{1}{2},0}|^2),$$

$$\frac{d\Gamma_T}{dq^2} = \frac{G_F^2|V_{CKM}|^2}{(2\pi)^3}\frac{q^2 p}{24M^2}(|H_{\frac{1}{2},1}|^2 + |H_{-\frac{1}{2},-1}|^2),$$

Light front quark model



$$|\mathcal{B}(P,S,S_z)\rangle = \int \{d^3p_1\}\{d^3p_2\}2(2\pi)^3\delta^3(P-\tilde{p}_1-\tilde{p}_2) \times \sum_{\lambda_1,\lambda_2} \Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2)|Q_1(p_1,\lambda_1)(di)(p_2,\lambda_2)\rangle,$$

- For the baryons with spin 1/2

$$\Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2) = \frac{1}{\sqrt{2(p_1\cdot\bar{P}+m_1M_0)}}\bar{u}(p_1,\lambda_1)\Gamma u(\bar{P},S_z)\phi(x,k_\perp)$$

For an axial-vector diquark

For a scalar diquark $\Gamma = 1$

$$\Gamma = -\frac{1}{\sqrt{3}}\gamma_5\left(\not{\epsilon}^*(p_2,\lambda_2) - \frac{M_0+m_1+m_2}{\bar{P}\cdot p_2+m_2M_0}\epsilon^*(p_2,\lambda_2)\cdot\bar{P}\right)$$

Ref: Chun-Khiang Chua, Phys. Rev. D 99, 014023 (2019)

Light front quark model

- For the baryons with spin 3/2

$$\Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2)=\frac{1}{\sqrt{2(p_1\cdot\bar{P}+m_1M_0)}}\bar{u}(p_1,\lambda_1)\Gamma_A^{\alpha}(p_2,\lambda_2)u_{\alpha}(\bar{P},S_z)\phi(x,k_{\perp})$$

$$\Gamma_A^{\alpha}=-\left(\epsilon^{*\alpha}(p_2,\lambda_2)-\frac{p_2^{\alpha}}{\bar{P}\cdot p_2+m_2M_0}\epsilon^{*}(p_2,\lambda_2)\cdot\bar{P}\right)$$

$$u^{\alpha}=\left(\epsilon^{\alpha}-\frac{1}{3}\left(\gamma^{\alpha}+v^{\alpha}\right)\not{\epsilon}\right)u$$

Transition matrix element : LFQM

$$\langle \mathcal{B}'_f(P', S' = \frac{1}{2}, S'_z) | \bar{q}\gamma_\mu(1-\gamma_5)Q | \mathcal{B}_i(P, S = \frac{1}{2}, S_z) \rangle$$

$$= \int \{d^3 p_2\} \frac{\phi'(x', k'_\perp)\phi(x, k_\perp)}{2\sqrt{p_1^+ p_1'^+ (p_1 \cdot \bar{P} + m_1 M_0)(p'_1 \cdot \bar{P}' + m'_1 M'_0)}}$$

$$\times \sum_{\lambda_2} \bar{u}(\bar{P}', S'_z)\bar{\Gamma}'_{S(A)}(\not{p}'_1 + m'_1)\gamma_\mu(1-\gamma_5)(\not{p}_1 + m_1)\Gamma_{S(A)} u(\bar{P}, S_z)$$

Tensor current

$$\langle \mathcal{B}'^*_f(P', S' = \frac{3}{2}, S'_z) | \bar{q}\gamma^\mu(1-\gamma_5)Q | \mathcal{B}_i(P, S = \frac{1}{2}, S_z) \rangle$$

For FCNC channels

$$= \int \{d^3 p_2\} \frac{\phi'(x', k'_\perp)\phi(x, k_\perp)}{2\sqrt{p_1^+ p_1'^+ (p_1 \cdot \bar{P} + m_1 M_0)(p'_1 \cdot \bar{P}' + m'_1 M'_0)}}$$

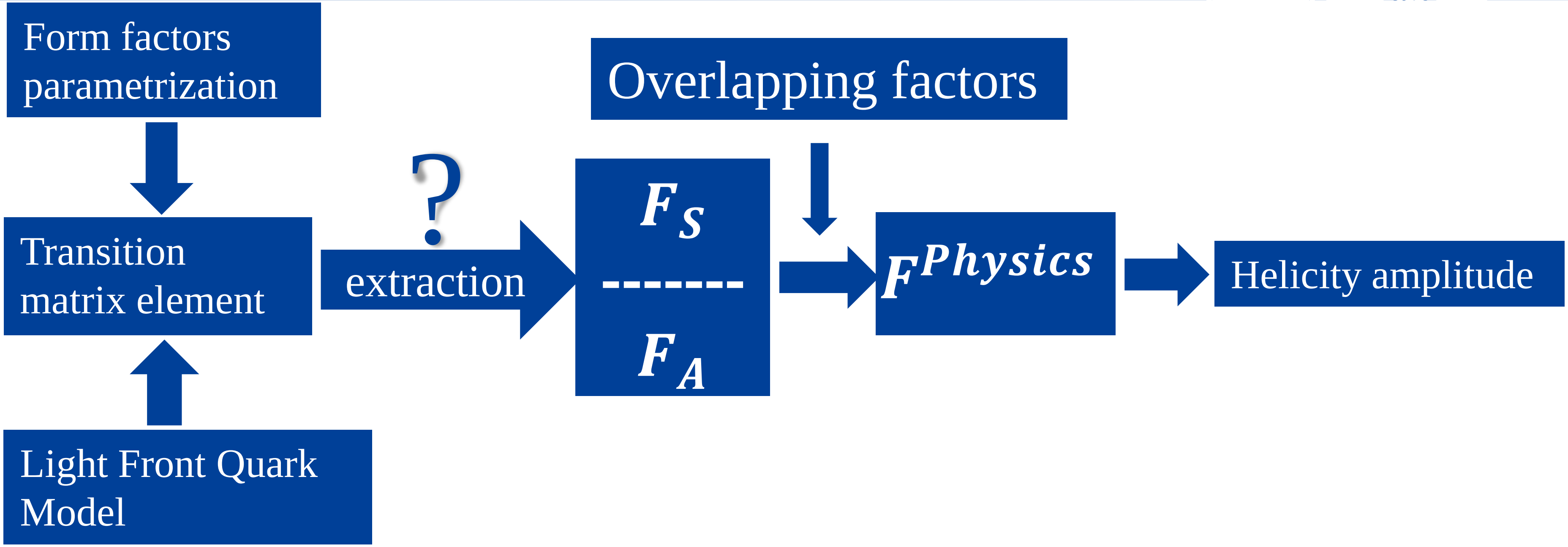
$$\bar{q} i\sigma_{\mu\nu}\frac{q^\nu}{M}(1+\gamma_5)Q$$

$$\times \sum_{\lambda_2} \bar{u}_\alpha(\bar{P}', S'_z)\left[\bar{\Gamma}'^\alpha_A(\not{p}'_1 + m'_1)\gamma^\mu(1-\gamma_5)(\not{p}_1 + m_1)\Gamma_A\right] u(\bar{P}, S_z)$$

Transition matrix element: form factors

$$\langle \mathcal{B}'_f(P', S' = \frac{1}{2}, S'_z) | \bar{s}\gamma_\mu b | \mathcal{B}_i(P, S = \frac{1}{2}, S_z) \rangle$$
$$= \bar{u}(P', S'_z) \left[\gamma_\mu f_{1,S(A)}(q^2) + i\sigma_{\mu\nu} \frac{q^\nu}{M} f_{2,S(A)}(q^2) + \frac{q_\mu}{M} f_{3,S(A)}(q^2) \right] u(P, S_z)$$

$$\langle \mathcal{B}'^*_f(P', S' = \frac{3}{2}, S'_z) | \bar{q}\gamma^\mu Q | \mathcal{B}_i(P, S = \frac{1}{2}, S_z) \rangle$$
$$= \bar{u}_\alpha(P', S'_z) \left[f_{1,A}(q^2) \frac{P^\alpha}{M} (\gamma^\mu - \frac{\not{q}}{q^2} q^\mu) + f_{2,A}(q^2) \frac{P^\alpha}{M^2} (\frac{M^2 - M'^2}{q^2} q^\mu - p^\mu) \right.$$
$$\left. + f_{3,A}(q^2) \frac{P^\alpha}{M^2} \frac{M^2 - M'^2}{q^2} q^\mu + f_{4,A}(q^2)(g^{\alpha\mu} - \frac{q^\alpha q^\mu}{q^2}) \right] \gamma_5 u(P, S_z)$$


Form factors parametrization
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?
extraction
F_S

F_A
Overlapping factors
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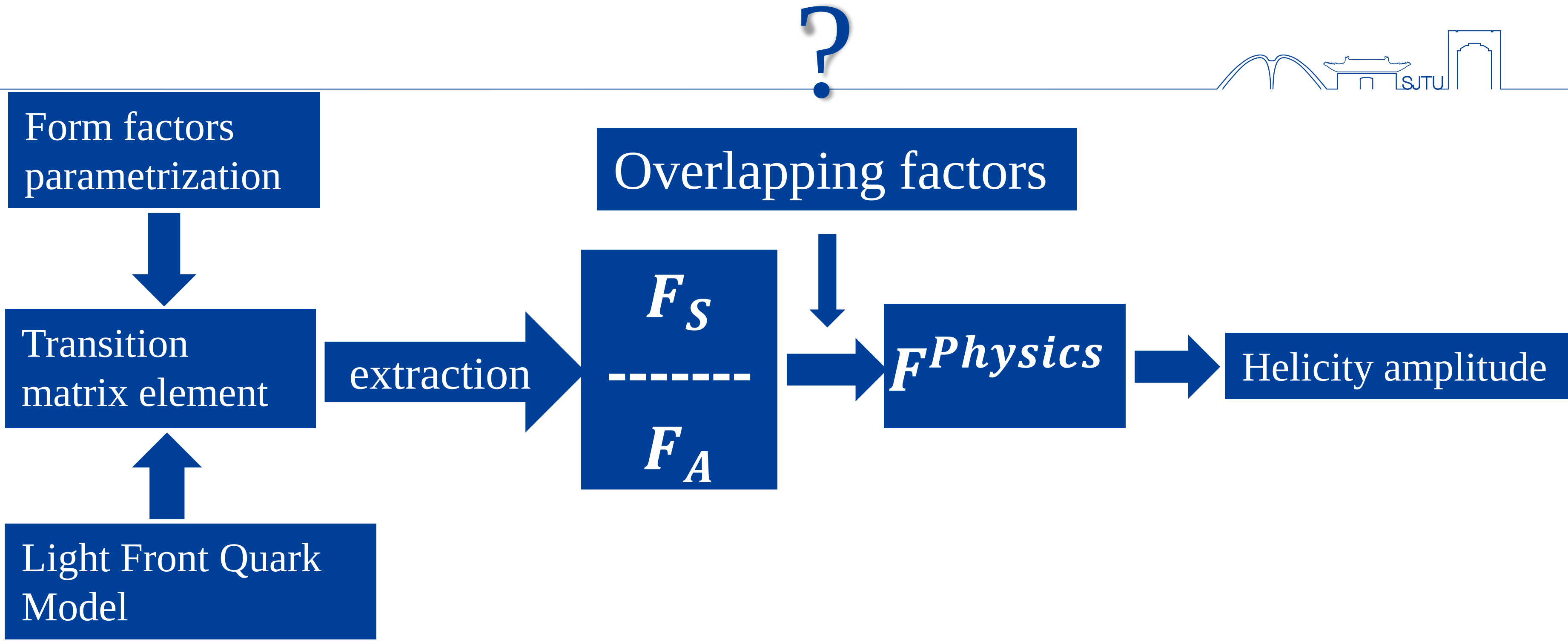
Helicity amplitude

Extraction of transition form factors

$$\langle \mathcal{B}'_f(P', S' = \frac{1}{2}, S'_z)|\bar{s}\gamma_\mu b|\mathcal{B}_i(P, S = \frac{1}{2}, S_z)\rangle$$
$$= \bar{u}(P', S'_z)\left[\gamma_\mu f_{1,S(A)}(q^2) + i\sigma_{\mu\nu}\frac{q^\nu}{M} f_{2,S(A)}(q^2) + \frac{q_\mu}{M} f_{3,S(A)}(q^2)\right] u(P, S_z)$$

$$\mathrm{Tr}\left\{(\Gamma^\mu)_i(\not{P}' + M')\left[\gamma_\mu f_{1,S(A)}(q^2) + i\sigma_{\mu\nu}\frac{q^\nu}{M} f_{2,S(A)}(q^2) + \frac{q_\mu}{M} f_{3,S(A)}(q^2)\right](\not{P} + M)\right\}$$
$$= \int \{d^3 p_2\} \frac{\phi'(x', k'_\perp)\phi(x, k_\perp)}{\sqrt{p_1^+ p_1'^+ (p_1 \cdot \bar{P} + m_1 M_0)(p'_1 \cdot \bar{P}' + m'_1 M'_0)}}$$
$$\times \sum_{\lambda_2} \mathrm{Tr}\left[(\Gamma^\mu)_i(\bar{\not{P}}' + M'_0)\bar{\Gamma}'_{S(A)}(\not{p}'_1 + m'_1)\gamma_\mu(\not{p}_1 + m_1)\Gamma_{S(A)}(\bar{\not{P}} + M_0)\right]$$

$$(\Gamma^\mu)_i = \{\gamma^\mu, P^\mu, P'^\mu\}$$


?
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Overlapping factors

Physical form factors = C_s F_S + C_A F_A

$$\langle B'|\Gamma_\mu|B\rangle = C_S\langle q_1[Q_2q]_S|\Gamma_\mu|Q_1[Q_2q]_S\rangle + C_A\langle q_1[Q_2q]_A|\Gamma_\mu|Q_1[Q_2q]_A\rangle$$

$|B\rangle$

$|Q_1Q_2q\rangle$ = B_s $|Q_1[Q_2q]\rangle$ + B_A $|Q_1\{Q_2q\}\rangle$

Decided by flavor-spin space wave function

$$\mathcal{B}_{bc} = -\frac{\sqrt{3}}{2}b(cq)_S + \frac{1}{2}b(cq)_A = -\frac{\sqrt{3}}{2}c(bq)_S + \frac{1}{2}c(bq)_A$$

For example:

$$\Xi_{cc}^{++} = \frac{1}{\sqrt{2}}[-\frac{\sqrt{3}}{2}c^1(c^2q)_S + \frac{1}{2}c^1(c^2q)_A + (c^1 \leftrightarrow c^2)]$$

$$\Lambda_c^+ = -\frac{1}{2}d(cu)_S + \frac{\sqrt{3}}{2}d(cu)_A$$

$C_S = \frac{1}{\sqrt{2}}\left(-\frac{\sqrt{3}}{2}\right) \times 2 \times \left(-\frac{1}{2}\right) = \frac{\sqrt{6}}{4}$	$C_A = \frac{1}{\sqrt{2}}\left(\frac{1}{2}\right) \times 2 \times \left(\frac{\sqrt{3}}{2}\right) = \frac{\sqrt{6}}{4}$

$$F_{Phys}^{\Xi_{cc}^{++}\to\Lambda_c^+} = \frac{\sqrt{6}}{4}F_s + \frac{\sqrt{6}}{4}F_A$$

$m_{B_{bc}}$~6.9**GeV**

The numerical result of form factors

F	$F(0)$	$m_{\rm fit}$	δ	F	$F(0)$	$m_{\rm fit}$	δ	F	$F(0)$	$m_{\rm fit}$	δ	F	$F(0)$	$m_{\rm fit}$	δ
$f_{1,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.203	4.07	0.66	$g_{1,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.167	4.99	1.32	$f_{1,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.196	3.56	0.74	$g_{1,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.056	4.81	1.19
$f_{2,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.079	3.37	0.65	$g_{2,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.097	2.84	0.70	$f_{2,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.203	3.68	0.69	$g_{2,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.027	2.78	0.83
$f_{3,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.015*	1.44*	0.74*	$g_{3,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.329	3.08	0.60	$f_{3,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.110	4.05	0.92	$g_{3,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.098	3.04	0.60
$f_{1,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.085	3.85	0.74	$g_{1,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.021*	0.92*	0.23*	$f_{1,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.180	3.69	0.69	$g_{1,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.001*	1.90*	0.27*
$f_{2,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.160	4.13	0.54	$g_{2,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	0.202	3.86	0.47	$f_{2,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.064	5.43	29.40	$g_{2,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{+,0}}$	−0.064	3.88	0.46
$f_{1,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.204	4.04	0.64	$g_{1,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.174	4.66	0.99	$f_{1,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.197	3.53	0.72	$g_{1,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.058	4.52	0.91
$f_{2,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.090	3.35	0.64	$g_{2,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.074	2.86	0.70	$f_{2,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.204	3.63	0.67	$g_{2,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.019	2.80	0.89
$f_{3,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.007	0.07	−0.00	$g_{3,S}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.300	3.15	0.61	$f_{3,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.118	3.86	0.80	$g_{3,A}^{\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.088	3.12	0.62
$f_{1,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.083	3.82	0.71	$g_{1,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.006	0.50	−0.03	$f_{1,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.177	3.65	0.67	$g_{1,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.006	6.30	5.21
$f_{2,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.169	4.01	0.51	$g_{2,S}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	0.200	3.95	0.52	$f_{2,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.065	5.16	23.60	$g_{2,A}^{T\Xi_{bc}^{(\prime)+,0}\to\Xi_c^{\prime+,0}}$	−0.063	3.98	0.52
$f_{1,S}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.192	3.91	0.66	$g_{1,S}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.165	4.40	0.90	$f_{1,A}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.187	3.45	0.74	$g_{1,A}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.055	4.29	0.85
$f_{2,S}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.091	3.25	0.67	$g_{2,S}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.064	2.86	0.77	$f_{2,A}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.191	3.55	0.70	$g_{2,A}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.017	2.81	0.96
$f_{3,S}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.004*	0.98*	0.07*	$g_{3,S}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.288	3.13	0.66	$f_{3,A}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.114	3.72	0.80	$g_{3,A}^{\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.085	3.11	0.67
$f_{1,S}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.081	3.68	0.72	$g_{1,S}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.001*	0.90*	0.07*	$f_{1,A}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.169	3.54	0.68	$g_{1,A}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.006	3.65	0.58
$f_{2,S}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.159	3.86	0.53	$g_{2,S}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	0.188	3.86	0.57	$f_{2,A}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.063	4.90	19.50	$g_{2,A}^{T\Omega_{bc}^{(\prime)0}\to\Omega_c^0}$	−0.060	3.90	0.57

The numerical result of decay widths

channels	$\Gamma/$ GeV	$\mathcal{B}$	Γ_L/Γ_T	channels	$\Gamma/$ GeV	$\mathcal{B}$	Γ_L/Γ_T
$\Xi_{cc}^{++} \to \Lambda_c^+ l^+ \nu_l$	7.97×10^{-15}	3.63×10^{-3}	2.42	$\Xi_{bb}^{0} \to \Sigma_b^+ l^- \bar{\nu}_l$	1.06×10^{-16}	5.96×10^{-5}	1.27
$\Xi_{cc}^{++} \to \Sigma_c^+ l^+ \nu_l$	1.09×10^{-14}	4.98×10^{-3}	0.86	$\Xi_{bb}^{0} \to \Xi_{bc}^+ l^- \bar{\nu}_l$	6.02×10^{-14}	3.38×10^{-2}	1.42
$\Xi_{cc}^{++} \to \Xi_c^+ l^+ \nu_l$	8.74×10^{-14}	3.99×10^{-2}	3.07	$\Xi_{bb}^{0} \to \Xi_{bc}^{\prime +} l^- \bar{\nu}_l$	3.21×10^{-14}	1.81×10^{-2}	0.84
$\Xi_{cc}^{++} \to \Xi_c^{\prime +} l^+ \nu_l$	1.43×10^{-13}	6.52×10^{-2}	0.94	$\Xi_{bb}^{-} \to \Lambda_b^0 l^- \bar{\nu}_l$	2.39×10^{-17}	1.35×10^{-5}	5.93
$\Xi_{cc}^{+} \to \Sigma_c^0 l^+ \nu_l$	2.17×10^{-14}	3.30×10^{-3}	0.86	$\Xi_{bb}^{-} \to \Sigma_b^0 l^- \bar{\nu}_l$	5.29×10^{-17}	2.98×10^{-5}	1.27
$\Xi_{cc}^{+} \to \Xi_c^0 l^+ \nu_l$	8.63×10^{-14}	1.31×10^{-2}	3.10	$\Xi_{bb}^{-} \to \Xi_{bc}^0 l^- \bar{\nu}_l$	6.02×10^{-14}	3.38×10^{-2}	1.42
$\Xi_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l$	1.41×10^{-13}	2.15×10^{-2}	0.95	$\Xi_{bb}^{-} \to \Xi_{bc}^{\prime 0} l^- \bar{\nu}_l$	3.21×10^{-14}	1.81×10^{-2}	0.84
$\Omega_{cc}^{+} \to \Xi_c^0 l^+ \nu_l$	5.87×10^{-15}	8.92×10^{-4}	2.94	$\Omega_{bb}^{-} \to \Xi_b^0 l^- \bar{\nu}_l$	2.18×10^{-17}	2.65×10^{-5}	5.98
$\Omega_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l$	1.03×10^{-14}	1.57×10^{-3}	0.87	$\Omega_{bb}^{-} \to \Xi_b^{\prime 0} l^- \bar{\nu}_l$	4.87×10^{-17}	5.92×10^{-5}	1.28
$\Omega_{cc}^{+} \to \Omega_c^0 l^+ \nu_l$	2.80×10^{-13}	4.26×10^{-2}	0.94	$\Omega_{bb}^{-} \to \Omega_{bc}^0 l^- \bar{\nu}_l$	5.24×10^{-14}	6.37×10^{-2}	1.64
				$\Omega_{bb}^{-} \to \Omega_{bc}^{\prime 0} l^- \bar{\nu}_l$	2.55×10^{-14}	3.11×10^{-2}	0.89

SU(3) Symmetry:

$$\Gamma(\Xi_{cc}^{++} \to \Lambda_c^+ l^+ \nu_l) = \Gamma(\Omega_{cc}^{+} \to \Xi_c^0 l^+ \nu_l)$$

$$\Gamma(\Xi_{cc}^{++} \to \Xi_c^+ l^+ \nu_l) = \Gamma(\Xi_{cc}^{+} \to \Xi_c^0 l^+ \nu_l)$$

$$\Gamma(\Omega_{cc}^{+} \to \Omega_c^0 l^+ \nu_l) = 2\Gamma(\Xi_{cc}^{++} \to \Xi_c^{\prime +} l^+ \nu_l) = 2\Gamma(\Xi_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l)$$

$$\Gamma(\Xi_{cc}^{+} \to \Sigma_c^0 l^+ \nu_l) = 2\Gamma(\Xi_{cc}^{++} \to \Sigma_c^+ l^+ \nu_l) = 2\Gamma(\Omega_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l)$$

Numerical analysis

$$\Gamma\left(\frac{1}{2} \to \frac{1}{2}\ with\ charged\ current\right) \sim (10^{-15} \sim 10^{-13})$$

$$\Gamma\left(\frac{1}{2} \to \frac{3}{2}\ with\ charged\ current\right) \sim (10^{-16} \sim 10^{-14})$$

$$\Gamma(\frac{1}{2} \to \frac{1}{2}\ with\ FCNC) \sim (10^{-21} \sim 10^{-19})$$

$$\Gamma(\frac{1}{2} \to \frac{3}{2}\ with\ FCNC) \sim (10^{-22} \sim 10^{-19})$$

Number of channels	Charged current	FCNC
$\frac{1}{2} \to \frac{1}{2}$	57	90
$\frac{1}{2} \to \frac{3}{2}$	36	54

May be firstly examined in experiment: LHCb, Belle-II

$\mathcal{B}(\Xi_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l) \sim 2.15 \times 10^{-2}$ $\mathcal{B}(\Xi_{cc}^{+} \to \Xi_c^{0} l^+ \nu_l) \sim 1.31 \times 10^{-2}$

$\mathcal{B}(\Xi_{bc}^{+} \to \Xi_b^{\prime 0} l^+ \nu_l) \sim 2.5 \times 10^{-2}$

Summary

- The transition form factors are calculated within light front quark model.
- This work modified the baryon wave function involved axial-vector diquark: Γ
- For the baryon wave function is decided by the spin and flavor space wave function, the physics form factors is $F^{physics} = C_S F_S + C_A F_A$.
- This work study four kinds of the doubly baryon weak decays and find that :

$$\Gamma\left(\frac{1}{2}\to\frac{1}{2}\ with\ charge\ current\right) > \Gamma\left(\frac{1}{2}\to\frac{3}{2}\ with\ charge\ current\right) > \Gamma\left(\frac{1}{2}\to\frac{1}{2}\ with\ FCNC\right)$$

$$> \Gamma\left(\frac{1}{2}\to\frac{3}{2}\ with\ FCNC\right)$$

- These channels may be firstly examined by experiment:

$$\mathcal{B}(\Xi_{cc}^{+}\to \Xi_c^{\prime 0} l^+ \nu_l)\sim 2.15\times 10^{-2} \qquad \mathcal{B}(\Xi_{cc}^{+}\to \Xi_c^{0} l^+ \nu_l)\sim 1.31\times 10^{-2}$$

$$\mathcal{B}(\Xi_{bc}^{+}\to \Xi_b^{\prime 0} l^+ \nu_l)\sim 2.5\times 10^{-2}$$

- We compared our results with SU(3) symmetry results.

Thank you!

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