$\Lambda_b \to \Lambda_c^*$ AT $O(1/m_c^2)$ IN HEAVY QUARK EXPANSION

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PRAGUE

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HEAVY QUARK EFFECTIVE THEORY

- **The presence of heavy quarks simplify the study of hadronic systems**

- $m_Q \gg \Lambda_{QCD}$
- Λ_{QCD} separates the perturbative and non-pertubative regimes.
- In the Standard Model: u, d, s are light; c, b, t are heavy.
- The heavy quark, surrounded by the strongly interacting «brown muck» is almost on-shell

$$P_Q^\mu = m_Q v^\mu + k^\mu \;, \quad k \sim \Lambda_{QCD}$$

- "Large" and " Small" component of the field $Q(x)$:

$$Q_+^v(x) = e^{i m_Q v \cdot x}\,\Pi_+ Q(x)\,, \quad Q_-^v(x) = e^{i m_Q v \cdot x}\,\Pi_- Q(x)\;,$$

- $\Pi_\pm = \frac{1 \pm \not{v}}{2}$ are the projector operators and $\not{v} Q_+^v = Q_+^v \;, \quad \not{v} Q_-^v = -Q_-^v \;.$

M. Neubert, Phys. Rept., 245, 259 (1994)

HQET LAGRANGIAN

- The QCD Lagrangian becomes: $\mathcal{L}_{\rm QCD} = \overline{Q}^v_+ iv\cdot D Q^v_+ + \overline{Q}^v_+ i\not{D}_\perp Q^v_- + \overline{Q}^v_- i\not{D}_\perp Q^v_+ - \overline{Q}^v_-(iv\cdot D + 2m_Q)Q^v_-$
- $D^\mu_\perp = D^\mu - (v\cdot D)v^\mu$ is transverse covariant derivative of QCD.
- $Q^v_-(x)$ can be integrated-out as it appears as a heavy degree of freedom with twice the heavy quark mass:

$$\mathcal{L}_{\rm HQET} = \overline{Q}^v_+ iv\cdot D Q^v_+ + \overline{Q}^v_+ i\not{D}_\perp \frac{1}{iv\cdot D + 2m_Q} i\not{D}_\perp Q^v_+ \,.$$

- The Lagrangian is now suitable for an expansion in $1/m_Q$:

$$\mathcal{L}_{\rm HQET} = \sum_{n=0} \mathcal{L}_n/(2m_Q)^n$$

- To second order: $\mathcal{L}_0 = \overline{Q}^v_+ iv\cdot D Q^v_+ \equiv \mathcal{L}^\infty_{\rm eff}\,,$

$$\mathcal{L}_1 = -\overline{Q}^v_+ \not{D}_\perp \not{D}_\perp Q^v_+ = -\overline{Q}^v_+ \left[D^2 + a_Q(\mu)\frac{g}{2}\sigma_{\alpha\beta}G^{\alpha\beta}\right] Q^v_+ \equiv O_{\rm kin} + O_{\rm mag}\,,$$

$$\mathcal{L}_2 = \overline{Q}^v_+ [\not{D}_\perp iv\cdot D \not{D}_\perp] Q^v_+ = g\overline{Q}^v_+ \left[v_\beta D_\alpha G^{\alpha\beta} - iv_\alpha \sigma_{\beta\gamma} D^\gamma G^{\alpha\beta}\right] Q^v_+ \,,$$

- $ig\,G^{\alpha\beta} = [D^\alpha, D^\beta]$ is the field-strength.

MATCHING ONTO QCD

- In terms of the large field components, the generic source term becomes:

$$\bar{J}Q \equiv \bar{J}^v \mathcal{J}_{\rm HQET} Q_+^v = \bar{J}^v \left[1 + \frac{1}{iv\cdot D + 2m_Q} i\not{D}_\perp\right] Q_+^v \ , \qquad J^v = e^{im_Q v\cdot x} J \ .$$

- The expansion in $1/m_Q$ gives

$$\mathcal{J}_{\rm HQET} = 1 + \Pi_- \sum_{n=1} \mathcal{J}_n/(2m_Q)^n \ , \qquad \mathcal{J}_1 = i\not{D}, \ \text{and} \ \mathcal{J}_2 = -\not{D}\not{D}$$

- We are interested in $H_b \to H_c$ transitions. The matching onto QCD is:

$$\frac{\langle H_c|\bar{c}\,\Gamma\, b|H_b\rangle}{\sqrt{m_{H_c} m_{H_b}}} = \langle H_c^{v'}| \frac{1}{\mathcal{Z}} \int \mathcal{D}\bar{c}_+^{v'} \mathcal{D}c_+^{v'} \mathcal{D}\bar{b}_+^v \mathcal{D}b_+^v$$

$$\exp\left\{ i \int d^4x [\mathcal{L}'_{\rm HQET} + \mathcal{L}_{\rm HQET}] \right\} \bar{c}_+^{v'} \bar{\mathcal{J}}'_{\rm HQET}\, \Gamma\, \mathcal{J}_{\rm HQET} b_+^v |H_b^v\rangle \ , \qquad \bar{\mathcal{J}}_n \equiv \gamma^0 \overleftarrow{\mathcal{J}}_n^\dagger \gamma^0$$

Bernlochner et al. Phys.Rev.D 106 (2022) 9, 096015

BARYON DECAYS

$$\Lambda_b \rightarrow \Lambda_c^*(2595, 2625)$$

- Indipendent determination of V_{cb}
- Lepton Flavor Universality ratios R_{Λ^*}
- Comparison with Lattice QCD results

SECOND-ORDER MATCHING

$$\frac{\langle H_c|\bar{c}\,\Gamma\,b|H_b\rangle}{\sqrt{m_{H_c}m_{H_b}}} \simeq \langle H_c^{v'}|\bar{c}_+^{v'}\,\Gamma\,b_+^v|H_b^v\rangle$$

$$+\frac{1}{2m_c}\langle H_c^{v'}|(\bar{c}_+^{v'}\overline{\mathcal{J}}_1' + \mathcal{L}_1'\circ c_+^{v'})\Gamma\,b_+^v|H_b^v\rangle$$

$$+\frac{1}{2m_b}\langle H_c^{v'}|\bar{c}_+^{v'}\,\Gamma(\mathcal{J}_1 b_+^v + b_+^v\circ\mathcal{L}_1)|H_b^v\rangle$$

$$+\frac{1}{4m_c^2}\langle H_c^{v'}|(\bar{c}_+^{v'}\overline{\mathcal{J}}_2'\Pi_-' + \mathcal{L}_2'\circ\bar{c}_+^{v'} + \mathcal{L}_1'\circ\bar{c}_+^{v'}\overline{\mathcal{J}}_1'\Pi_-' + \frac{1}{2}\mathcal{L}_1'\circ\mathcal{L}_1'\circ\bar{c}_+^{v'})\Gamma\,b_+|H_b^v\rangle$$

$$+\frac{1}{4m_b^2}\langle H_c^{v'}|\bar{c}_+^{v'}\,\Gamma(\Pi_-\mathcal{J}_2 b_+^v + b_+^v\circ\mathcal{L}_2 + \Pi_-\mathcal{J}_1 b_+^v\circ\mathcal{L}_1 + \frac{1}{2}b_+^v\circ\mathcal{L}_1\circ\mathcal{L}_1)|H_b^v\rangle$$

$$+\frac{1}{4m_c m_b}\langle H_c^{v'}|(\bar{c}_+^{v'}\overline{\mathcal{J}}_1' + \mathcal{L}_1'\circ\bar{c}_+^{v'})\Gamma(\mathcal{J}_1 b_+^v + b_+^v\circ\mathcal{L}_1)|H_b^v\rangle$$

RESIDUAL CHIRAL EXPANSION

VANISHING CHROMOMAGNETIC

The symbol "$\circ$" denotes an operator product:

$$\mathcal{L}_1'\circ\bar{c}_+^{v'}(z) = i\int d^4x\,\mathcal{L}_1'(x)\bar{c}_+^{v'}(z)$$

PLUS SHORT DISTANCE CORRECTIONS $\mathcal{O}(\alpha_s)$

RESIDUAL CHIRAL EXPANSION

$$\mathcal{L}_{\rm QCD} = \bar{Q}^v_+ iv\cdot D Q^v_+ + \bar{Q}^v_+ i\not{D}_\perp Q^v_- + \bar{Q}^v_- i\not{D}_\perp Q^v_+ - \bar{Q}^v_- (iv\cdot D + 2m_Q) Q^v_- \,.$$

- The mixed term breaks the $U(1)_+ \times U(1)_-$ chiral symmetry of the kinetic Lagrangian.
- New power counting: $i\not{D}_\perp \to i\theta\not{D}_\perp$.
- At $\mathcal{O}(1/m_c^2, \theta^2)$:

$$\frac{\langle H_c|\bar{c}\,\Gamma\, b|H_b\rangle}{\sqrt{m_{H_c} m_{H_b}}} \simeq \big\langle H_c^{v'} \big|\bar{c}_+^{v'}\,\Gamma\, b_+^v\big|H_b^v\big\rangle$$
$$+ \frac{1}{2m_c}\big\langle H_c^{v'}\big|\big(\bar{c}_+^{v'}\bar{\mathcal{J}}_1' + \mathcal{L}_1'\circ c_+^{v'}\big)\Gamma\, b_+^v\big|H_b^v\big\rangle + \frac{1}{2m_b}\big\langle H_c^{v'}\big|\bar{c}_+\,\Gamma\big(\mathcal{J}_1 b_+^v + b_+^v\circ\mathcal{L}_1\big)\big|H_b^v\big\rangle$$
$$+ \frac{1}{4m_c^2}\big\langle H_c^{v'}\big|\big(\bar{c}_+^{v'}\bar{\mathcal{J}}_2'\Pi_-' + \mathcal{L}_2'\circ\bar{c}_+^{v'}\big)\Gamma\, b_+^v\big|H_b^v\big\rangle\,.$$

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VANISHING CHROMOMAGNETIC LIMIT

- In the VC limit $G_{\alpha\beta} \to 0$ $\longrightarrow$ $\mathcal{L}_1 = -\bar{Q}_+^v D^2 Q_+^v ; \quad \mathcal{L}_2 = 0 \, .$
- At $\mathcal{O}(1/m_c^2)$:

$$
\begin{aligned}
\frac{\langle H_c | \bar{c}\, \Gamma\, b | H_b \rangle}{\sqrt{m_{H_c} m_{H_b}}} \simeq & \langle H_c^{v'} | \bar{c}_+^{v'}\, \Gamma\, b_+^v | H_b^v \rangle + \\
& + \frac{1}{2m_c} \langle H_c^{v'} | \left(\bar{c}_+^{v'} \overline{\mathcal{J}}_1' - \bar{c}_+^{v'} D^2 c_+^{v'} \circ \bar{c}_+^{v'} \right) \Gamma\, b_+^v | H_b^v \rangle + \frac{1}{2m_b} \langle H_c^{v'} | \bar{c}_+^{v'}\, \Gamma \left(\mathcal{J}_1 b_+^v - b_+^v \circ \bar{b}_+^v D^2 b_+^v \right) | H_b^v \rangle + \\
& + \frac{1}{4m_c^2} \langle H_c^{v'} | \left(-\bar{c}_+^{v'} D^2 c_+^{v'} \circ \bar{c}_+^{v'} \overline{\mathcal{J}}_1' \Pi_-' + \frac{1}{2} \bar{c}_+^{v'} D^2 c_+^{v'} \circ \bar{c}_+^{v'} D^2 c_+^{v'} \circ \bar{c}_+^{v'} \right) \Gamma\, b_+^v | H_b^v \rangle \, .
\end{aligned}
$$

HADRONIC MATRIX ELEMENTS IN QCD

$\Lambda_b^0 \to \Lambda_c^*[2595]$ ($J^P = 1/2^-$) matrix element in QCD

$$\langle \Lambda_c(2595)^+(k,\eta(\lambda_c),s_c)|\,\bar c\gamma^\mu b\,|\Lambda_b^0(p,s_b)\rangle = +\bar u_\alpha^{(1/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i f_i(q^2)\Gamma_{V,i}^{\alpha\mu}\right]u(p,s_b)\,,$$

$$\langle \Lambda_c(2595)^+(k,\eta(\lambda_c),s_c)|\,\bar c\gamma^\mu\gamma_5 b\,|\Lambda_b^0(p,s_b)\rangle = -\bar u_\alpha^{(1/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i g_i(q^2)\gamma_5\Gamma_{A,i}^{\alpha\mu}\right]u(p,s_b)\,,$$

$$\langle \Lambda_c(2595)^+(k,\eta(\lambda_c),s_c)|\,\bar c\, i\sigma^{\mu\nu}q_\nu b\,|\Lambda_b^0(p,s_b)\rangle = -\bar u_\alpha^{(1/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i t_i(q^2)\Gamma_{T,i}^{\alpha\mu}\right]u(p,s_b)\,,$$

$$\langle \Lambda_c(2595)^+(k,\eta(\lambda_c),s_c)|\,\bar c\, i\sigma^{\mu\nu}q_\nu\gamma_5 b\,|\Lambda_b^0(p,s_b)\rangle = -\bar u_\alpha^{(1/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i t_i^5(q^2)\gamma_5\Gamma_{T5,i}^{\alpha\mu}\right]u(p,s_b)\,.$$

$\Lambda_b^0 \to \Lambda_c^*[2625]$($J^P = 3/2^-$) matrix element in QCD

$$\langle \Lambda_c(2625)^+(k,\eta(\lambda_c),s_c)|\,\bar c\gamma^\mu b\,|\Lambda_b^0(p,s_b)\rangle = +\bar u_\alpha^{(3/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i F_i(q^2)\Gamma_{V,i}^{\alpha\mu}\right]u(p,s_b)\,,$$

$$\langle \Lambda_c(2625)^+(k,\eta(\lambda_c),s_c)|\,\bar c\gamma^\mu\gamma_5 b\,|\Lambda_b^0(p,s_b)\rangle = -\bar u_\alpha^{(3/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i G_i(q^2)\gamma_5\Gamma_{A,i}^{\alpha\mu}\right]u(p,s_b)\,,$$

$$\langle \Lambda_c(2595)^+(k,\eta(\lambda_c),s_c)|\,\bar c\, i\sigma^{\mu\nu}q_\nu b\,|\Lambda_b^0(p,s_b)\rangle = -\bar u_\alpha^{(3/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i T_i(q^2)\Gamma_{T,i}^{\alpha\mu}\right]u(p,s_b)\,,$$

$$\langle \Lambda_c(2595)^+(k,\eta(\lambda_c),s_c)|\,\bar c\, i\sigma^{\mu\nu}q_\nu\gamma_5 b\,|\Lambda_b^0(p,s_b)\rangle = -\bar u_\alpha^{(3/2)}(k,\eta(\lambda_c),s_c)\left[\sum_i T_i^5(q^2)\gamma_5\Gamma_{T5,i}^{\alpha\mu}\right]u(p,s_b)\,.$$

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HQET MATRIX ELEMENTS

MATRIX ELEMENT PARAMETERISATION FOR A GENERIC CURRENT

$$\Gamma^\mu \mapsto J^\mu_\Gamma = \underbrace{\sum_\Gamma C_\Gamma(w) J_\Gamma}_{\mathcal{O}(\alpha_s)} + \underbrace{\Delta J^\mu_\Gamma + \Delta \bar{J}^\mu_\Gamma}_{\mathcal{O}(1/m_{b,c})} + \underbrace{\delta \bar{J}^\mu_\Gamma}_{\mathcal{O}(1/m_c^2)} + \mathcal{O}(1/m_b^2, 1/m_b m_c, \alpha_s/m) \,, \quad \Gamma = V, A, T, T5 \,.$$

- We work out the vector current example

$$\gamma^\mu \mapsto J^\mu_V = \underbrace{C_1(w)\gamma^\mu + C_2(w)v^\mu + C_3(w)v'^\mu}_{\mathcal{O}(\alpha_s)} + \underbrace{\Delta J^\mu_V + \Delta \bar{J}^\mu_V}_{\mathcal{O}(1/m_{b,c})} + \underbrace{\delta \bar{J}^\mu_V}_{\mathcal{O}(1/m_c^2)} + \mathcal{O}(1/m_b^2, 1/m_b m_c, \alpha_s/m)$$

- **At $\mathcal{O}(1/m)$ order the local terms are:**

$$\langle \Lambda_c^*(k,\eta,s_c)|\, \bar{c}_+^{v'}\, \gamma^\mu\, b_+^v \,|\bar{\Lambda}(p,s_b)\rangle = \sqrt{4}\bar{u}_\alpha(m_{\Lambda_c^*}v',\eta,s_c)\gamma^\mu u(m_{\Lambda_b}v,s_b)\zeta^\alpha(w)\,,$$

$$\langle \Lambda_c^*(k,\eta,s_c)|\, \bar{c}_+^{v'} \gamma^\mu \mathcal{J}_1 b_+^v \,|\bar{\Lambda}(p,s_b)\rangle = \sqrt{4}\bar{u}_\alpha(m_{\Lambda_c^*}v',\eta,s_c)\gamma^\mu\gamma^\beta u(m_{\Lambda_b}v,s_b)\zeta_b^{\alpha\beta}(w)\,,$$

$$\langle \Lambda_c^*(k,\eta,s_c)|\, \bar{c}_+^{v'} \bar{\mathcal{J}}_1 \gamma^\mu b_+^v \,|\bar{\Lambda}(p,s_b)\rangle = \sqrt{4}\bar{u}_\alpha(m_{\Lambda_c^*}v',\eta,s_c)\gamma^\beta\gamma^\mu u(m_{\Lambda_b}v,s_b)\zeta_c^{\alpha\beta}(w)\,.$$

$$w = v\cdot v' = \frac{m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2}{2 m_{\Lambda_b} m_{\Lambda_c^*}}\,, \quad q = p - k\,.$$

$$\zeta^\alpha(w) = \zeta(w)(v-v')^\alpha\,,$$

$$\zeta_{(q)}^{\alpha\beta}(w) = (v-v')^\alpha \left[\zeta_1^{(q)}(w) v^\beta + \zeta_2^{(q)}(w) v'^\beta\right] + g^{\alpha\beta}\zeta_3^{(q)}(w)\,.$$

- $\zeta(w)$, $\zeta_i^{(q)}$ are the leading and sub-leading Isgur-Wise functions.
- Only one independent sub-leading IW function: $\zeta_3^{(b)} \equiv \zeta_{SL}$.

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- **At $\mathcal{O}(1/m)$ the non-local terms $\mathcal{L}_1^{(\prime)} = \mathcal{L}_{kin}^{(\prime)} + \mathcal{L}_{mag}^{(\prime)}$:**

$$\langle\Lambda_c^*(k,\eta,s_c)|\,\mathcal{L}_{\rm kin}\circ\bar{c}_+^{v'}\gamma^\mu b_+^v\,|\Lambda_b(p,s_b)\rangle = \sqrt{4}\eta^{(b)}_{\rm kin}(w)\,v^\alpha\bar{u}_\alpha(m_{\Lambda_c^*}v',\eta,s_c)\gamma^\mu u(m_{\Lambda_b}v,s_b)\,,$$

$$\langle\Lambda_c^*(k,\eta,s_c)|\,\mathcal{L}'_{\rm kin}\circ\bar{c}_+^{v'}\gamma^\mu b_+^v\,|\Lambda_b(p,s_b)\rangle = \sqrt{4}\eta^{(c)}_{\rm kin}(w)\,v^\alpha\bar{u}_\alpha(m_{\Lambda_c^*}v',\eta,s_c)\gamma^\mu u(m_{\Lambda_b}v,s_b)\,,$$

$$\langle\Lambda_c^*(k,\eta,s_c)|\,\mathcal{L}_{\rm mag}\circ\bar{c}_+^{v'}\gamma^\mu b_+^v\,|\Lambda_b(p,s_b)\rangle = \eta^{(b)}_{\rm mag}(w)\,g_{\mu\alpha}v'_\nu\bar{u}^\alpha(m_{\Lambda_c^*}v',\eta,s_c)\;\gamma^\mu\Pi_+\;i\sigma^{\mu\nu}u(m_{\Lambda_b}v,s_b)\,,$$

$$\langle\Lambda_c^*(k,\eta,s_c)|\,\mathcal{L}'_{\rm mag}\circ\bar{c}_+^{v'}\gamma^\mu b_+^v\,|\Lambda_b(p,s_b)\rangle = \eta^{(c)}_{\rm mag}(w)\,g_{\mu\alpha}v_\nu\bar{u}^\alpha(m_{\Lambda_c^*}v',\eta,s_c)\;i\sigma^{\mu\nu}\Pi'_+\gamma^\mu u(m_{\Lambda_b}v,s_b)\;.$$

RESIDUAL CHIRAL

- **At $\mathcal{O}(1/\,m_c^2\,,\theta^2)$ in the RC expansion:**

$$\langle\Lambda_c^*(k,\eta,s_c)|\,\bar{c}_+^{v'}\mathcal{J}'_2\Pi'_-\Gamma\,b_+^v\,|\Lambda_b(p,s_b)\rangle = \sqrt{4}\bar{u}_\mu\gamma_\alpha v'_\beta\Gamma u\,\psi^{\alpha\beta\mu}(v,v')\;,$$

$$\psi^{\alpha\beta\mu}(v,v') = \psi_1(w)v^\mu(v^\alpha v'^\beta - v^\beta v'^\alpha) + \psi_2(w)(g^{\alpha\mu}v^\beta - g^{\beta\mu}v^\alpha) + \psi_3(w)(g^{\alpha\mu}v'^\beta - g^{\beta\mu}v'^\alpha)\;.$$

Non-local terms are reabsorbed:

$$\eta^{(c)}_{\rm kin}(w) + \frac{1}{2m_c}\lambda(w) \to \eta^{(c)}_{\rm kin}(w)\;,$$

$$\eta^{(c)}_{\rm mag}(w) + \frac{1}{2m_c}\eta(w) \to \eta^{(c)}_{\rm mag}(w).$$

VANISHING CHROMOMAGNETIC

- **At $\mathcal{O}(1/\,m_c^2)$ in the VC limit:**

$$\langle\Lambda_c^*(k,\eta,s_c)|-\bar{c}_+^{v'}\,D^2\,c_+^{v'}\circ\bar{c}_+^{v'}\,\mathcal{J}'_1\,\Pi'_-\,\Gamma\,b_+^v\,|\Lambda_b(p,s_b)\rangle = \sqrt{4}\bar{u}_\mu\gamma_\alpha\,\Pi'_-\Gamma\,u\,\beta^{\mu\alpha}(v,v')\;,$$

$$\langle\Lambda_c^*(k,\eta,s_c)|\,\bar{c}_+^{v'}\,D^2\,c_+^{v'}\circ\bar{c}_+^{v'}\,D^2\,c_+^{v'}\circ\bar{c}_+^{v'}\,\Gamma\,b_+^v\,|\Lambda_b(p,s_b)\rangle = \sqrt{4}\bar{u}_\mu\,\Gamma\,u\,\alpha^\mu(v,v')\;,$$

$$\beta^{\mu\alpha}(v,v') = v^\mu(\beta_1(w)v^\alpha + \beta_2(w)v'^\alpha) + \beta_3(w)\,g^{\mu\alpha}\;,$$

$$\alpha^\mu(v,v') = \alpha(w)(v-v')^\mu\;.$$

FIT TO THE LATTICE RESULTS

The Form Factors depend on 7 and 5 Isgur-Wise functions in the RC expansion and VC limit respectively.

- Isgur-Wise functions are not known from first principles.
- We use the lattice results given in the form:

$$f_i = F_i + A_i(w-1).$$

- We expand the IW functions to the first order in $(w-1)$:

$$\zeta = \zeta^{(0)} + \zeta^{(1)}(w-1).$$

- We fit our Form Factors to the lattice results.
- We use a χ^2 minimisation and find remarkably good fits.
- Neglecting NNLO terms, we achieve a poor fit.

- **NNLO corrections are necessary to reconcile HQET with LQCD results.**

RC EXPANSION

Parameter	Best fit
$\zeta^{(0)}$	0.52 ± 0.16
$\zeta^{(1)}$	-6.11 ± 1.27
$\zeta_{SL}^{(0)}$	0.15 ± 0.01
$\zeta_{SL}^{(1)}$	-0.38 ± 0.11
$\eta_{kin,c}^{(0)}$	-0.26 ± 0.44
$\eta_{kin,c}^{(1)}$	9.77 ± 3.08
$\eta_{mag,c}^{(0)}$	0.01 ± 0.10
$\eta_{mag,c}^{(1)}$	-0.15 ± 1.44
$\eta_{mag,b}^{(0)}$	-0.08 ± 0.06
$\eta_{mag,b}^{(1)}$	0.25 ± 0.70
$\psi_1^{(0)}$	1.58 ± 0.72
$\psi'^{(0)}$	0.82 ± 0.05
$\psi'^{(1)}$	-1.13 ± 0.52

$$\frac{\chi^2_{RC}}{d.o.f} = 0.89$$

VC LIMIT

Parameter	Best fit
$\zeta^{(0)}$	0.52 ± 0.16
$\zeta^{(1)}$	-5.97 ± 1.24
$\zeta_{SL}^{(0)}$	0.15 ± 0.01
$\zeta_{SL}^{(1)}$	-0.31 ± 0.10
$\eta_{kin,c}^{(0)}$	-0.24 ± 0.42
$\eta_{kin,c}^{(1)}$	9.48 ± 3.06
$\beta_1^{(0)}$	1.58 ± 0.71
$\beta_3^{(0)}$	0.81 ± 0.05
$\beta_3^{(1)}$	-0.96 ± 0.50

$$\frac{\chi^2_{VC}}{d.o.f.} = 0.84$$

Meinel, Rendon PRD
105 (2022) 5, 054511

USING VECTOR AND AXIAL FORM FACTORS AS INPUT

↓

WE PREDICT TENSOR AND PSEUDO-TENSOR FORM FACTORS

RC EXPANSION

Parameter	Best fit
$\zeta^{(0)}$	0.43 ± 0.50
$\zeta^{(1)}$	-6.59 ± 1.62
$\zeta_{SL}^{(0)}$	0.16 ± 0.01
$\zeta_{SL}^{(1)}$	-0.58 ± 0.17
$\eta_{kin,c}^{(0)}$	0.01 ± 1.30
$\eta_{kin,c}^{(1)}$	10.72 ± 4.01
$\eta_{mag,c}^{(0)}$	-0.04 ± 0.12
$\eta_{mag,c}^{(1)}$	-0.07 ± 1.61
$\eta_{mag,b}^{(0)}$	-0.01 ± 0.07
$\eta_{mag,b}^{(1)}$	-0.75 ± 0.93
$\psi_1^{(0)}$	1.48 ± 1.01
$\psi'^{(0)}$	0.83 ± 0.10
$\psi'^{(1)}$	-1.76 ± 0.68

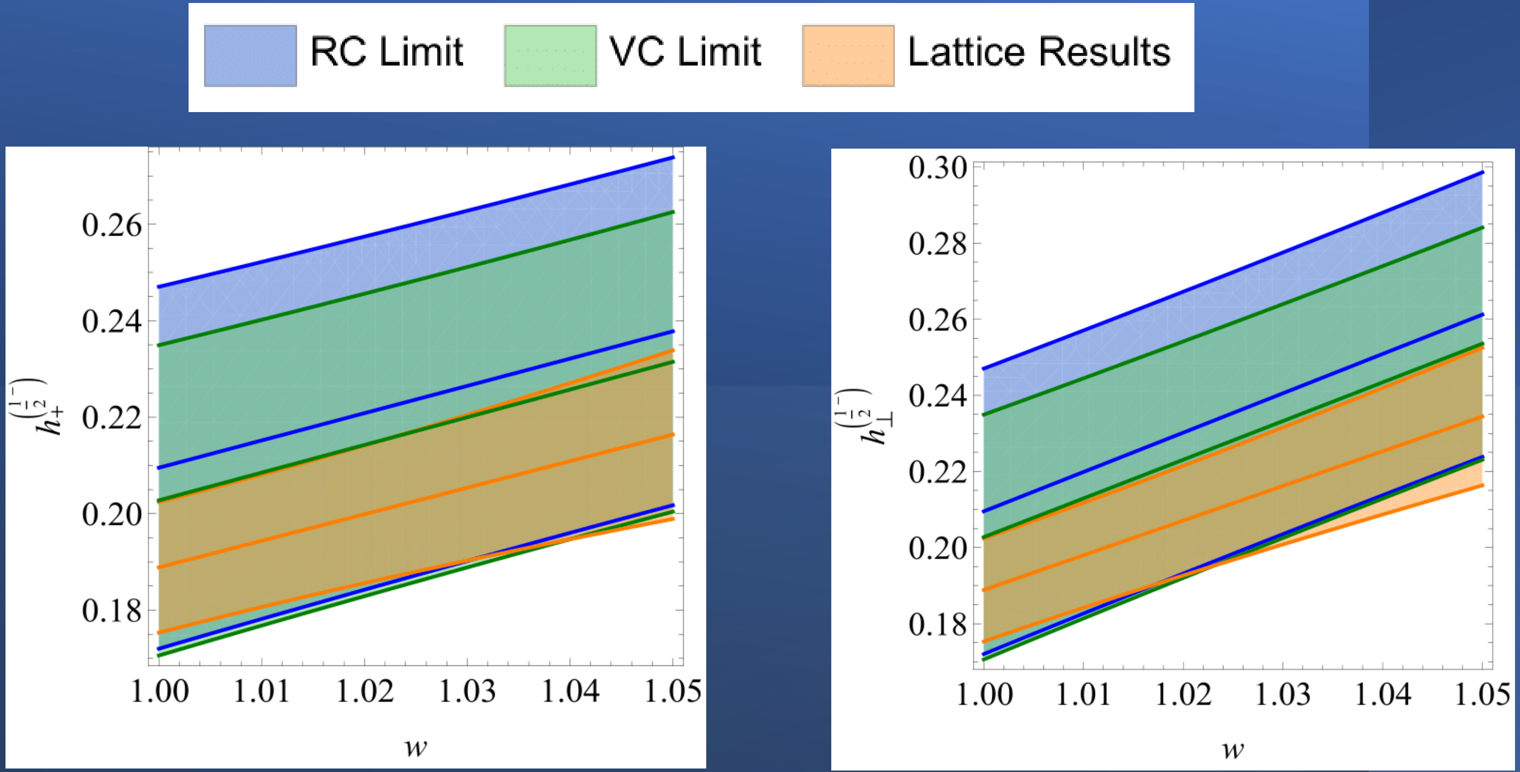
$$\frac{\chi^2_{RC}}{d.o.f} = 0.84$$

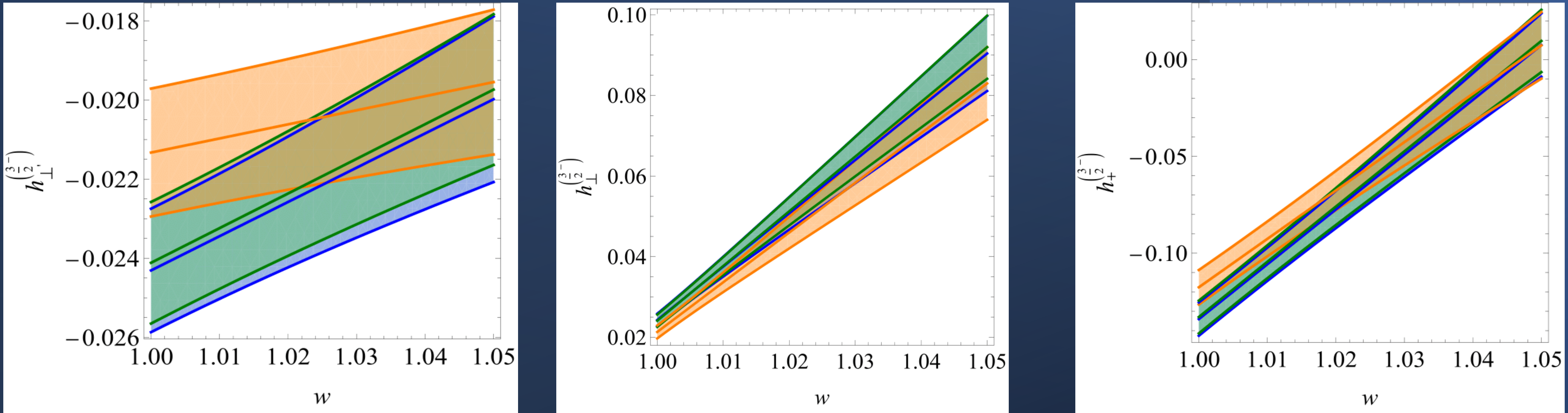
VC LIMIT

Parameter	Best fit
$\zeta^{(0)}$	0.52 ± 0.43
$\zeta^{(1)}$	-6.49 ± 1.55
$\zeta_{SL}^{(0)}$	0.16 ± 0.01
$\zeta_{SL}^{(1)}$	-0.57 ± 0.17
$\eta_{kin,c}^{(0)}$	-0.21 ± 1.10
$\eta_{kin,c}^{(1)}$	10.56 ± 3.94
$\beta_1^{(0)}$	1.42 ± 0.96
$\beta_3^{(0)}$	0.84 ± 0.09
$\beta_3^{(1)}$	-1.69 ± 0.64

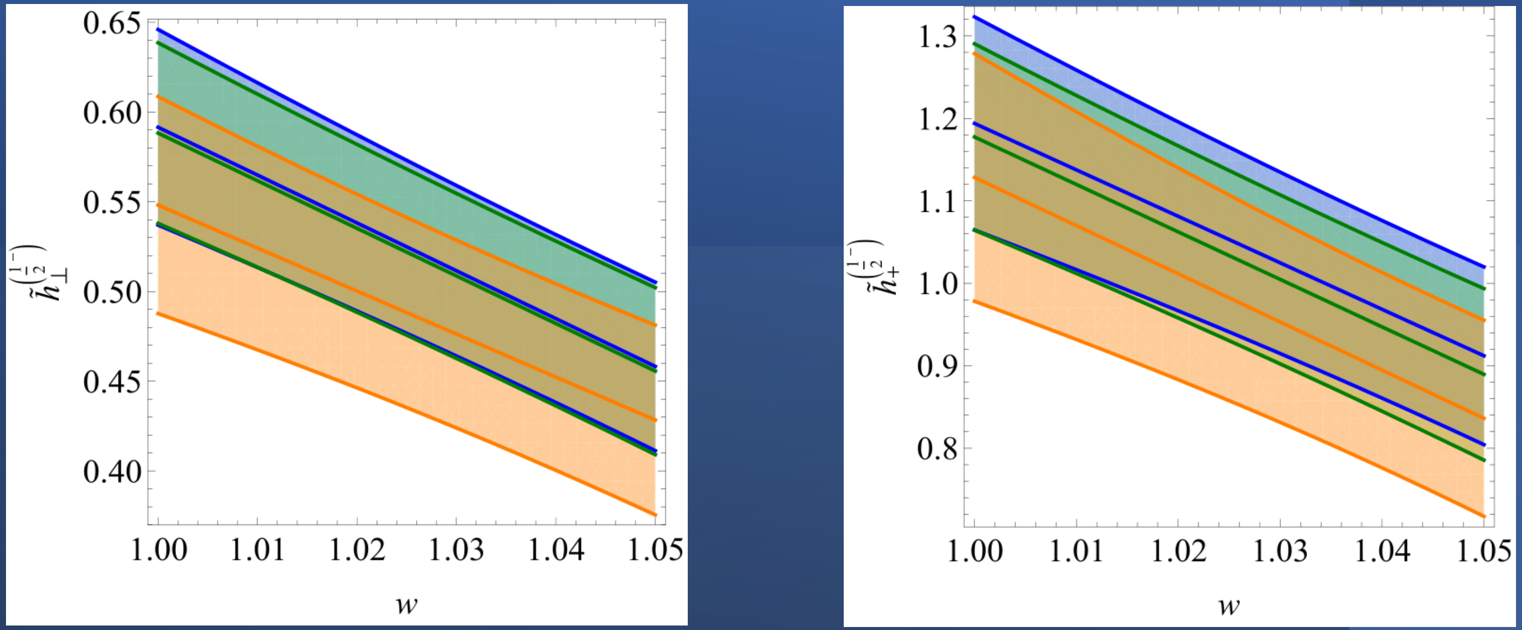
$$\frac{\chi^2_{VC}}{d.o.f.} = 0.72$$

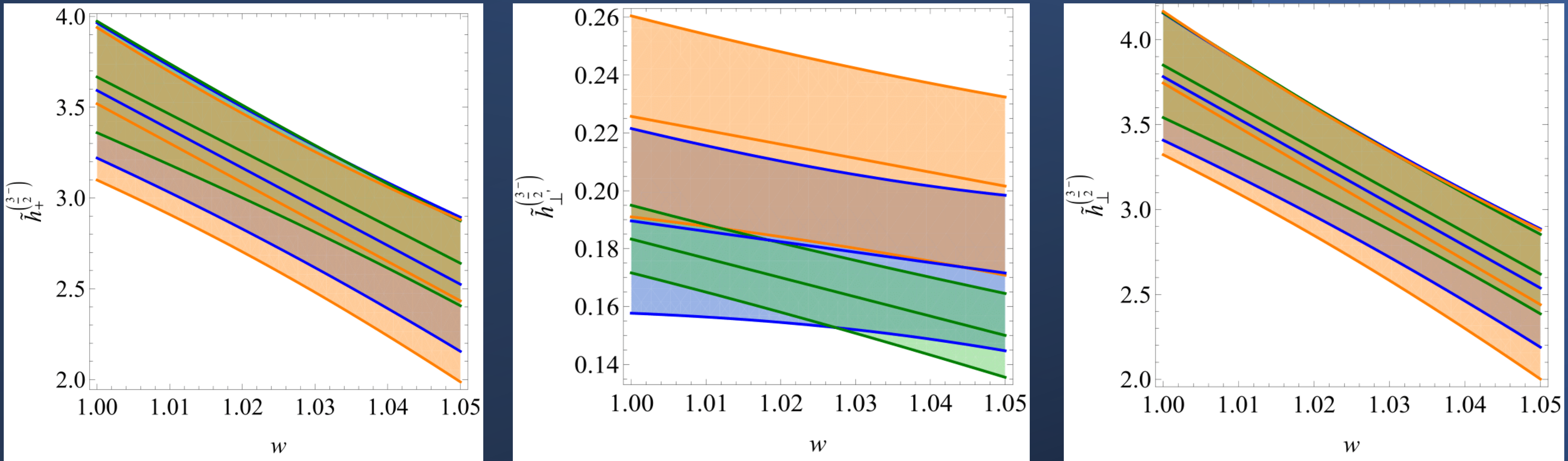
TENSOR FORM FACTORS





PSEUDO TENSOR FORM FACTORS





CONCLUSIONS

- **HQET IS A VALUABLE TOOL TO STUDY HADRONS CONTAINING A HEAVY QUARK**

➢ $\Lambda_b \to \Lambda_c^*(2595, 2625)$ represent relevant applications.

➢ We went beyond previous analysis of this channel computing Form Factors at $\mathcal{O}(1/m_c^2)$.

➢ We showed the relevance of the novel $\mathcal{O}(1/m_c^2)$ terms to reconcile HQET with the lattice QCD results.

THANK YOU
FOR YOUR ATTENTION!

BACKUP SLIDES

SPIN-FLAVOUR SYMMETRY & ISGUR-WISE FUNCTION

- $\mathcal{L}_{\text{eff}}^{\infty}$ is invariant under $SU(2)$ spin group.
- For N_h heavy quarks $\mathcal{L}_{\text{eff}}^{\infty} = \sum_{i=1}^{N_h} \bar{Q}_{+}^{v\,i} iv \cdot DQ_{+}^{v\,i}$, and $SU(2) \Rightarrow SU(2N_h)$ → **SPIN-FLAVOUR SYMMETRY**
- Symmetry breaking terms are suppressed by powers of $1/m_Q$.
- Scattering of a pseudo-scalar meson $P(v) \rightarrow P'(v')$ involving the transition $Q \rightarrow Q'$.

What happens to the brown muck?

- If $v = v'$ nothing happens
- If $v \neq v'$ form factor suppression

- The hadronic matrix element can be written as

$$\langle P'(v')|\bar{Q}'^{v'}_{+}\gamma^{\mu}Q^{v}_{+}|P(v)\rangle = \xi(v \cdot v')(v+v')^{\mu}$$

- The universal form factor $\xi(v \cdot v')$ is the "Isgur-Wise" function.

HELICITY AMPLITUDES

$$\mathcal{A}_\Gamma(s_b, s_c, \lambda_c, \lambda_q) \equiv \langle \Lambda_c^*(s_c, \eta(\lambda_c))|\, \bar{c}\, \Gamma^\mu \varepsilon_\mu^*(\lambda_q) b\, |\Lambda_b(s_b)\rangle \ , \qquad \begin{cases} s_{b,c} \in \left\{+\frac{1}{2}, -\frac{1}{2}\right\}, \\ \lambda_c \in \{0, +1, -1\}, \\ \lambda_q \in \{t, 0, +1, -1\} \ . \end{cases}$$

Helicity Amplitudes for $J = 1/2$

$$\mathcal{A}_\Gamma^{(1/2)}(+1/2, +1/2, 0) \equiv -\sqrt{\frac{1}{3}}\mathcal{A}_\Gamma(+1/2, +1/2, 0, 0) + \sqrt{\frac{2}{3}}\mathcal{A}_\Gamma(+1/2, -1/2, +1, 0)\,,$$

$$\mathcal{A}_\Gamma^{(1/2)}(+1/2, +1/2, t) \equiv -\sqrt{\frac{1}{3}}\mathcal{A}_\Gamma(+1/2, +1/2, 0, t) + \sqrt{\frac{2}{3}}\mathcal{A}_\Gamma(+1/2, -1/2, +1, t)\,,$$

$$\mathcal{A}_\Gamma^{(1/2)}(+1/2, -1/2, -1) \equiv \sqrt{\frac{1}{3}}\mathcal{A}_\Gamma(+1/2, -1/2, 0, -1) - \sqrt{\frac{2}{3}}\mathcal{A}_\Gamma(+1/2, +1/2, -1, -1)\,.$$

Helicity Amplitudes for $J = 3/2$

$$\mathcal{A}_\Gamma^{(3/2)}(+1/2, +3/2, +1) \equiv \mathcal{A}_\Gamma(+1/2, +1/2, +1, +1)\,,$$

$$\mathcal{A}_\Gamma^{(3/2)}(+1/2, +1/2, 0) \equiv \sqrt{\frac{2}{3}}\mathcal{A}_\Gamma(+1/2, +1/2, 0, 0) + \sqrt{\frac{1}{3}}\mathcal{A}_\Gamma^{(3/2)}(+1/2, -1/2, +1, 0)\,,$$

$$\mathcal{A}_\Gamma^{(3/2)}(+1/2, +1/2, t) \equiv \sqrt{\frac{2}{3}}\mathcal{A}_\Gamma(+1/2, +1/2, 0, t) + \sqrt{\frac{1}{3}}\mathcal{A}_\Gamma^{(3/2)}(+1/2, -1/2, +1, t)\,,$$

$$\mathcal{A}_\Gamma^{(3/2)}(+1/2, -1/2, -1) \equiv \sqrt{\frac{2}{3}}\mathcal{A}_\Gamma(+1/2, -1/2, 0, -1) + \sqrt{\frac{1}{3}}\mathcal{A}_\Gamma^{(3/2)}(+1/2, +1/2, -1, -1)\,.$$

(RC) VECTOR FORM FACTORS

$$
\begin{aligned}
f_{1/2,0} =& \frac{\zeta s_-\sqrt{s_+}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}\left(C_1+\frac{C_2 s_+}{2m_{\Lambda_b}(m_{\Lambda_b}+m_{\Lambda_c^*})}+\frac{C_3 s_+}{2m_{\Lambda_c^*}(m_{\Lambda_b}+m_{\Lambda_c^*})}\right)+\\
&+\varepsilon_b\frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}'-2\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\varepsilon_c\frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}-2\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\frac{s_-\sqrt{s_+}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}(\varepsilon_c\eta_{\mathrm{kin}}^{(c)}+\varepsilon_b\eta_{\mathrm{mag}}^{(b)}-\varepsilon_c\eta_{\mathrm{mag}}^{(c)})+\\
&+\varepsilon_c^2\frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(3(\psi_3+w\psi_2)-\frac{s_-s_+\psi_1}{4(m_{\Lambda_b}m_{\Lambda_c^*})^2}\right),\\
f_{1/2,t} =& \frac{\zeta s_+\sqrt{s_-}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}\left(C_1+\frac{C_2 s_+}{2m_{\Lambda_b}(m_{\Lambda_b}-m_{\Lambda_c^*})}+\frac{C_3 s_+}{2m_{\Lambda_c^*}(m_{\Lambda_b}-m_{\Lambda_c^*})}\right)+\\
&+\varepsilon_b\frac{\sqrt{s_-}(m_{\Lambda_b}+m_{\Lambda_c^*})}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}'-2\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\varepsilon_c\frac{\sqrt{s_-}(m_{\Lambda_b}+m_{\Lambda_c^*})}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}-2\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\frac{s_+\sqrt{s_-}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}(\varepsilon_c\eta_{\mathrm{kin}}^{(c)}+\varepsilon_b\eta_{\mathrm{mag}}^{(b)}-\varepsilon_c\eta_{\mathrm{mag}}^{(c)})+\\
&+\varepsilon_c^2\frac{\sqrt{s_-}(m_{\Lambda_b}+m_{\Lambda_c^*})}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(3(\psi_3+w\psi_2)-\frac{s_-s_+\psi_1}{4(m_{\Lambda_b}m_{\Lambda_c^*})^2}\right),\\
f_{1/2,\perp} =& \frac{C_1\zeta s_-\sqrt{s_+}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}+\varepsilon_b\frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}-\bar{\Lambda}'\zeta\right)+\\
&+\varepsilon_c\frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\bar{\Lambda}\zeta-2\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\frac{s_-\sqrt{s_+}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}(\varepsilon_c\eta_{\mathrm{kin}}^{(c)}-\varepsilon_c\eta_{\mathrm{mag}}^{(c)})+\varepsilon_c^2\frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(3(\psi_3+w\psi_2)-\frac{s_-s_+\psi_1}{4(m_{\Lambda_b}m_{\Lambda_c^*})^2}\right),
\end{aligned}
$$

$\Lambda_b \rightarrow \Lambda_c^*(2595)$

$\Lambda_b \rightarrow \Lambda_c^*(2625)$

$$
\begin{aligned}
F_{1/2,0} =& \frac{\zeta s_-\sqrt{s_+}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}\left(C_1+\frac{C_2 s_+}{2m_{\Lambda_b}(m_{\Lambda_b}+m_{\Lambda_c^*})}+\frac{C_3 s_+}{2m_{\Lambda_c^*}(m_{\Lambda_b}+m_{\Lambda_c^*})}\right)+\\
&+\varepsilon_b\frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}'+\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\varepsilon_c\frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}+\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2\right)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\frac{\sqrt{s_+}s_-}{4(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}(2\varepsilon_c\eta_{\mathrm{kin}}^{(c)}-\varepsilon_b\eta_{\mathrm{mag}}^{(b)}+\varepsilon_c\eta_{\mathrm{mag}}^{(c)})-\\
&-\varepsilon_c^2\frac{s_+^{3/2}s_-(m_{\Lambda_b}-m_{\Lambda_c^*})}{4(m_{\Lambda_b}+m_{\Lambda_c^*})(m_{\Lambda_b}m_{\Lambda_c^*})^{5/2}}\psi_1,\\
F_{1/2,t} =& \frac{\zeta s_+\sqrt{s_-}}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}\left(C_1+\frac{m_{\Lambda_c^*}(m_{\Lambda_b}^2-m_{\Lambda_c^*}^2+q^2)}{2(m_{\Lambda_b}-m_{\Lambda_c^*})m_{\Lambda_b}m_{\Lambda_c^*}}C_2+\frac{m_{\Lambda_b}(m_{\Lambda_b}^2-m_{\Lambda_c^*}^2-q^2)}{2(m_{\Lambda_b}-m_{\Lambda_c^*})m_{\Lambda_b}m_{\Lambda_c^*}}C_3\right)+\\
&+\varepsilon_b\frac{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{s_-}}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}'+\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\varepsilon_c\frac{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{s_-}}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}+\zeta_{\mathrm{SL}}-\frac{\zeta\bar{\Lambda}'(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\frac{s_+\sqrt{s_-}}{4(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}(2\varepsilon_c\eta_{\mathrm{kin}}^{(c)}-\varepsilon_b\eta_{\mathrm{mag}}^{(b)}+\varepsilon_c\eta_{\mathrm{mag}}^{(c)})-\\
&-\varepsilon_c^2\frac{s_+s_-^{3/2}(m_{\Lambda_b}+m_{\Lambda_c^*})}{4(m_{\Lambda_b}-m_{\Lambda_c^*})(m_{\Lambda_b}m_{\Lambda_c^*})^{5/2}}\psi_1,\\
F_{1/2,\perp} =& \frac{\zeta\sqrt{s_+}s_-}{2(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}C_1+\varepsilon_b\zeta\frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\frac{\bar{\Lambda}(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2)}{2m_{\Lambda_b}m_{\Lambda_c^*}}-\bar{\Lambda}'\right)+\\
&+\varepsilon_c\frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\left(\zeta\bar{\Lambda}+\zeta_{\mathrm{SL}}-\zeta\frac{\bar{\Lambda}'(m_{\Lambda_b}^2+m_{\Lambda_c^*}^2-q^2)}{2m_{\Lambda_b}m_{\Lambda_c^*}}\right)+\\
&+\frac{\sqrt{s_+}s_-}{4(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}(2\varepsilon_c\eta_{\mathrm{kin}}^{(c)}+\varepsilon_c\,\eta_{\mathrm{mag}}^{(c)})-\varepsilon_c^2\frac{s_+^{3/2}s_-}{4\,(m_{\Lambda_b}m_{\Lambda_c^*})^{5/2}}\psi_1,\\
F_{3/2,\perp} =& -\varepsilon_b\frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b}m_{\Lambda_c^*}}}\zeta_{\mathrm{SL}}-\varepsilon_b\frac{s_-\sqrt{s_+}}{4(m_{\Lambda_b}m_{\Lambda_c^*})^{3/2}}\,\eta_{\mathrm{mag}}^{(b)},
\end{aligned}
$$

(VC) VECTOR FORM FACTORS

$\Lambda_b \to \Lambda_c^*(2595)$

$$
\begin{aligned}
f_{1/2,0} =& \frac{\zeta s_- \sqrt{s_+}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \left(C_1 + \frac{C_2 s_+}{2m_{\Lambda_b}(m_{\Lambda_b}+m_{\Lambda_c^*})} + \frac{C_3 s_+}{2m_{\Lambda_c^*}(m_{\Lambda_b}+m_{\Lambda_c^*})} \right) + \\
&+\varepsilon_b \frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda}' - 2\zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda} - 2\zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\eta_{\mathrm{kin}}^{(c)} s_- \sqrt{s_+}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} + \varepsilon_c^2 \frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(3\beta_3 - \frac{s_- s_+ \beta_1}{4(m_{\Lambda_b} m_{\Lambda_c^*})^2} \right),
\end{aligned}
$$

$$
\begin{aligned}
f_{1/2,t} =& \frac{\zeta s_+ \sqrt{s_-}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \left(C_1 + \frac{C_2 s_+}{2m_{\Lambda_b}(m_{\Lambda_b}-m_{\Lambda_c^*})} + \frac{C_3 s_+}{2m_{\Lambda_c^*}(m_{\Lambda_b}-m_{\Lambda_c^*})} \right) + \\
&+\varepsilon_b \frac{\sqrt{s_-}(m_{\Lambda_b}+m_{\Lambda_c^*})}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda}' - 2\zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\sqrt{s_-}(m_{\Lambda_b}+m_{\Lambda_c^*})}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda} - 2\zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\eta_{\mathrm{kin}}^{(c)} s_+ \sqrt{s_-}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} + \varepsilon_c^2 \frac{\sqrt{s_-}(m_{\Lambda_b}+m_{\Lambda_c^*})}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(3\beta_3 - \frac{s_- s_+ \beta_1}{4(m_{\Lambda_b} m_{\Lambda_c^*})^2} \right),
\end{aligned}
$$

$$
\begin{aligned}
f_{1/2,\perp} =& \frac{C_1 \zeta s_- \sqrt{s_+}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} + \varepsilon_b \frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} - \bar{\Lambda}'\zeta \right) + \\
&+\varepsilon_c \frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\bar{\Lambda}\zeta - 2\zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\eta_{\mathrm{kin}}^{(c)} s_- \sqrt{s_+}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} + \varepsilon_c^2 \frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(3\beta_3 - \frac{s_- s_+ \beta_1}{4(m_{\Lambda_b} m_{\Lambda_c^*})^2} \right),
\end{aligned}
$$

$\Lambda_b \to \Lambda_c^*(2625)$

$$
\begin{aligned}
F_{1/2,0} =& \frac{\zeta s_- \sqrt{s_+}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \left(C_1 + \frac{C_2 s_+}{2m_{\Lambda_b}(m_{\Lambda_b}+m_{\Lambda_c^*})} + \frac{C_3 s_+}{2m_{\Lambda_c^*}(m_{\Lambda_b}+m_{\Lambda_c^*})} \right) + \\
&+\varepsilon_b \frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda}' + \zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\sqrt{s_+}(m_{\Lambda_b}-m_{\Lambda_c^*})}{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda} + \zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}'\left(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2\right)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\sqrt{s_+} s_-}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \eta_{\mathrm{kin}}^{(c)} - \varepsilon_c^2 \frac{(m_{\Lambda_b}-m_{\Lambda_c^*}) s_+^{3/2} s_-}{4(m_{\Lambda_b}+m_{\Lambda_c^*})(m_{\Lambda_b} m_{\Lambda_c^*})^{5/2}} \beta_1,
\end{aligned}
$$

$$
\begin{aligned}
F_{1/2,t} =& \frac{\zeta s_+ \sqrt{s_-}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \left(C_1 + \frac{m_{\Lambda_c^*}(m_{\Lambda_b}^2 - m_{\Lambda_c^*}^2 + q^2)}{2(m_{\Lambda_b}-m_{\Lambda_c^*}) m_{\Lambda_b} m_{\Lambda_c^*}} C_2 + \frac{m_{\Lambda_b}(m_{\Lambda_b}^2 - m_{\Lambda_c^*}^2 - q^2)}{2(m_{\Lambda_b}-m_{\Lambda_c^*}) m_{\Lambda_b} m_{\Lambda_c^*}} C_3 \right) + \\
&+\varepsilon_b \frac{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{s_-}}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda}' + \zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{(m_{\Lambda_b}+m_{\Lambda_c^*})\sqrt{s_-}}{(m_{\Lambda_b}-m_{\Lambda_c^*})\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda} + \zeta_{\mathrm{SL}} - \frac{\zeta\bar{\Lambda}'(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{s_+ \sqrt{s_-}}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \eta_{\mathrm{kin}}^{(c)} - \varepsilon_c^2 \frac{(m_{\Lambda_b}+m_{\Lambda_c^*}) s_+ s_-^{3/2}}{4(m_{\Lambda_b}-m_{\Lambda_c^*})(m_{\Lambda_b} m_{\Lambda_c^*})^{5/2}} \beta_1,
\end{aligned}
$$

$$
\begin{aligned}
F_{1/2,\perp} =& \frac{\zeta \sqrt{s_+} s_-}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} C_1 + \varepsilon_b \zeta \frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\frac{\bar{\Lambda}(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2)}{2m_{\Lambda_b} m_{\Lambda_c^*}} - \bar{\Lambda}' \right) + \\
&+\varepsilon_c \frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \left(\zeta\bar{\Lambda} + \zeta_{\mathrm{SL}} - \zeta \frac{\bar{\Lambda}'(m_{\Lambda_b}^2 + m_{\Lambda_c^*}^2 - q^2)}{2m_{\Lambda_b} m_{\Lambda_c^*}} \right) + \\
&+\varepsilon_c \frac{\sqrt{s_+} s_-}{2(m_{\Lambda_b} m_{\Lambda_c^*})^{3/2}} \eta_{\mathrm{kin}}^{(c)} - \varepsilon_c^2 \frac{s_+^{3/2} s_-}{4(m_{\Lambda_b} m_{\Lambda_c^*})^{5/2}} \beta_1,
\end{aligned}
$$

$$
F_{3/2,\perp} = -\varepsilon_b \frac{\sqrt{s_+}}{\sqrt{m_{\Lambda_b} m_{\Lambda_c^*}}} \zeta_{\mathrm{SL}}.
$$