Angular Distribution of polarised Λ_b decay with NP operators

Based on the paper "Phys. Rev. D 104 (2021) 1, 013002" in collab. with Dr. Diganta Das

Ria Sain

Delhi University
and
Institute of Mathematical Sciences, Chennai

August 27, 2021

Motivation

- In recent years, special attention has been given in the semileptonic $b \to s\ell^+\ell^-$ decays.
- In the rare decay $B \to K^{(*)}\ell^+\ell^-$ involves a $b \to s$ flavor changing loop induced transition at the quark level making it sensitive to physics beyond the Standard Model.

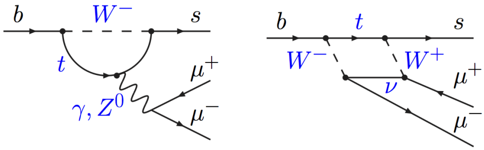


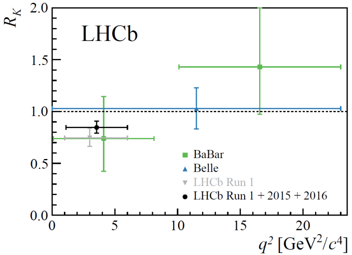
Figure: quark level diagram for $b \to s\ell^+\ell^-$ decay

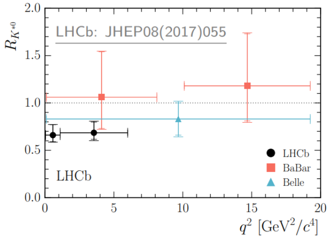
$b \to s\ell^+\ell^-$ decay

- There are several discrepancies observed when compared to the SM predictions, among these, $R_{K^{(*)}}$, the ratio of the differential decay rate $d(B \to K^{(*)}\ell^+\ell^-)/dq^2$, for $\ell = \mu$ and e, has generated a great deal of interest.
- $R_{K^{(*)}}$ is defined within a given range of the dilepton mass squared $q^2_{\rm min}$ to $q^2_{\rm max}$ as,

$$R_{K^{(*)}} = \frac{\displaystyle\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\Gamma(B \to K^{(*)}\mu^+\mu^-)}{dq^2} dq^2}{\displaystyle\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{d\Gamma(B \to K^{(*)}e^+e^-)}{dq^2} dq^2} \qquad (1)$$

Flavor Anomaly





The measured R_K and R_{K^*}, lie systematically below the SM expectations:

$$R_K(q^2 \in [1.1:6]\,\mathrm{GeV}^2) = 0.846^{+0.060+0.016}_{-0.054-0.014} \to 2.5\sigma \text{ from SM},$$
$$R_{K^*}(q^2 \in [0.045:1.1]\,\mathrm{GeV}^2) = 0.660^{+0.110}_{-0.070} \pm 0.024 \to 2.1\sigma \text{ from SM},$$
$$R_{K^*}(q^2 \in [1.1:6]\,\mathrm{GeV}^2) = 0.685^{+0.113}_{-0.069} \pm 0.047 \to 2.4\sigma \text{ from SM}.$$

Flavor Anomaly

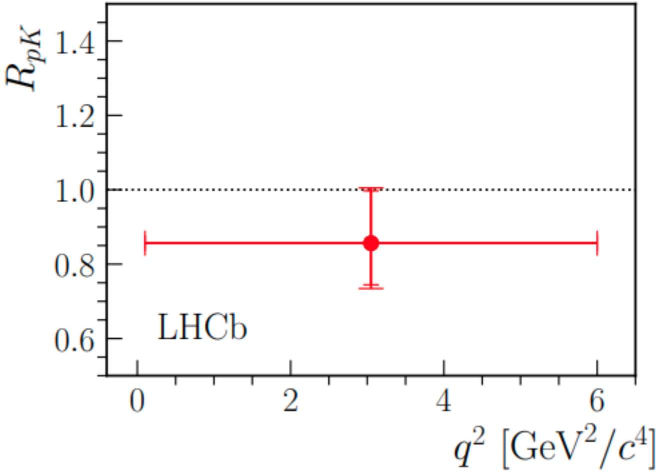


Figure: Lepton Universality ratio R_{pK} for $\Lambda_b \to pK\ell^+\ell^-$ at $4.7 fb^{-1}$
JHEP05(2020)040

Motivation for $\Lambda_b \to \Lambda \ell^+ \ell^-$ decay

- Among the other $b \to s\ell^+\ell^-$ processes, the baryonic decay mode $\Lambda_b \to \Lambda \ell^+ \ell^-$ can provide complementary phenomenological information
- since the weak decay of daughter $\Lambda \to p\pi$, $\implies$ additional angular observables not present in B decay
- In contrast to spin-0 B, the Λ_b has spin-$\frac{1}{2}$, $\implies$ polarised Λ_b $\implies$ increasing significantly the number of angular observables.

In the SM the rare $b \to s\ell^+\ell^-$ transition proceeds through loop diagrams which are described by

$$\mathcal{O}_7 = \frac{m_b}{e}\left[\bar{s}\sigma^{\mu\nu}P_R b\right]F_{\mu\nu}\,, \mathcal{O}_9 = \left[\bar{s}\gamma^{\mu}P_L b\right]\left[\ell\gamma_\mu\ell\right]\,,$$
$$\mathcal{O}_{10} = \left[\bar{s}\gamma^{\mu}P_L b\right]\left[\ell\gamma_\mu\gamma_5\ell\right]\,. \tag{2}$$

If we add new physics operators like the chiral operators and scalar operators

$$\mathcal{O}_{9'} = \left[\bar{s}\gamma^{\mu}P_R b\right]\left[\bar{\ell}\gamma_\mu\ell\right]\,, \mathcal{O}_{10'} = \left[\bar{s}\gamma^{\mu}P_R b\right]\left[\bar{\ell}\gamma_\mu\gamma_5\ell\right]$$
$$\mathcal{O}_{S^{(\prime)}} = \left[\bar{s}P_{R(L)}b\right]\left[\bar{\ell}\ell\right]\,, \mathcal{O}_{P^{(\prime)}} = \left[\bar{s}P_{R(L)}b\right]\left[\bar{\ell}\gamma_5\ell\right]. \tag{3}$$

The Wilson coefficients corresponding to $\mathcal{O}_{9',10'}$, $\mathcal{O}_{S^{(\prime)},P^{(\prime)}}$ are $\mathcal{C}_{9',10'}$ and $\mathcal{C}_{S^{(\prime)},P^{(\prime)}}$, respectively. The most general effective short distance effective Hamiltonian for $b \to s\ell^+\ell^-$ transition can be written as:

$$\mathcal{H}_{\rm eff} = -\frac{G_F}{\sqrt{2}}V_{tb}V_{ts}^{*}\sum_i\left[\mathcal{C}_i(\mu)O_i(\mu)\right] \tag{4}$$

$\Lambda_b \to \Lambda\mu^+\mu^-$: Matrix element

- Assuming factorization between the hadronic and leptonic parts, the amplitude of the decay process $\Lambda_b(p,s) \to \Lambda(p\prime, s')j_{eff}(\to \mu^+(q_+)\mu^-(q_-))$ can be written as -

$$\mathcal{M}^{\lambda_1,\lambda_2}(s,s') = -\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_{i=L,R} \sum_{\lambda} \left[\eta_\lambda H^{i,s,s'}_{\mathrm{VA},\lambda} L^{\lambda_1,\lambda_2}_{i,\lambda} + H^{i,s,s'}_{\mathrm{SP}} L^{\lambda_1,\lambda_2}_{i} \right] \tag{5}$$

- $p, p\prime, q_+, q_-$: momentum of $\Lambda_b, \Lambda, \mu^+, \mu^-$
- λ_1, λ_2: helicity of μ^+, μ^-
- $H^{i,s,s}$: the hadronic helicity amplitudes
- $L_i^{\lambda_1,\lambda_2}$: the leptonic amplitudes

Form-factors

The matrix elements are parametrized by the following 10 form-factors (f_i's):

$$\langle\Lambda(p',s')|\bar{s}\,\gamma^\mu\,b|\Lambda_b(p,s)\rangle =$$
$$\bar{u}_\Lambda(p',s')\Big[f_0(q^2)\,(m_{\Lambda_b}-m_\Lambda)\frac{q^\mu}{q^2} \qquad + f_+(q^2)\frac{m_{\Lambda_b}+m_\Lambda}{s_+}\left(p^\mu+p'^\mu-(m^2_{\Lambda_b}-m^2_\Lambda)\frac{q^\mu}{q^2}\right)$$
$$+ f_\perp(q^2)\left(\gamma^\mu-\frac{2m_\Lambda}{s_+}p^\mu-\frac{2m_{\Lambda_b}}{s_+}p'^\mu\right)\Big]u_{\Lambda_b}(p,s),$$
$$\langle\Lambda(p',s')|\bar{s}\,\gamma^\mu\gamma_5\,b|\Lambda_b(p,s)\rangle =$$
$$-\,\bar{u}_\Lambda(p',s')\,\gamma_5\Big[g_0(q^2)\,(m_{\Lambda_b}+m_\Lambda)\frac{q^\mu}{q^2} \qquad + g_+(q^2)\frac{m_{\Lambda_b}-m_\Lambda}{s_-}\left(p^\mu+p'^\mu-(m^2_{\Lambda_b}-m^2_\Lambda)\frac{q^\mu}{q^2}\right)$$
$$+ g_\perp(q^2)\left(\gamma^\mu+\frac{2m_\Lambda}{s_-}p^\mu-\frac{2m_{\Lambda_b}}{s_-}p'^\mu\right)\Big]u_{\Lambda_b}(p,s),$$
$$\langle\Lambda(p',s')|\bar{s}\,i\sigma^{\mu\nu}q_\nu\,b|\Lambda_b(p,s)\rangle = -\bar{u}_\Lambda(p',s')\Big[h_+(q^2)\frac{q^2}{s_+}\left(p^\mu+p'^\mu-(m^2_{\Lambda_b}-m^2_\Lambda)\frac{q^\mu}{q^2}\right)$$
$$+ h_\perp(q^2)\,(m_{\Lambda_b}+m_\Lambda)\left(\gamma^\mu-\frac{2m_\Lambda}{s_+}\,p^\mu-\frac{2m_{\Lambda_b}}{s_+}\,p'^\mu\right)\Big]u_{\Lambda_b}(p,s),$$
$$\langle\Lambda(p',s')|\bar{s}\,i\sigma^{\mu\nu}q_\nu\gamma_5\,b|\Lambda_b(p,s)\rangle = -\bar{u}_\Lambda(p',s')\,\gamma_5\Big[\widetilde{h}_+(q^2)\,\frac{q^2}{s_-}\left(p^\mu+p'^\mu-(m^2_{\Lambda_b}-m^2_\Lambda)\frac{q^\mu}{q^2}\right)$$
$$+ \widetilde{h}_\perp(q^2)\,(m_{\Lambda_b}-m_\Lambda)\left(\gamma^\mu+\frac{2m_\Lambda}{s_-}\,p^\mu-\frac{2m_{\Lambda_b}}{s_-}\,p'^\mu\right)\Big]u_{\Lambda_b}(p,s),$$

$\Lambda \to p\pi$ matrix element

The secondary weak decay is governed by the Hamiltonian

$$H^{\text{eff}}_{\Delta S=1} = \frac{4G_F}{\sqrt{2}} V^*_{ud} V_{us} [\bar{d}\gamma_\mu P_L u][\bar{u}\gamma^\mu P_L s] \,. \tag{6}$$

The $\Lambda(k, s_\Lambda) \to p(k_1, s_p)\pi(k_2)$ matrix elements are parametrized as

$$\begin{aligned} H_2(s_\Lambda, s_p) &\equiv \langle p(k_1, s_p)\pi^-(k_2)| \left[\bar{d}\gamma_\mu P_L u\right] [\bar{u}\gamma^\mu P_L s] \,|\Lambda(k, s_\Lambda)\rangle \\ &= \left[\bar{u}(k_1, s_p)(\xi\,\gamma_5 + \omega)\,u(k, s_\Lambda)\right] . \end{aligned} \tag{7}$$

In the final distribution only the parity violating parameter is relevant

$$\alpha_\Lambda = \frac{-2\mathrm{Re}(\omega\xi)}{\sqrt{\frac{r_-}{r_+}}|\xi|^2 + \sqrt{\frac{r_+}{r_-}}|\omega|^2} \equiv \alpha^{\text{exp}} \,. \tag{8}$$

- for this decay define the angles θ_b and ϕ_b are made by the proton in the Λ rest frame.

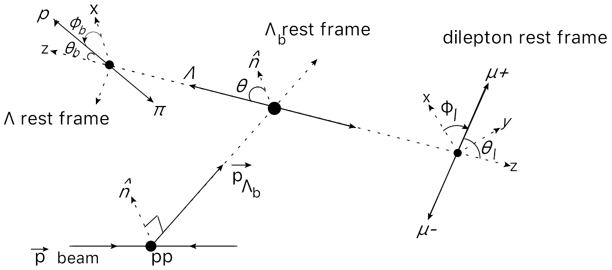
Polarisation of Λ_b

- when polarization of the initial Λ_b is considered, define a normal vector $\hat{n} = \hat{p}_{\rm beam}^{\{\rm lab\}} \times \hat{p}_{\Lambda_b}^{\{\rm lab\}}$ where $\hat{p}_{\rm beam}^{\{\rm lab\}}, \hat{p}_{\Lambda_b}^{\{\rm lab\}}$ are unit vectors in the lab frame.
- The polarisation angle θ between the $\hat{n}$ and the direction of Λ, in the Λ_b rest frame is defined as $\cos\theta = \hat{n}.\hat{p}_{\Lambda}^{\{\Lambda_b\}}$.
- The polarisation $\implies$ the density matrix which is defined as

$$\rho_{\lambda,\lambda'} = \frac{1}{2}\begin{pmatrix} 1 + P_{\Lambda_b}\cos\theta & P_{\Lambda_b}\sin\theta \\ P_{\Lambda_b}\sin\theta & 1 - P_{\Lambda_b}\cos\theta \end{pmatrix} , \quad (9)$$

where P_{Λ_b} is the polarization of the parent baryon Λ_b.

The Notation



The lab frame and the 3 rest frames are shown.

Leptonic Matrix Element

The leptonic helicity amplitudes are defined as

$$L^{\lambda_1\lambda_2}_{L(R)} = \langle\bar{\ell}(\lambda_1)\ell(\lambda_2)|\bar{\ell}(1\mp\gamma_5)\ell|0\rangle\,, \quad (10)$$

$$L^{\lambda_1\lambda_2}_{L(R),\lambda} = \bar{\epsilon}^{\mu}(\lambda)\langle\bar{\ell}(\lambda_1)\ell(\lambda_2)|\bar{\ell}\gamma_\mu(1\mp\gamma_5)\ell|0\rangle\,, \quad (11)$$

- where ϵ^{μ} is the polarization of the virtual gauge boson that decays to the dilepton pair.
- $L^{\lambda_1,\lambda_2}_{L(R),\lambda}$, calculated in the dilepton rest frame, in terms of the angles θ_ℓ and ϕ_ℓ are made by the μ^+

We convert the helicity amplitudes to tranversity amplitudes and for SM+SM′ set of operators the transversity amplitudes are

$$\begin{aligned}
A_{\perp_1}^{L,(R)} &= -\sqrt{2}N\left(f_\perp^V\sqrt{2s_-}\mathcal{C}_{\mathrm{VA}+}^{L,(R)} + \frac{2m_b}{q^2}f_\perp^T(m_{\Lambda_b}+m_\Lambda)\sqrt{2s_-}\mathcal{C}_7^{\mathrm{eff}}\right),\\
A_{\parallel_1}^{L,(R)} &= \sqrt{2}N\left(f_\perp^A\sqrt{2s_+}\mathcal{C}_{\mathrm{VA}-}^{L,(R)} + \frac{2m_b}{q^2}f_\perp^{T5}(m_{\Lambda_b}-m_\Lambda)\sqrt{2s_+}\mathcal{C}_7^{\mathrm{eff}}\right),\\
A_{\perp_0}^{L,(R)} &= \sqrt{2}N\left(f_0^V(m_{\Lambda_b}+m_\Lambda)\sqrt{\frac{s_-}{q^2}}\mathcal{C}_{\mathrm{VA}+}^{L,(R)} + \frac{2m_b}{q^2}f_0^T\sqrt{q^2s_-}\mathcal{C}_7^{\mathrm{eff}}\right),\\
A_{\parallel_0}^{L,(R)} &= -\sqrt{2}N\left(f_0^A(m_{\Lambda_b}-m_\Lambda)\sqrt{\frac{s_+}{q^2}}\mathcal{C}_{\mathrm{VA}-}^{L,(R)} + \frac{2m_b}{q^2}f_0^{T5}\sqrt{q^2s_+}\mathcal{C}_7^{\mathrm{eff}}\right),\\
A_{\perp t} &= -2\sqrt{2}N(\mathcal{C}_{10}+\mathcal{C}_{10'})(m_{\Lambda_b}-m_\Lambda)\sqrt{\frac{s_+}{q^2}}f_t^V,\\
A_{\parallel t} &= 2\sqrt{2}N(\mathcal{C}_{10}-\mathcal{C}_{10'})(m_{\Lambda_b}+m_\Lambda)\sqrt{\frac{s_-}{q^2}}f_t^A,
\end{aligned}$$

for scalar and pseudoscalar amplitudes

$$\begin{aligned}
A_{\perp \mathrm{S}}^{L(R)} &= \sqrt{2}Nf_t^V\frac{m_{\Lambda_b}-m_\Lambda}{m_b-m_s}\mathcal{C}_{\mathrm{SP}+}^{L(R)},\\
A_{\parallel \mathrm{S}}^{L(R)} &= -\sqrt{2}Nf_t^A\frac{m_{\Lambda_b}+m_\Lambda}{m_b+m_s}\mathcal{C}_{\mathrm{SP}-}^{L(R)},
\end{aligned}$$

Pol. Λ_b full angular distribution

the decay distribution can be expressed in terms of angular observables as

$$
\begin{aligned}
\frac{\mathrm{d}^6\mathcal{B}}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}(\theta_\ell,\phi_\ell,\theta_b,\phi_b,\theta)} = \frac{3}{32\pi^2}\Big(& \left(K_1\sin^2\theta_\ell + K_2\cos^2\theta_\ell + K_3\cos\theta_\ell\right) + \\
& \left(K_4\sin^2\theta_\ell + K_5\cos^2\theta_\ell + K_6\cos\theta_\ell\right)\cos\theta_b + \\
& \left(K_7\sin\theta_\ell\cos\theta_\ell + K_8\sin\theta_\ell\right)\sin\theta_b\cos\left(\phi_b+\phi_\ell\right) + \\
& \left(K_9\sin\theta_\ell\cos\theta_\ell + K_{10}\sin\theta_\ell\right)\sin\theta_b\sin\left(\phi_b+\phi_\ell\right) + \\
& \left(K_{11}\sin^2\theta_\ell + K_{12}\cos^2\theta_\ell + K_{13}\cos\theta_\ell\right)\cos\theta + \\
& \left(K_{14}\sin^2\theta_\ell + K_{15}\cos^2\theta_\ell + K_{16}\cos\theta_\ell\right)\cos\theta_b\cos\theta + \\
& \left(K_{17}\sin\theta_\ell\cos\theta_\ell + K_{18}\sin\theta_\ell\right)\sin\theta_b\cos\left(\phi_b+\phi_\ell\right)\cos\theta + \\
& \left(K_{19}\sin\theta_\ell\cos\theta_\ell + K_{20}\sin\theta_\ell\right)\sin\theta_b\sin\left(\phi_b+\phi_\ell\right)\cos\theta + \\
& \left(K_{21}\cos\theta_\ell\sin\theta_\ell + K_{22}\sin\theta_\ell\right)\sin\phi_\ell\sin\theta + \\
& \left(K_{23}\cos\theta_\ell\sin\theta_\ell + K_{24}\sin\theta_\ell\right)\cos\phi_\ell\sin\theta + \\
& \left(K_{25}\cos\theta_\ell\sin\theta_\ell + K_{26}\sin\theta_\ell\right)\sin\phi_\ell\cos\theta_b\sin\theta + \\
& \left(K_{27}\cos\theta_\ell\sin\theta_\ell + K_{28}\sin\theta_\ell\right)\cos\phi_\ell\cos\theta_b\sin\theta + \\
& \left(K_{29}\cos^2\theta_\ell + K_{30}\sin^2\theta_\ell + K_{35}\cos\theta_\ell\right)\sin\theta_b\sin\phi_b\sin\theta + \\
& \left(K_{31}\cos^2\theta_\ell + K_{32}\sin^2\theta_\ell + K_{36}\cos\theta_\ell\right)\sin\theta_b\cos\phi_b\sin\theta + \\
& \left(K_{33}\sin^2\theta_\ell\right)\sin\theta_b\cos\left(2\phi_\ell+\phi_b\right)\sin\theta + \\
& \left(K_{34}\sin^2\theta_\ell\right)\sin\theta_b\sin\left(2\phi_\ell+\phi_b\right)\sin\theta\Big). \qquad (3.1)
\end{aligned}
$$

Angular Co-efficient

Since we have retained the masses of the final state leptons, we write each of the K_i's as

$$K_{\{\dots\}} = \mathcal{K}_{\{\dots\}} + \frac{m_\ell}{\sqrt{q^2}}\mathcal{K}'_{\{\dots\}} + \frac{m_\ell^2}{q^2}\mathcal{K}''_{\{\dots\}}\,. \qquad (12)$$

The each angular co-efficient looks like, for example:

$$\begin{aligned}
\mathcal{K}_{11} &= \frac{P_{\Lambda_b}}{2}\mathrm{Re}\Big(2A^R_{\|_0}A^{*R}_{\perp_0} - A^R_{\|_1}A^{*R}_{\perp_1} + \{R \leftrightarrow L\} \\
&\quad + 2A^R_{\mathrm{S}\perp}A^{*R}_{\mathrm{S}\|} + \{R \leftrightarrow L\}\Big)\,, \\
\mathcal{K}'_{11} &= P_{\Lambda_b}\mathrm{Re}\Big(A^R_{\mathrm{S}\perp}A^*_{\|t} + A^R_{\mathrm{S}\|}A^*_{\perp t} - \{R \leftrightarrow L\}\Big)\,, \\
\mathcal{K}''_{11} &= -2P_{\Lambda_b}\mathrm{Re}\Big(A^R_{\|_0}A^{*R}_{\perp_0} + A^R_{\mathrm{S}\perp}A^{*R}_{\mathrm{S}\|} + \{R \leftrightarrow L\} - A_{\perp t}A^*_{\|t} \\
&\quad + (A^R_{\|_1}A^{*L}_{\perp_1} - A^R_{\|_0}A^{*L}_{\perp_0} + A^L_{\mathrm{S}\perp}A^{*R}_{\mathrm{S}\|} + \{\| \leftrightarrow \perp\})\Big)\,,
\end{aligned}$$

Angular Co-efficient

- including the scalar and pseudoscalar these actually introduce 2 more angular co-efficients which are

$$K_{35}\cos\theta_\ell \sin\theta_b \sin\phi_b \sin\theta$$
$$K_{36}\cos\theta_\ell \sin\theta_b \cos\phi_b \sin\theta \tag{13}$$

- Integrations over the angles give differential decay distribution

$$\frac{d\mathcal{B}}{dq^2} = 2K_1 + K_2\,. \tag{14}$$

- This is used to define normalized observables as

$$M_i = \frac{K_i}{d\mathcal{B}/dq^2}\,, \tag{15}$$

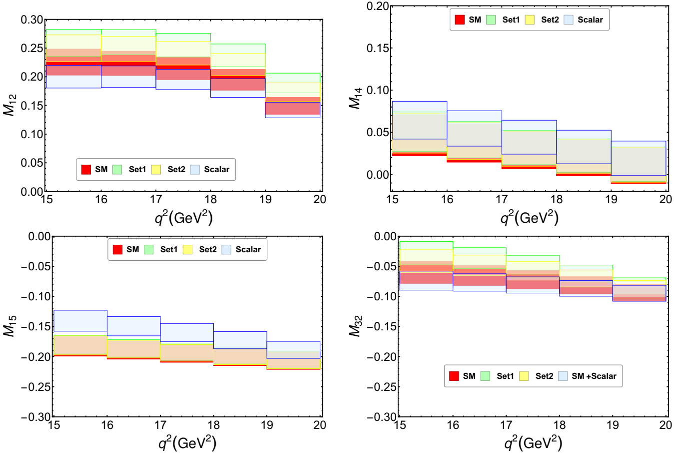
Pol. Λ_b Latest measument from LHCb

Recently LHCb has measured full angular distribution of polarised Λ_b in [JHEP 09 (2018)] in $15 < q^2 < 20 GeV^2$ bin.

TABLE III: Angular observables combining the results of the moments obtained from Run 1 and Run 2 data The first and second uncertainties are statistical and systematic, respectively.

Obs.	Value	Obs.	Value
K_1	$0.346 \pm 0.020 \pm 0.004$	K_{18}	$-0.108 \pm 0.058 \pm 0.008$
K_2	$0.308 \pm 0.040 \pm 0.008$	K_{19}	$-0.151 \pm 0.122 \pm 0.022$
K_3	$-0.261 \pm 0.029 \pm 0.006$	K_{20}	$-0.116 \pm 0.056 \pm 0.008$
K_4	$-0.176 \pm 0.046 \pm 0.016$	K_{21}	$-0.041 \pm 0.105 \pm 0.020$
K_5	$-0.251 \pm 0.081 \pm 0.016$	K_{22}	$-0.014 \pm 0.045 \pm 0.007$
K_6	$0.329 \pm 0.055 \pm 0.012$	K_{23}	$-0.024 \pm 0.077 \pm 0.012$
K_7	$-0.015 \pm 0.084 \pm 0.013$	K_{24}	$0.005 \pm 0.033 \pm 0.005$
K_8	$-0.099 \pm 0.037 \pm 0.012$	K_{25}	$-0.226 \pm 0.176 \pm 0.030$
K_9	$0.005 \pm 0.084 \pm 0.012$	K_{26}	$0.140 \pm 0.074 \pm 0.014$
K_{10}	$-0.045 \pm 0.037 \pm 0.006$	K_{27}	$0.016 \pm 0.140 \pm 0.025$
K_{11}	$-0.007 \pm 0.043 \pm 0.009$	K_{28}	$0.032 \pm 0.058 \pm 0.009$
K_{12}	$-0.009 \pm 0.063 \pm 0.014$	K_{29}	$-0.127 \pm 0.097 \pm 0.016$
K_{13}	$0.024 \pm 0.045 \pm 0.010$	K_{30}	$0.011 \pm 0.061 \pm 0.011$
K_{14}	$0.010 \pm 0.082 \pm 0.013$	K_{31}	$0.180 \pm 0.094 \pm 0.015$
K_{15}	$0.158 \pm 0.117 \pm 0.027$	K_{32}	$-0.009 \pm 0.055 \pm 0.008$
K_{16}	$0.050 \pm 0.084 \pm 0.023$	K_{33}	$0.022 \pm 0.060 \pm 0.009$
K_{17}	$-0.000 \pm 0.120 \pm 0.022$	K_{34}	$0.060 \pm 0.058 \pm 0.009$

Polarized Λ_b baryon decay



Here we show how the polarised observables behave in SM and in presence of Scalar and Pseudo scalar operators.

HQET simplifiaction

Including one-loop corrections to the Isgur-Wise relations, the transversity amplitudes read [Boer et al. 2014]

$$A_{\perp_1}^{L(R)} \simeq -2N\mathcal{C}_+^{L(R)}\sqrt{s_-}f_\perp^V\,, \qquad A_{\|_1}^{L(R)} = 2N\mathcal{C}_-^{L(R)}\sqrt{s_+}f_\perp^A\,, \quad (16)$$

$$A_{\perp_0}^{L(R)} \simeq \sqrt{2}N\mathcal{C}_+^{L(R)}\frac{m_{\Lambda_b}+m_\Lambda}{\sqrt{q^2}}\sqrt{s_-}f_0^V\,, \quad (17)$$

$$A_{\|_0}^{L(R)} \simeq -\sqrt{2}N\mathcal{C}_+^{L(R)}\frac{m_{\Lambda_b}-m_\Lambda}{\sqrt{q^2}}\sqrt{s_+}f_0^A\,, \quad (18)$$

where the Wilson coefficients are given by

$$\mathcal{C}_+^{L(R)} = \left((\mathcal{C}_9+\mathcal{C}_{9'}) \mp (\mathcal{C}_{10}+\mathcal{C}_{10'}) + \frac{2\kappa m_b m_{\Lambda_b}}{q^2}\mathcal{C}_7\right),$$
$$\mathcal{C}_-^{L(R)} = \left((\mathcal{C}_9-\mathcal{C}_{9'}) \mp (\mathcal{C}_{10}-\mathcal{C}_{10'}) + \frac{2\kappa m_b m_{\Lambda_b}}{q^2}\mathcal{C}_7\right).$$

The parameter $\kappa \equiv \kappa(\mu) = 1-(\alpha_s C_F/2\pi)\ln(\mu/m_b)$ accounts for the radiative QCD corrections to the form factors relations.

HQET notation for WC

- The simplifications of the transversity amplitudes yield factorizations between short- and long-distance physics in the angular observables.
- In the factorized expressions, the vector and axial-vector Wilson coefficient contributes through the following short-distance coefficients [Boer et al. 2014]

$$\begin{aligned}
\rho_1^{\pm} &= \frac{1}{2}\left(|\mathcal{C}_{\pm}^{R}|^2 + |\mathcal{C}_{\pm}^{L}|^2\right) = |\mathcal{C}_{79} \pm \mathcal{C}_{9'}|^2 + |\mathcal{C}_{10} \pm \mathcal{C}_{10'}|^2 \,, \\
\rho_2 &= \frac{1}{4}\left(\mathcal{C}_{+}^{R}\mathcal{C}_{-}^{R*} - \mathcal{C}_{-}^{L}\mathcal{C}_{+}^{L*}\right) = \mathrm{Re}(\mathcal{C}_{79}\mathcal{C}_{10}^{*} - \mathcal{C}_{9'}\mathcal{C}_{10'}^{*}) - i\mathrm{Im}(\mathcal{C}_{79}\mathcal{C}_{9'}^{*} + \mathcal{C}_{10}\mathcal{C}_{10'}^{*}) \,. \\
\rho_3^{\pm} &= \frac{1}{2}\left(|\mathcal{C}_{\pm}^{R}|^2 - |\mathcal{C}_{\pm}^{L}|^2\right) = 2\,\mathrm{Re}(\mathcal{C}_{79} \pm \mathcal{C}_{9'})(\mathcal{C}_{10} \pm \mathcal{C}_{10'})^{*} \\
\rho_4 &= \frac{1}{4}\left(\mathcal{C}_{+}^{R}\mathcal{C}_{-}^{R*} + \mathcal{C}_{-}^{L}\mathcal{C}_{+}^{L*}\right) \\
&= \left(|\mathcal{C}_{79}|^2 - |\mathcal{C}_{9'}|^2 + |\mathcal{C}_{10}|^2 - |\mathcal{C}_{10'}|^2\right) - i\mathrm{Im}\mathcal{C}_{79}\,\mathcal{C}_{10'}^{*} - \mathcal{C}_{9'}\,\mathcal{C}_{10}^{*} \,,
\end{aligned}$$

for scalars:

$$\begin{aligned}
\rho_{\mathrm{S}}^{\pm} &= |\mathcal{C}_{\mathrm{SP}\pm}^{L}|^2 + |\mathcal{C}_{\mathrm{SP}\pm}^{R}|^2 \,, \\
\rho_{\mathrm{S1}} &= 2(\mathcal{C}_{\mathrm{SP}+}^{L}\mathcal{C}_{\mathrm{SP}-}^{L*} + \mathcal{C}_{\mathrm{SP}+}^{R}\mathcal{C}_{\mathrm{SP}-}^{R*}) \,.
\end{aligned}$$

Null tests

- If the SP operators are absent, then this ratio is equal to $\mathrm{Re}(\rho_2)/\alpha_\Lambda \mathrm{Re}(\rho_4)$.

$$\frac{K_3}{K_5} = -\frac{16 m_b^2 f_\perp^A f_\perp^V \mathrm{Re}(\rho_2)}{16\alpha_\Lambda m_b^2 f_\perp^A f_\perp^V \mathrm{Re}(\rho_4) + \alpha_\Lambda (m_{\Lambda_b}^2 - m_\Lambda^2) f_t^A f_t^V \mathrm{Re}(\rho_{\mathrm{S1}})}. \quad (19)$$

- the ratios K_5/K_7 independent of any short distance physics but are modified in the presence of SP operators as

$$\frac{K_5}{K_7} = \frac{\sqrt{q^2}\left[32 f_\perp^A f_\perp^V \mathrm{Re}(\rho_4) + (m_{\Lambda_b}^2 - m_\Lambda^2) f_t^A f_t^V \mathrm{Re}(\rho_{\mathrm{S1}})\right]}{16 m_b^2 \mathrm{Re}(\rho_4)\left[(m_{\Lambda_b} + m_\Lambda) f_\perp^A f_0^V - (m_{\Lambda_b} - m_\Lambda) f_0^A f_\perp^V\right]}, \quad (20)$$

Null tests

- The ratio K_5/K_{23} is independent of any short distance physics in SM but modified in the presence of SP operators :

$$\frac{K_5}{K_{23}} = \frac{\sqrt{q^2}\Big[32 f_\perp^A f_\perp^V \mathrm{Re}(\rho_4) + (m_{\Lambda_b}^2 - m_\Lambda^2) f_t^A f_t^V \mathrm{Re}(\rho_{\mathrm{S1}})\Big]}{16 m_b^2 P_{\Lambda_b} \mathrm{Re}(\rho_4)\Big[(m_{\Lambda_b} + m_{\Lambda_b}) f_\perp^A f_0^V + (m_{\Lambda_b} - m_\Lambda) f_0^A f_\perp^V\Big]} . \tag{21}$$

- We find another null test of $\rho_{\mathrm{S}\pm}$ from the following combination

$$K_2 + \frac{K_{15}}{P_{\Lambda_b}\alpha_\Lambda} = 2\left(|f_t^V|^2 s_+ \frac{(m_{\Lambda_b} - m_\Lambda)^2}{m_b^2}\rho_{\mathrm{S}}^+ + |f_t^A|^2 s_- \frac{(m_{\Lambda_b} + m_\Lambda)^2}{m_b^2}\rho_{\mathrm{S}}^-\right) . \tag{22}$$

Polarized Λ_b baryon decay

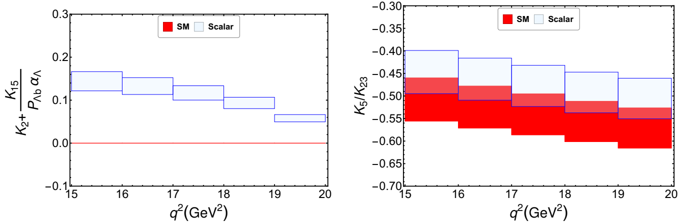


Figure: These plots show how these new found observables can be used to distinguish NP scalar operators from the scenario where only SM operators are present.

Polarized Λ_b baryon decay: Summary

- In this work we have done the full angular distribution of Pol. Λ_b taking the full kinematics and retaining the lepton mass.
- the distribution is done with SM operators along with Chirality flipped counterparts and Scalar and Pseudo scalar operators.
- Applying HQET framework valid in high q^2 region we obtain factorization of long and short-distance physics in the angular observables.
- we construct several tests of form factors and Wilson coefficients, including some null test of the Standard Model and its chirality flipped counterparts.
- Our analysis shows that new insight to $b \to s\ell^+\ell^-$ transition can be obtained from this mode.

Conclusion

Thank you!

Backup slides: Expected experimental precision

Obs.	Run 1 + Run 2	$50fb^{-1}$	$300fb^{-1}$	Obs.	Run 1 + Run 2	$50fb^{-1}$	$300fb^{-1}$
M_1	0.020	0.006	0.002	M_{18}	0.058	0.017	0.007
M_2	0.040	0.011	0.005	M_{19}	0.122	0.035	0.014
M_3	0.029	0.008	0.0033	M_{20}	0.056	0.016	0.006
M_4	0.046	0.013	0.0052	M_{21}	0.105	0.030	0.012
M_5	0.081	0.023	0.009	M_{22}	0.045	0.013	0.005
M_6	0.055	0.016	0.006	M_{23}	0.077	0.022	0.009
M_7	0.084	0.024	0.010	M_{24}	0.033	0.009	0.004
M_8	0.037	0.011	0.004	M_{25}	0.176	0.050	0.020
M_9	0.084	0.024	0.009	M_{26}	0.074	0.021	0.008
M_{10}	0.037	0.011	0.004	M_{27}	0.140	0.040	0.016
M_{11}	0.043	0.012	0.005	M_{28}	0.058	0.017	0.007
M_{12}	0.063	0.018	0.007	M_{29}	0.097	0.028	0.011
M_{13}	0.045	0.013	0.005	M_{30}	0.061	0.017	0.007
M_{14}	0.082	0.023	0.009	M_{31}	0.094	0.027	0.011
M_{15}	0.117	0.033	0.013	M_{32}	0.055	0.016	0.006
M_{16}	0.084	0.024	0.001	M_{33}	0.060	0.017	0.006
M_{17}	0.120	0.034	0.014	M_{34}	0.058	0.017	0.006

Figure: Expected experimental precision on the angular observables achievable at the future LHCb