The $\bar{B} \to \bar{K}\pi\ell\ell$ distribution at low hadronic recoil.

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Motivation.

- The $\bar{B} \to \bar{K}\pi\ell\ell$ decay is $|\Delta_B| = |\Delta_S| = 1$ Flavour Changing Neutral Current (FCNC) processes and therefore sensitive to New Physics(NP).
- At LHCb with $3fb^{-1}$ luminosity, significant numbers($\sim$ 3K) of $\bar{B} \to \bar{K}\pi\ell\ell$ events will be produced.
- $\bar{B} \to \bar{K}\pi\ell\ell$ contributes as background to $\bar{B} \to \bar{K}^*(\to \bar{K}\pi)\ell\ell$.

Theoretical Framework

The operator basis for $|\Delta_B| = |\Delta_S| = 1$ rare decays is

$$\mathcal{O}_7^{(\prime)} = \frac{m_b}{e}\bar{s}\sigma^{\mu\nu}P_R(P_L)bF_{\mu\nu}\,, \quad \mathcal{O}_9^{(\prime)} = \bar{s}\gamma_\mu P_L(P_R)b\,\bar{\ell}\gamma^\mu\ell\,, \quad \mathcal{O}_{10}^{(\prime)} = \bar{s}\gamma_\mu P_L(P_R)b\,\bar{\ell}\gamma^\mu\gamma_5\ell\,,.$$

the transversity amplitudes to the lowest order OPE in $1/m_b$

$$H_{0,\parallel}^{L/R} = C_-^{L/R}(q^2)\,F_{0,\parallel}(q^2,p^2,\cos\theta_K)\,, \quad H_\perp^{L/R} = C_+^{L/R}(q^2)\,F_\perp(q^2,p^2,\cos\theta_K)\,,.$$

[Grinstein/Pirjol Phys. Rev. D**70**, 114005(2004), Hiller and Zwicky, JHEP 1403 (2014) 042]

short-distance coefficients

$$C_\pm^{L/R}(q^2) = C_9^{\rm eff}(q^2) \pm C_9' \mp (C_{10} \pm C_{10}') + \kappa\frac{2m_b m_B}{q^2}(C_7^{\rm eff} \pm C_7')\,,$$

$$\rho_1^\pm = \frac{1}{2}(|C_\pm^R|^2 + |C_\pm^L|^2)\,, \quad \delta\rho = \frac{1}{4}(|C_-^R|^2 - |C_-^L|^2)\,, \quad \rho_2^\pm = \frac{1}{4}(C_+^R C_-^{R*} \mp C_-^L C_+^{L*})\,.$$

$$\rho_1 \equiv \rho_1^\pm = 2\text{Re}\rho_2^-\,, \quad \rho_2 \equiv \text{Re}\rho_2^+ = \delta\rho\,, \quad \text{Im}\rho_2^\pm = 0, \quad \text{in SM basis}$$

- $\delta\rho$ and ρ_2^- are new

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014), Böer/Feldmann/Dyk 1410.2115]

Generalized transversity form factors

$$\mathcal{F}_0(q^2, p^2, \cos\theta_K) = F_0(q^2, p^2, \cos\theta_K) + \sum_R P^0_{J_R}(\cos\theta_K) \cdot F_{0\,J_R}(q^2, p^2)\,,$$

$$\mathcal{F}_i(q^2, p^2, \cos\theta_K) = F_i(q^2, p^2, \cos\theta_K) + \sum_R \frac{P^1_{J_R}(\cos\theta_K)}{\sin\theta_K} \cdot F_{i\,J_R}(q^2, p^2)\,, \quad i = \parallel, \perp\ .$$

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

Generalized transversity form factors

$$\mathcal{F}_0(q^2,p^2,\cos\theta_K) = F_0(q^2,p^2,\cos\theta_K) + \sum_R P^0_{J_R}(\cos\theta_K)\cdot F_{0J_R}(q^2,p^2)\,,$$

$$\mathcal{F}_i(q^2,p^2,\cos\theta_K) = F_i(q^2,p^2,\cos\theta_K) + \sum_R \frac{P^1_{J_R}(\cos\theta_K)}{\sin\theta_K}\cdot F_{iJ_R}(q^2,p^2)\,,\quad i=\parallel,\perp\;.$$

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

The transversity form factors for $\bar{B}\to\bar{K}\pi\ell\ell$ decay are

$$F_0 = \frac{\mathcal{N}_{nr}}{2}\left[\lambda^{1/2}w_+ + \frac{1}{p^2}\{(m_K^2-m_\pi^2)\lambda^{1/2} - (m_B^2-q^2-p^2)\lambda_p^{1/2}\cos\theta_K\}w_-\right],$$

$$F_\parallel = \mathcal{N}_{nr}\sqrt{\lambda_p\frac{q^2}{p^2}}\,w_-\,,\quad F_\perp = \frac{\mathcal{N}_{nr}}{2}\sqrt{\lambda\lambda_p\frac{q^2}{p^2}}\,h\,.$$

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014), Lee/Lu/Wise, Phys. Rev. D46, 5040]

Form factors $w_\pm(q^2,p^2,\cos\theta_K)$ and $h(q^2,p^2,\cos\theta_K)$ are known form heavy hadron chiral perturbation theory (HHχPT) calculations. In terms of HHχPT coupling constant g, to the lowest order in $1/m_b$

$$w_\pm\sim g,\qquad h\sim g^2,\qquad g=0.569\pm0.076$$

[Flynn *et al.*, arXiv:1311.2251]

Theoretical Framework

Generalized transversity form factors

$$\mathcal{F}_0(q^2, p^2, \cos\theta_K) = F_0(q^2, p^2, \cos\theta_K) + \sum_R P^0_{J_R}(\cos\theta_K) \cdot F_{0J_R}(q^2, p^2)\,,$$

$$\mathcal{F}_i(q^2, p^2, \cos\theta_K) = F_i(q^2, p^2, \cos\theta_K) + \sum_R \frac{P^1_{J_R}(\cos\theta_K)}{\sin\theta_K} \cdot F_{iJ_R}(q^2, p^2)\,, \quad i = \parallel, \perp\ .$$

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

$F_{(0,\parallel,\perp)J_R}$ are the polarization dependent form factors for a resonance with spin J_R.
For $\bar{B} \to \bar{K}^* \ell\ell$ decay these are

$$F_{0P}(q^2, p^2) = -3 f_0(q^2)\, BW_{K^*}(p^2)\, e^{i\delta_{K^*}}\,, \quad F_{\parallel P}(q^2, p^2) = -3\sqrt{\frac{1}{2}}\, f_\parallel(q^2)\, BW_{K^*}(p^2)\, e^{i\delta_{K^*}}\,,$$

$$F_{\perp P}(q^2, p^2) = 3\sqrt{\frac{1}{2}}\, f_\perp(q^2)\, BW_{K^*}(p^2)\, e^{i\delta_{K^*}}\ .$$

$f_{0,\parallel,\perp}(q^2)$ are the $\bar{B} \to \bar{K}^*$ transversity form factors

[Bobeth/Hiller/Dyk JHEP 1007 (2010) 098]

Angular Distribution at Low recoil

The $\bar{B} \to \bar{K}\pi\ell\ell$ angular distribution in terms of angles θ_l, θ_K, ϕ

$$d^5\Gamma = \frac{1}{2\pi}\left[\sum_{i=1}^{9} c_i(\theta_l,\phi) I_i(q^2,p^2,\cos\theta_K)\right] dq^2 dp^2 d\cos\theta_K d\cos\theta_\ell d\phi \,.$$

[Bobeth/Hiller/Piranishvili JHEP 0807, 106]

The angular coefficients $I_i(q^2,p^2,\cos\theta_K)$ are given in terms of $\mathcal{F}_{0,\parallel,\perp}$ and ρ's

The long- and short-distance contributions factorize in the angular coefficients I_i.

In the SM basis there are only two universal short-distance coefficients $\rho_{1,2}$.

–possibility to construct observables sensitive to electroweak physics only

–possibility to probe the relative string phase δ_{K^*}

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

$$F_0 = \sum_{\ell=0} a_0^\ell(q^2,p^2)\, P_\ell^{m=0}(\cos\theta_K)\,,\, F_\| = \sum_{\ell=1} a_\|^\ell(q^2,p^2)\, \frac{P_\ell^{m=1}(\cos\theta_K)}{\sin\theta_K}\,,$$

$$F_\perp = \sum_{\ell=1} a_\perp^\ell(q^2,p^2)\, \frac{P_\ell^{m=1}(\cos\theta_K)}{\sin\theta_K}\,.$$

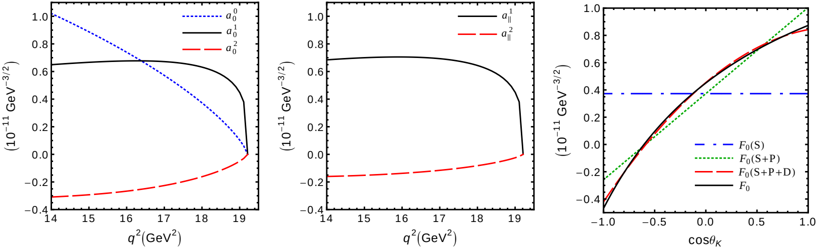


Figure: The first few angular coefficients a_i^ℓ (left $i=0$, middle $i=\|$) of the non-resonant form factors F_i, for central values of the input parameters at $p^2 = m_{K*}^2$. The blue dotted, black solid and red dashed lines correspond to S, P and D coefficients, respectively. In the plot to the right the form factor F_0 is shown at $p^2 = m_{K*}^2$ and $q^2 = 18\,\mathrm{GeV}^2$ in S (blue short-long dashed), S+P (green dotted) and S+P+D (red dashed) approximation, together with the full result (solid black curve).

Kinematics and Angular Distributions: S+P+D angular projection

$$\frac{d^5\Gamma(S+P+D)}{dq^2 dp^2 d\cos\theta_K d\cos\theta_\ell d\phi} = \frac{1}{2\pi}\Bigg[\sum_{i=1,2} c_i\left(J_{icc}\cos^2\theta_K + J_{iss}\sin^2\theta_K + J_{ic}\cos\theta_K\right.$$

$$\left.+J_{issc}\,\sin^2\theta_K\,\cos\theta_K + J_{isscc}\,\sin^2\theta_K\,\cos^2\theta_K\right)$$

$$+\sum_{i=3,6,9} c_i\left(J_{icc}\cos^2\theta_K + J_i + J_{ic}\cos\theta_K\right)\sin^2\theta_K$$

$$+\sum_{i=4,5,7,8} c_i\left(J_{icc}\cos^2\theta_K + J_{iss}\sin^2\theta_K + J_{ic}\cos\theta_K + J_{issc}\sin^2\theta_K\cos\theta_K\right)\sin\theta_K\Bigg]$$

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

For $\bar{B} \to \bar{K}^*\ell\ell$ decay, only the coefficients $J_{1,2cc}$, $J_{1,2ss}$, $J_{3,6,9}$ and J_{4-8c} appear .

i) no S-wave contribution to $I_{3,6,9}$.

ii) The D-wave contributions to $I_{3,6,9}$ can be separated from the pure P-one by an angular analysis.

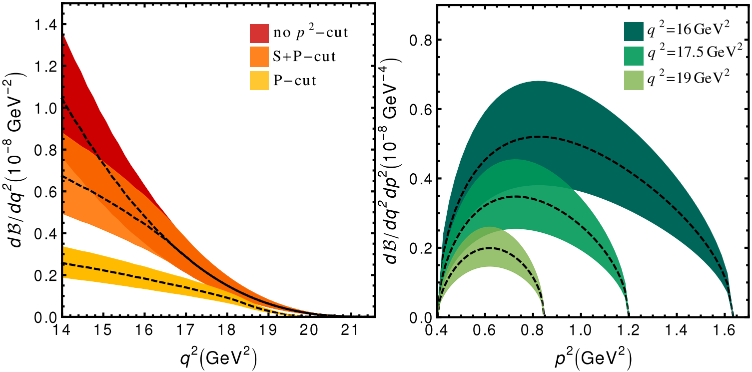
iii) separation of S- and D-wave contributions to $I_{1,2}$ need sideband subtractions.

iv) S-P and D-P interference to $I_{4,5,7,8}$ can be separated from the pure P-wave contribution by angular analysis.

–full non-resonant phase space: $p^2_{min} \equiv (m_K + m_\pi)^2 \leq p^2 < (m_B - \sqrt{q^2})^2$

–P-wave ‘signal’ window: 0.64GeV^2 $\leq p^2$ <1GeV^2

–S+P-wave ‘total’ window: $p^2_{min} \leq p^2 < 1.44$GeV^2



[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

comparison of non-resonant $\bar{B} \to \bar{K}\pi\ell\ell$ and resonant $\bar{B} \to \bar{K}_0^*\ell\ell$ as background to $\bar{B} \to \bar{K}^*\ell\ell$

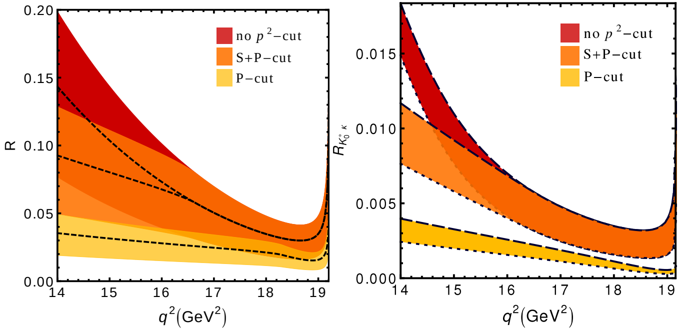


Figure: Left: $R = (d\mathcal{B}(\bar{B} \to \bar{K}\pi\ell\ell)/dq^2)/(d\mathcal{B}(\bar{B} \to \bar{K}^*\ell\ell)/dq^2)$ in the SM basis for the three p^2-regions of interest. Left: $R_{K_0^*\kappa} = (d\mathcal{B}(\bar{B} \to (\bar{K}_0^*(1430) + \kappa(800))\ell\ell)/dq^2)/(d\mathcal{B}(\bar{B} \to \bar{K}^*\ell\ell)/dq^2)$ for the resonant S-wave contributions in the SM basis for the three p^2-cuts.

[DD/Hiller/Jung/Shires JHEP **1409**, 109 (2014)]

the non-resonant $\bar{B} \to \bar{K}\pi\ell\ell$ constitutes the dominant background to $\bar{B} \to \bar{K}^*\ell\ell$

Non-resonant contributions to $\bar{B} \to \bar{K}^* \ell\ell$ decay

$$f = \frac{\int_{p^2\text{-cut}} d\mathcal{B}(\bar{B} \to K^*(\to \bar{K}\pi)\ell\ell)/dp^2 dq^2}{\int_{p^2\text{-cut}} d\mathcal{B}(\bar{B} \to \bar{K}\pi\ell\ell)/dp^2 dq^2}$$

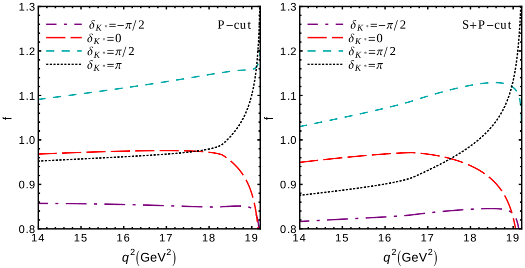


Figure: The fraction of resonant $\bar{B} \to \bar{K}^* \ell\ell$ to $\bar{B} \to \bar{K}\pi\ell\ell$ double differential branching ratios in the standard model as a function of q^2. The denominator includes contributions form the resonant $\bar{B} \to \bar{K}^* \ell\ell$, non-resonant $\bar{B} \to \bar{K}\pi\ell\ell$ and their interference. The distributions are shown in P-wave signal window and S+P-wave total window and for different values of the relative strong phase $\delta_{K^*} = -\pi/2, 0, \pi/2, \pi$.

[DD/Hiller/Jung]

Non-resonant contributions to $\bar{B} \to \bar{K}^* \ell\ell$ decay

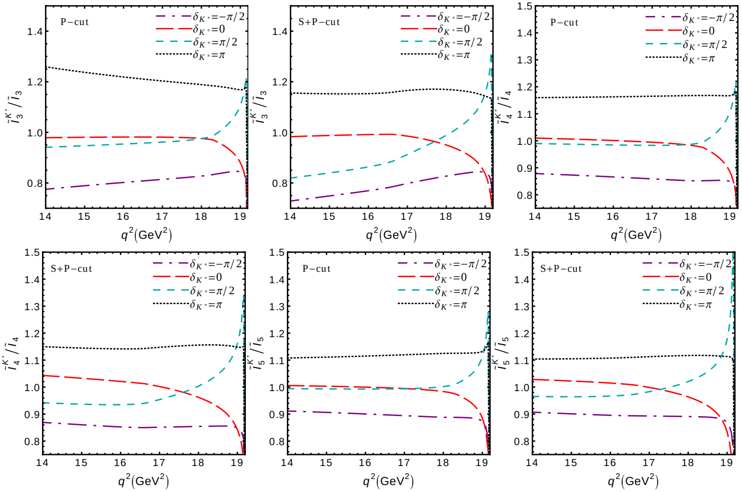
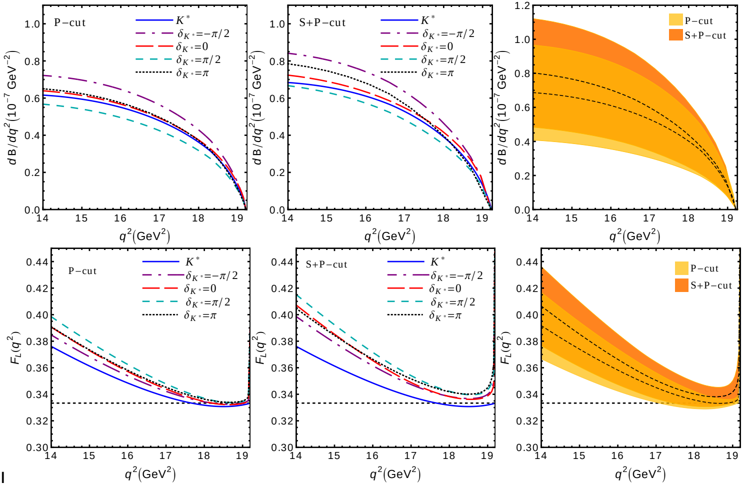


Figure: The ratios of the angular coefficients resonant $\bar{B} \to \bar{K}^* \ell\ell$ to that of $\bar{B} \to \bar{K}\pi\ell\ell$ decay in the standard model. The later contains contributions from resonant and non-resonant modes and their interference. The distributions are shown in P-wave signal window and S+P-wave total window and for different values of the relative strong phase, $\delta_{K^*} = -\pi/2, 0, \pi/2, \pi$.

Non-resonant contributions to $\bar{B} \to \bar{K}^* \ell\ell$ decay



[DD/Hiller/Jung]

Non-resonant contributions to $\bar{B} \to \bar{K}^* \ell\ell$ decay

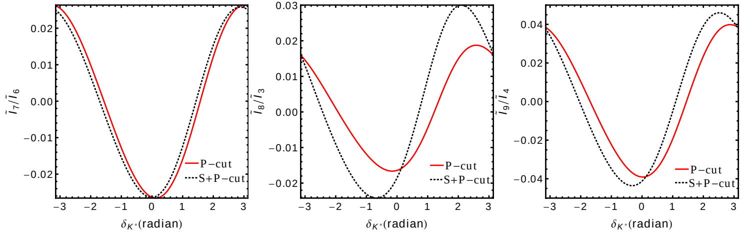


Figure: The ratios of $\bar{B} \to \bar{K}\pi\ell\ell$ angular coefficients as a function of the relative strong phase δ_{K^*} in P-wave signal window and S+P-wave total window.

[DD/Hiller/Jung]

Summary

–Phenomenological results for $\bar{B} \to \bar{K}\pi\ell\ell$ decay at low hadronic recoil are presented.

–Non-resonant $\bar{B} \to \bar{K}\pi\ell\ell$ is dominant background to $\bar{B} \to \bar{K}^*\ell\ell$.

–We have studied the impact of $\bar{B} \to \bar{K}\pi\ell\ell$ on $\bar{B} \to \bar{K}^*\ell\ell$

thank you