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Weak Decays of Doubly Heavy Baryons to Singly Heavy Baryons with FCNC

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Introduction

ODTÜ METU

In this work, we are examining the following decays:

- $\Xi_{ccq} \to \Sigma^*_{cuq}$
- $\Xi_{bbq} \to \Sigma^*_{bdq}$
- $\Xi_{bbq} \to \Xi^*_{bsq}$
- $\Omega_{bbs} \to \Omega^*_{bss}$
- $\Omega_{bbs} \to \Xi^*_{bds}$
- $\Omega_{ccs} \to \Xi^*_{cus}$

Introduction

- Decays induced by flavor-changing neutral current take place at the loop level.
- All the QCD dynamics are encoded in the hadronic matrix elements induced by the weak current.
- These matrix elements are parameterized in terms of the form factors.
- Determining these form factors constitutes a central problem in studying such a class of decays.

- Matrix elements are defined as

$$\left\langle B_Q \ell^+ \ell^- \middle| \mathcal{H}_{eff} \middle| B_{QQ} \right\rangle$$

- where $\mathcal{H}_{eff}$ for $b \to s, d$ is

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} V_{tb} V_{tq}^* \sum_i C_i^b(\mu) \mathcal{O}_i^b(\mu)$$

and for $c \to u$ is

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \sum_{j=b,s,d} V_{cj} V_{uj}^* \sum_i C_i^c(\mu) \mathcal{O}_i^c(\mu)$$

- To calculate the matrix element, we need to calculate

$$\langle B_Q|\bar{q}\Gamma_\mu Q|B_{QQ}\rangle$$

where $\Gamma_\mu = \sigma_{\mu\nu}(1-\gamma_5)q^\nu$ or $\Gamma_\mu = \gamma_\mu(1-\gamma_5)$

$$\langle B_Q(p)|\bar{q}\gamma_\mu(\gamma_5)|B_{QQ}(p+q)\rangle =$$
$$\bar{u}^\alpha(p)\Big[(q_\alpha p_\mu - pq g_{\alpha\mu} F_1^{V(A)} + (q_\alpha\gamma_\mu - \not{q} g_{\alpha\mu})F_2^{V(A)}$$
$$+ (q_\alpha q\mu - q^2 g_{\alpha\mu} F_3^{V(A)} + q_\alpha q_\mu F_0^{V(A)}\Big](\gamma_5)u(p+q)$$

$$\langle B_Q(p)|i\bar{q}\sigma^{\mu\nu}Q|B_{QQ}(p+q)\rangle =$$
$$i\bar{u}_\alpha\Big((p+q)^\alpha(X_1(-i\sigma^{\mu\nu}) + X_2\gamma^{[\mu}(p+q)^{\nu]}$$
$$+ X_3\gamma^{[\mu}p^{\nu]} + X_4(p+q)^{[\mu}p^{\nu]})$$
$$+ X_5 g^{\alpha[\mu}\gamma^{\nu]} + X_6 g^{\alpha[\mu}(p+q)^{\nu]} + X_7 g^{\alpha[\mu}p^{\nu]}\Big)$$

(Hiller and Zwicky, 2021)

$$T_1^V = 2X_1 + \Delta_-(X_2 + X_3) + q^2 X_4 + X_5 + X_6$$

$$T_2^V = -\Delta_+ X_1 + \frac{1}{2}(m_2^2 - q^2 - 1)X_2 + \frac{1}{2}(m_2^2 + q^2 - 1)X_3 + X_5$$

$$T_3^V = -X_1 + \Delta_- X_2 - \frac{1}{2}(m_2^2 + q^2 - 1)X_4 - X_6$$

$$T_1^A = 2X_A + \Delta_-(X_2 + X_3) + X_6 + X_7$$

$$T_2^A = -\Delta_- X_1 + \frac{1}{2}(q^2 + 2m_2^2 - m^2 - 1)(X_2 + X_3) + X_5 + m_2(X_6 + X_7)$$

$$T_3^A = -X_1 + m_2(X_2 + X_3)$$

where $\Delta_\pm = m_1 \pm m_2$ and m_1 is the mass the mass of the B_{QQ} and m_2 is the mass of the B_Q

- Collecting all, the transition amplitude can be written as

$$\mathcal{M} = \bar{u}_\alpha(p)\Big\{(\gamma_5)(\mathcal{F}_i^{A(V)}\mathcal{P}_i^{\alpha\mu} + C_9\mathcal{P}_0^{\alpha\mu}F_0^{A(V)})\bar{\ell}\gamma_\mu\ell$$

$$+ (\gamma_5)(\mathcal{F}_4^{A(V)}\mathcal{P}_1^{\alpha\mu} + \mathcal{F}_5^{A(V)}\mathcal{P}_2^{\alpha\mu}$$

$$+ \mathcal{F}_6^{A(V)}\mathcal{P}_3^{\alpha\mu} + C_10\mathcal{P}_0^{\alpha\mu}F_0^{A(V)})\bar{\ell}\gamma_\mu\gamma_5\ell\Big\}$$

where $\mathcal{F}_i^{V(A)} = (-)C_9F_i^{V(A)} - \frac{2m_Q}{q^2}C_7T_i^{V(A)}$ with $i = 1, 2, 3$ and $\mathcal{F}_{4,5,6}^{V(A)} = (-)C_{10}F_{1,2,3}^{V(A)}$

- Using the sum rules method to calculate the form factors, we need the correlation function

$$\Pi_\mu = i\int d^4x e^{iqx}\,\langle B_Q(p)|\mathcal{T}\left\{\bar{q}(x)\Gamma_\mu Q(x) j^\dagger_{QQ}(0)\right\}|0\rangle$$

where $j_{QQ} = \varepsilon^{abc}(Q^{aT} C\gamma^\alpha Q^b)\gamma_\alpha\gamma_5$ (Aliev et al., 2022)

- Using Wick theorem to calculate the correlation function with the QCD parameters, we contract the $Q(x)$ and the $\bar{Q}(0)$ from the $j^{\dagger}_{QQ}(0)$ we are left with matrix elements

$$\langle B_Q|\bar{q}_\alpha(x)\bar{q}'_\beta(0)\bar{Q}_\gamma(0)|0\rangle$$

where α, β and γ are spinor indices. These matrix elements are calculated in (Ali et al., 2013)

- We can also calculate the correlation function in terms of hadronic transition matrix elements. To calculate, we need to correlate the expression of the correlation function in the region $(p+q)^2 > 0$ and $(p+q)^2 << 0$ using the spectral representation.

$$\Pi((p+q)^2) = \int_0^\infty ds \frac{\rho(s, q^2, p^2)}{s - (p+q)^2} + \text{ polynomial in } (p+q)^2$$

where $\rho(s, q^2, p^2)$ is the spectral density.

$$\rho^{phen}(s, q^2, p^2) = \langle B_Q | \bar{q} \Gamma_\mu Q | B_{QQ} \rangle \; \langle B_Q Q | j^\dagger_{QQ} | 0 \rangle \; \delta(s - m^2_{QQ}) + \rho^{higher}(s)$$

where $\rho^{higher}(s)$ represents the higher state and continuum contributions.

- To eliminate the polynomials and higher state and continuum contributions, Borel transformation and continuum subtraction can be applied. Finally, we get

$$\int_0^{s_0} dse^{-s/M^2}\rho^{QCD}(s,q^2,p^2) = \int_0^{s_0} e^{-s/M^2}\rho^{phen}(s,q^2,p^2)$$

- To calculate the ρ^{phen} we need $\langle B_{QQ}|j^{\dagger}_{QQ}|0\rangle$ and it can be calculated with the following correlation function

$$\Pi = i\int d^4x e^{ipx}\langle 0|\mathcal{T}\left\{j_{QQ}(x)j^{\dagger}_{QQ}(0)\right\}|0\rangle$$

- After calculating both sides, we get different structures consisting of p and q and gamma matrices (i.e., $\gamma_\mu \not{q} q_\kappa$).
- Equating the coefficients of the structures on both sides, we can finally find the numerical values of the form factors.

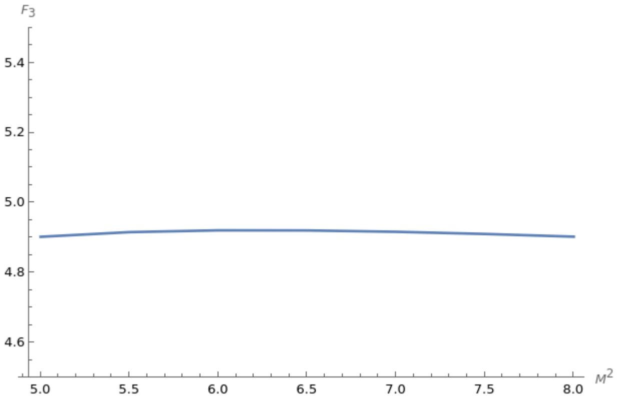

Figure: M^2 dependence

Graphs

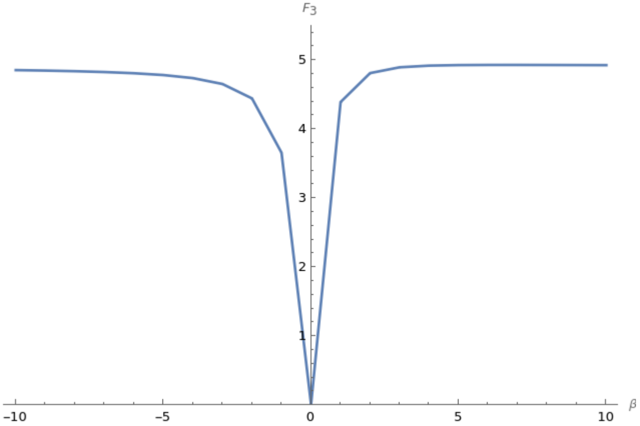

Figure: β dependecy

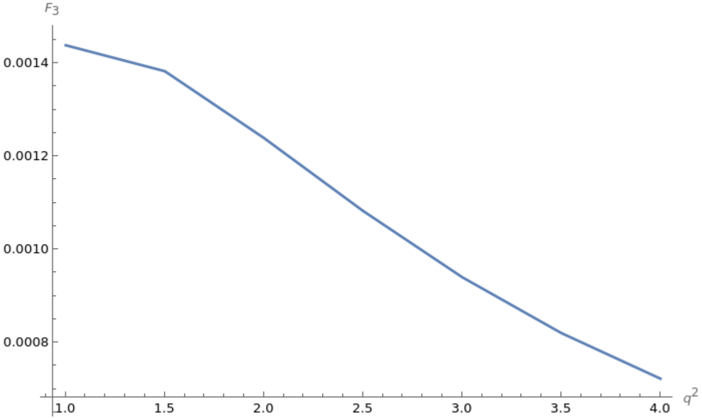

Figure: q^2 dependency

- We need the q^2 dependency of the form factors up to $(m_{QQ} - m_Q)^2$.
- Using the numerical values of the form factors for different q^2 values, we will find a fit

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

where m_{fit} and δ are fit parameters.

- Using these results, we will calculate the matrix elements.

Ali, A., Hambrock, C., Parkhomenko, A. Y., & Wang, W. (2013).Light-Cone Distribution Amplitudes of the Ground State Bottom Baryons in HQET. *Eur. Phys. J. C*, *73*(2), 2302. https://doi.org/10.1140/epjc/s10052-013-2302-4

Aliev, T. M., Savci, M., & Bilmis, S. (2022).Analysis of FCNC ΞQQ→ΛQl+l- decay in light-cone sum rules. *Phys. Rev. D*, *106*(3), 034017. https://doi.org/10.1103/PhysRevD.106.034017

Hiller, G., & Zwicky, R. (2021).Endpoint relations for baryons. *JHEP*, *11*, 073. https://doi.org/10.1007/JHEP11(2021)073

Thank You

for your attention.

Do you have any question?