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

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based on
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Motivation.

- The $\bar{B} \to \bar{K}\pi\ell\ell$ 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.
- As far as high precision measurements are concerned, $\bar{B} \to \bar{K}\pi\ell\ell$ is a significant background to $\bar{B} \to \bar{K}^*(\to \bar{K}\pi)\ell\ell$.

Effective Hamiltonian for $|\Delta_B| = |\Delta_S| = 1$ decays is

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i C_i(\mu) \mathcal{O}_i(\mu)\,.$$

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

The $\bar{B}(p_B) \to \bar{K}(p_K)\pi(p_\pi)$ hadronic matrix element can be parameterized as

$$\langle \bar{K}\pi | \bar{s}\gamma_\mu (1-\gamma_5) b | \bar{B} \rangle = i\left[w_+ p_\mu + w_- P_\mu + r q_\mu + i h \epsilon_{\mu\alpha\beta\gamma} p_B^\alpha p^\beta P^\gamma \right]\,,$$

$$\langle \bar{K}\pi | \bar{s} i q^\nu \sigma_{\mu\nu} (1+\gamma_5) b | \bar{B} \rangle = -i m_B \left[w'_+ p_\mu + w'_- P_\mu + r' q_\mu + i h' \varepsilon_{\mu\alpha\beta\gamma} p_B^\alpha p^\beta P^\gamma \right]\,,$$

where $q = p_{\ell^-} + p_{\ell^+}\,, p = p_K + p_\pi$.

[Buchalla and Isidori, Nucl. Phys. B525, 333]

[Lee, Lu and Wise, Phys. Rev. D46, 5040]

The form factors $w_\pm^{(\prime)}$, $h_\pm^{(\prime)}$ and $r_\pm^{(\prime)}$ are functions of p^2, q^2 and $\cos\theta_K$.
$r^{(\prime)}$ does not contribute in vanishing lepton mass limit employed here.
θ_K: angle between the K and the B in the $K\pi$ rest frame.

HHχPT form factor

Improved Isgur-Wise relations at lowest order in $1/m_b$ including $\mathcal{O}(\alpha_s)$ corrections, using QCD equation of motion

$$i\partial^\nu(\bar{s}i\sigma_{\mu\nu}(1+\gamma_5)b) = -m_b\bar{s}\gamma_\mu(1-\gamma_5)b + i\partial_\mu(\bar{s}(1+\gamma_5)b) - 2\bar{s}i\overleftarrow{D}_\mu(1+\gamma_5)b$$

[Grinstein and Pirjol, Phys. Rev. D 70, 114005 (2004)]

$$w'_\pm = w_\pm \kappa\,, \quad h' = h\kappa\,.$$

The lowest order heavy hadron chiral perturbation theory (HHχPT) expressions for $w_\pm(q^2, p^2, \cos\theta_K)$ and $h(q^2, p^2, \cos\theta_K)$ are

[Lee, Lu and Wise, Phys. Rev. D46, 5040]

$$w_\pm = \pm\frac{g f_B}{2f_\pi^2}\frac{m_B}{v\cdot p_\pi + \Delta}\,,$$
$$h = \frac{g^2 f_B}{2f_\pi^2}\frac{1}{[v\cdot p_\pi + \Delta][v\cdot p + \Delta + \mu_s]}\,,$$

where $v = p_B/m_B$, $\Delta = m_{B^*} - m_B$ MeV and $\mu_s = m_{B_s} - m_B$ MeV .

$g = 0.569 \pm 0.076,$ [Lattice result on $B^*B\pi$ from Flynn *et al.*, arXiv:1311.2251]

$g = 0.59 \pm 0.070$ [$D^*D\pi$ coupling from CLEO Collaboration, PhysRevLett.87.251801]

Transversity Amplitudes

- The transversity amplitudes at low hadronic recoil with OPE in $1/m_b$ [Hiller and Zwicky, JHEP 1403 (2014) 042]

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

$$C^{L/R}_{\pm}(q^2) = C^{\mathrm{eff}}_9(q^2) \pm C'_9 \mp (C_{10} \pm C'_{10}) + \kappa \frac{2 m_b m_B}{q^2} (C^{\mathrm{eff}}_7 \pm C'_7)\,.$$

- The transversity form factors for $\bar{B} \to \bar{K}\pi\ell\ell$ decay are [DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10] [Lee, Lu and Wise, Phys. Rev. D46, 5040]

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

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

- Generalized transversity form factors to include resonance (spin J_R) contributions.

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

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

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

Kinematics and Angular Distributions: Low recoil

The $\bar{B} \to \bar{K}\pi\ell\ell$ angular distribution in terms of angles θ_l, θ_K, ϕ [Bobeth, Hiller and Piranishvili, JHEP 0807, 106]

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

Angular coefficients can written in terms of short distance physics $\rho_1^\pm, \rho_2^\pm, \delta\rho$ and long distance physics $\mathcal{F}_{0,||,\perp}$.

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

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

The coefficients $\rho_1^\pm$ and ρ_2^+ also appear in $\bar{B} \to \bar{K}^*\ell\ell$ decay [Bobeth, Hiller and Dyk, JHEP 1007, 098, Phys.Rev. D87 (2013) 034016].
The coefficients $\delta\rho$ and ρ_2^- are new.
The strong phase differences between the generalized form factors $\mathcal{F}_i$ allows us to measure these short distance coefficients.

$$I_7 = \delta\rho Im(\mathcal{F}_0\mathcal{F}_{||}^*)\sin\theta_K\,,$$

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

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

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

$$+J_{issc}\,\sin^2\theta_K\,\cos\theta_K + J_{isscc}\,\sin^2\theta_K\,\cos^2\theta_K\big)$$

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

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

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

For pure P-wave, only the coefficients J_{1ss}, J_{2ss}, $J_{3,6,9}$ and J_{4c}, J_{5c}, J_{7c} J_{8c} appear .

There is no S-wave contribution to $I_{3,6,9}$.[Becirevic, et.al 2013, Blake et.al 2013, Matias et.al 2012, Bobeth et.al 2013]

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

Phenomenology $\bar{B} \to \bar{K}\pi\ell\ell$: p^2 distributions

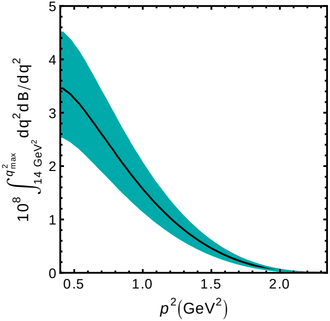

Figure: Differential branching fraction in SM, integrated over low recoil region [14 GeV^2-q^2_{max}] as a function of lower p^2-integration boundary. q^2_{max}=$(m_B - \sqrt{p^2})^2$ for given p^2.

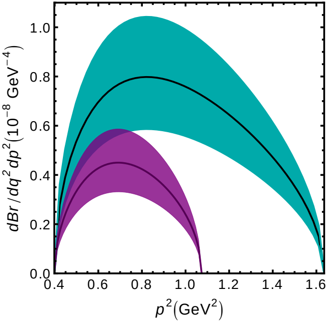

Figure: $d\mathcal{B}(\bar{B} \to \bar{K}\pi\ell\ell)/dq^2dp^2$ in SM for fixed $q^2 = 16$ GeV^2(outer curve) and $q^2 = 18$ GeV^2(inner curve).

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

Phenomenology of $\bar{B} \to \bar{K}\pi\ell\ell$: p^2 cuts

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

–P-wave 'signal' window: 0.64GeV$^2 \le p^2 <$1GeV^2

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

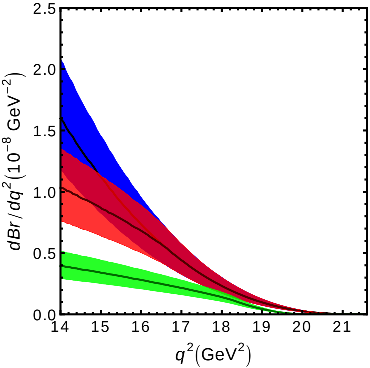

Figure: $d\mathcal{B}(\bar{B} \to \bar{K}\pi\ell\ell)/dq^2$ in SM without any p^2 cut (blue), in the S+P wave window (red) and in the P wave signal window (green).

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

$\bar{B} \to \bar{K}\pi\ell\ell$ as background to $\bar{B} \to \bar{K}^*\ell\ell$

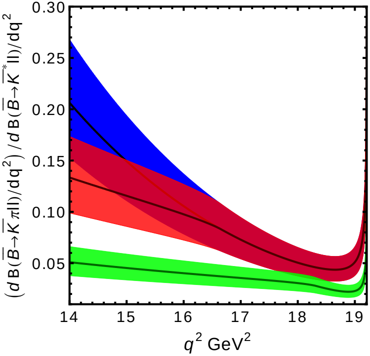

Figure: $[d\mathcal{B}(\bar{B} \to \bar{K}\pi\ell\ell)/dq^2]/[d\mathcal{B}(\bar{B} \to \bar{K}^*\ell\ell)/dq^2]$ in SM without any p^2 cut (blue), in S+P-wave total window (red) and P wave signal window (green).

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

S-wave as background to $\bar{B} \to \bar{K}^* \ell\ell$

$$BW_S(p^2) = \mathcal{N}_S \left[\frac{-g_\kappa}{(m_\kappa - i\Gamma_\kappa/2)^2 - p^2} + \frac{1}{(m_{K_0^*} - i\Gamma_{K_0^*}/2)^2 - p^2} \right]$$

$|g_\kappa| = 0.2$, $\text{Arg}(g_\kappa) = \pi/2$, [Becirevic and Tayduganov, Nucl. Phys. B868, 368]

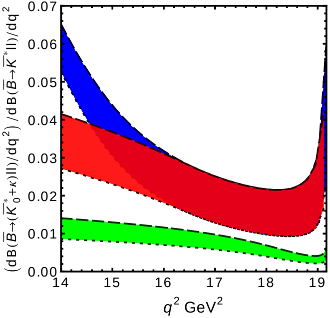

Figure: $[d\mathcal{B}(\bar{B} \to (\bar{K}_0^*(1430) + \kappa)\ell\ell)/dq^2]/[d\mathcal{B}(\bar{B} \to \bar{K}^*\ell\ell)/dq^2]$ in SM without p^2 cut (blue), in S+P wave window (red) and in P-wave signal window (green). The bands are obtained by varying $|g_\kappa| \in [0, 0.2]$ and $\text{Arg}(g_\kappa) \in [\pi/2, \pi]$. The maximum contribution is obtained for $|g_\kappa| = 0.2$, $\text{Arg}(g_\kappa) = \pi/2$ (dashed lines). For $g_\kappa = 0$ the lower edge of the band(dotted lines) is obtained.

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

Endpoint relations

[Hiller and Zwicky, JHEP 1403 (2014) 042]

– Kinematic endpoint correspond to $q^2 = q^2_{max} = (m_B - \sqrt{p^2})^2$ at fixed p^2

– Only F_0 and $F_{||}$ survive and dominated by P-wave amplitudes

$$I_3 = -\frac{I_1 + I_2}{2}, \quad I_4 = -\sqrt{\frac{(I_1 + I_2)(I_1 - 3I_2)}{2}}, \quad I_{5,6,7,8,9} = 0$$

$$\frac{d^3\Gamma}{dp^2 dq^2 d\cos\theta_K} / (\frac{d^2\Gamma}{dp^2 dq^2})|_{endpoint} = \frac{1}{2},$$

$$\frac{d^3\Gamma}{dp^2 dq^2 d\cos\theta_l} / (\frac{d^2\Gamma}{dp^2 dq^2})|_{endpoint} = \frac{1}{2},$$

$$\frac{d^3\Gamma}{dp^2 dq^2 d\cos\phi} / (\frac{d^2\Gamma}{dp^2 dq^2})|_{endpoint} = \frac{1}{2\pi}(1 - \frac{1}{3}\cos 2\phi),$$

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

$$F_L\Big|_{\text{endpoint}} = \frac{1}{3},$$ [Hiller and Zwicky, JHEP 1403 (2014) 042]

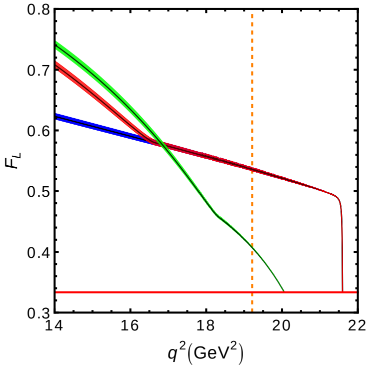

Figure: Angular observable F_L in SM for $\bar{B} \to \bar{K}\pi\ell\ell$ in the P-wave signal window(green), S+P window (red) and without any p^2-cut (blue). The vertical dashed line correspond to $K^*(892)$ end point and the horizontal line is $1/3$. Uncertainties cancel to a large extent in ratio.

[DD, Hiller, Jung, Shires, arXiv: 1406.****, DO-TH 14/10]

Summary

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

–$\bar{B} \to \bar{K}\pi\ell\ell$ could be a viable rare signal.

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

–Improved Isgur-Wise relations between the vector and tensor current.

–Endpoint relations for $\bar{B} \to \bar{K}\pi\ell\ell$ decay.

Ongoing analysis for $\bar{B} \to \bar{K}K\ell\ell$ corresponding to $B_s \to \phi(\to \bar{K}K)\ell\ell$.

thank you