Massless lepton in $B \to K^* \mu\mu$ at LHCb

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2.3.1 The first large-recoil bin [0.1,0.98]

The still limited statistics of LHCb data requires taking the limit of massless leptons for the determination of angular observables. The impact of this assumption is completely negligible in all bins except for the lowest bin [0.1,0.98]. Once included in the computation, the lepton mass yields a sizeable effect, pushing the SM prediction in the direction of data for P_2, $P'_{4,5}$ and F_L. Indeed, the first terms of the distribution at LHCb are given by

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^3(\Gamma+\bar{\Gamma})}{d\Omega} = \frac{9}{32\pi}\left[\frac{3}{4}(1-F_L^{\rm LHCb})\sin^2\theta_K + F_L^{\rm LHCb}\cos^2\theta_K \right. \left. + \frac{1}{4}(1-F_L^{\rm LHCb})\sin^2\theta_K\cos 2\theta_l - F_L^{\rm LHCb}\cos^2\theta_K\cos 2\theta_l + \ldots\right] \tag{32}$$

which is modified once lepton masses are considered [55]

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^3(\Gamma+\bar{\Gamma})}{d\Omega} = \frac{9}{32\pi}\left[\frac{3}{4}\hat{F}_T\sin^2\theta_K + \hat{F}_L\cos^2\theta_K \right. \left. + \frac{1}{4}F_T\sin^2\theta_K\cos 2\theta_l - F_L\cos^2\theta_K\cos 2\theta_l + \ldots\right] \tag{33}$$

where $\hat{F}_{T,L}$ and $F_{L,T}$ are detailed in Ref. [54] [8]. All our observables are thus written and computed in terms of the longitudinal and transverse polarisation fractions $F_{L,T}$

$$F_L = -\frac{J_{2c}}{d(\Gamma+\bar{\Gamma})/dq^2} \qquad F_T = 4\frac{J_{2s}}{d(\Gamma+\bar{\Gamma})/dq^2}\,. \tag{34}$$

However, LHCb measures F_L from the expression Eq. (32) without lepton masses, where the dominant term is the $\cos^2\theta_K$ term. This means that the experimental analysis actually extracts $\hat{F}_L$, where

$$\hat{F}_L = \frac{J_{1c}}{d(\Gamma+\bar{\Gamma})/dq^2}\,. \tag{35}$$

The difference between F_L and $\hat{F}_L$ has a negligible impact in all bins except for the bin [0.1,0.98]. We have recomputed the first bin of P_2, $P'_{4,5}$ using $\hat{F}_L$ instead of F_L and imposing the LHCb condition $\hat{F}_T = 1 - \hat{F}_L$. For these observables, the central value for

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The assumption $m_\mu = 0$ implies $F_L = F_T$, hence reduces statistical uncertainties

This assumption can be relaxed afterwards by noting that the distribution is dominated by a single term, that can be reinterpreted in the non zero mass hypothesis

Can we do better, from the same experimental analysis but maybe with more information made publicly available from it ?

Ratios of branching ratios

[Justine's examples]
$B_s \to \mu\mu$ at LCHb, 1703.05747

The signal branching fractions are measured with

$$\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-) = \frac{\mathcal{B}_{\rm norm}\,\epsilon_{\rm norm}\,f_{\rm norm}}{N_{\rm norm}\,\epsilon_{\rm sig}\,f_{d(s)}} \times N_{B^0_{(s)}\to\mu^+\mu^-} \equiv \alpha^{\rm norm}_{B^0_{(s)}\to\mu^+\mu^-} \times N_{B^0_{(s)}\to\mu^+\mu^-},$$

where $N_{B^0_{(s)}\to\mu^+\mu^-}$ is the number of observed signal decays, $N_{\rm norm}$ is the number of normalisation-channel decays ($B^+ \to J/\psi K^+$ and $B^0 \to K^+\pi^-$), $\mathcal{B}_{\rm norm}$ is the corresponding branching fraction [15], and $\epsilon_{\rm sig}$ ($\epsilon_{\rm norm}$) is the total efficiency for the signal (normalisation) channel. The fraction $f_{d(s)}$ indicates the probability for a b quark to fragment into a $B^0_{(s)}$ meson. Assuming $f_d = f_u$, the fragmentation probability $f_{\rm norm}$ for the B^0 and B^+ normalisation channel is set to f_d. The value of f_s/f_d in pp collision data at $\sqrt{s} = 7$ TeV has been measured by LHCb to be 0.259 ± 0.015 [25]. The stability of f_s/f_d at $\sqrt{s} = 8$ TeV and 13 TeV is evaluated by comparing the observed variation of the ratio of the efficiency-corrected yields of $B^0_s \to J/\psi\phi$ and $B^+ \to J/\psi K^+$ decays. The effect of increased collision energy is found to be negligible for data at $\sqrt{s} = 8$ TeV while a scaling factor of 1.068 ± 0.046 is applied for data at $\sqrt{s} = 13$ TeV.

The efficiency $\epsilon_{\rm sig(norm)}$ includes the detector acceptance, trigger, reconstruction and selection efficiencies of the final-state particles. The acceptance, reconstruction and selection efficiencies are computed with samples of simulated events whose decay-time distributions are generated according to the SM prediction. The tracking and particle identification efficiencies are determined using control channels in data [26, 27]. The trigger efficiencies are evaluated with data-driven techniques [28].

The numbers of $B^+ \to J/\psi K^+$ and $B^0 \to K^+\pi^-$ decays are $(1964.2 \pm 1.5) \times 10^3$ and $(31.3 \pm 0.4) \times 10^3$, respectively. The normalisation factors derived from the two channels are consistent. Taking correlations into account, their weighted averages are $\alpha^{\rm norm}_{B^0_s\to\mu^+\mu^-} = (5.7 \pm 0.4) \times 10^{-11}$ and $\alpha^{\rm norm}_{B^0\to\mu^+\mu^-} = (1.60 \pm 0.04) \times 10^{-11}$. In the SM scenario, the analysed data sample is expected to contain an average of 62 ± 6 $B^0_s \to \mu^+\mu^-$ and 6.7 ± 0.6 $B^0 \to \mu^+\mu^-$ decays in the full BDT range.

Ratios of branching ratios

[Justine's examples]

R_{pK} at LCHb, 19212.08139

Relying on the well-tested LU in $J/\psi \to \ell^+\ell^-$ decays [27], the measurement is performed as a double ratio of the branching fractions of the $\Lambda_b^0 \to pK^-\ell^+\ell^-$ and $\Lambda_b^0 \to pK^- J/\psi(\to \ell^+\ell^-)$ decays:

$$R_{pK}^{-1} = \frac{\mathcal{B}(\Lambda_b^0 \to pK^- e^+e^-)}{\mathcal{B}(\Lambda_b^0 \to pK^- J/\psi(\to e^+e^-))} \Bigg/ \frac{\mathcal{B}(\Lambda_b^0 \to pK^- \mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to pK^- J/\psi(\to \mu^+\mu^-))}\,, \qquad (2)$$

Q: what is the needed information needed to update these results following to improvement of external inputs ?