LFU: model dependence of the experimental measurements

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Beyond the Flavour Anomalies
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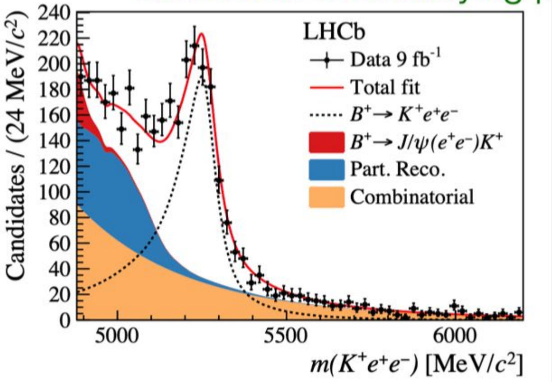
Measuring LFU ratios

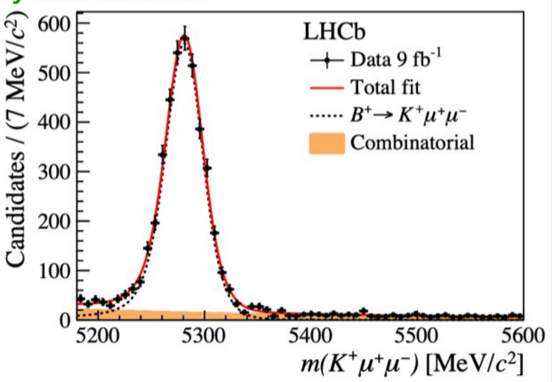
$$R_H = \left(\frac{1}{r_{J/\psi}}\right) \cdot \frac{N(B \to H^+ e^+ e^-)}{N(B \to H^+ \mu^+ \mu^-)} \cdot \frac{\varepsilon(B \to H e^+ e^-)}{\varepsilon(B \to H \mu^+ \mu^-)}$$

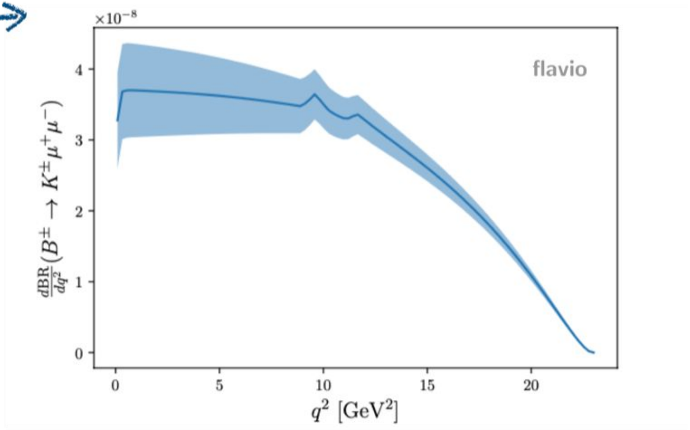
=1

Invariant mass shapes influenced by radiative corrections (QED) but otherwise not very correlated to underlying physics model

Efficiency calculation assumes SM differential decay rate
(SM uncertainty included as syst)
- q^2 spectrum
- angular distribution







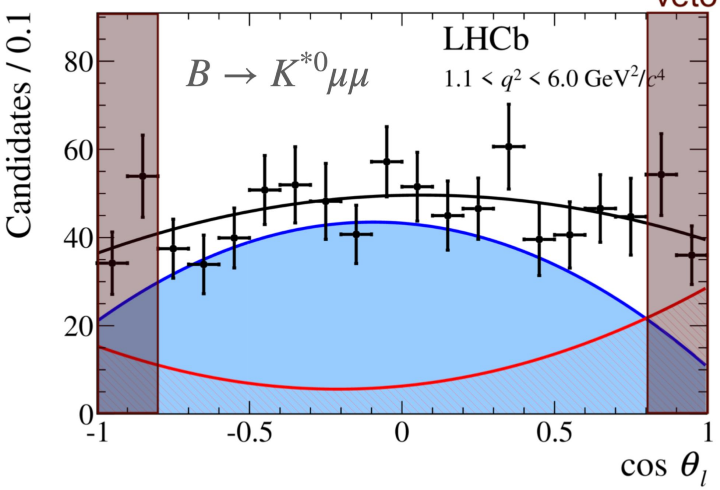
- For a null test of the SM, it does not matter
- But could this bias interpretation in terms of certain NP operators?

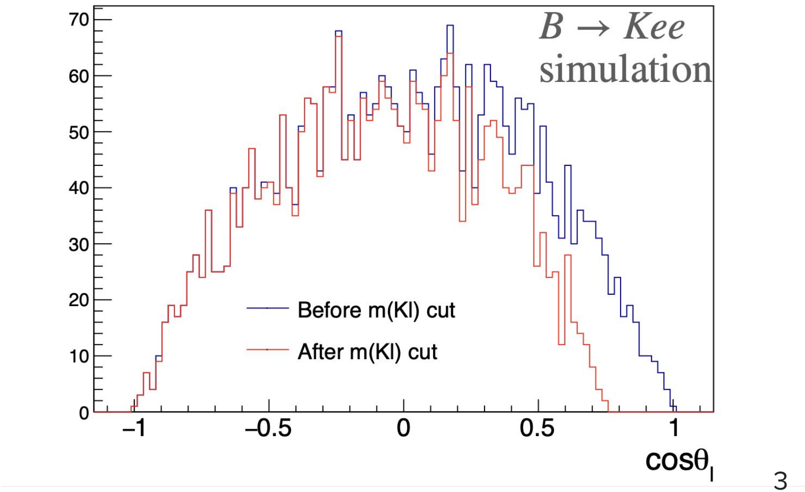
Signal selection

- The efficiency of the signal selection is not uniform
  - q^2 selection [1.1, 6] GeV^2/c^4
  - Cascade veto: To suppress background such as $B \to D^0(\to K^+\ell^-\nu)\ell^+\nu$
    - R(K): $m(K^+\ell^-) > m(D^0)$
    - R(K*): $|\cos\theta_\ell| < 0.8$
  - More complicated effects induced by trigger, PID, …

- How much/in what direction would R_K/R_{K^*} shift in a NP scenario?

[LHCb JHEP 02 (2016) 104]





The B→Kll Angular Distribution

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{3}{4}(1 - F_{\mathrm{H}})(1 - \cos^2\theta_l) + \frac{1}{2}F_{\mathrm{H}} + A_{\mathrm{FB}}\cos\theta_l$$

"Flat term"

- $F_H \backsimeq 0$ in the Standard Model
- Sensitive to (pseudo)scalar and tensor operators

Forward-backward asymmetry

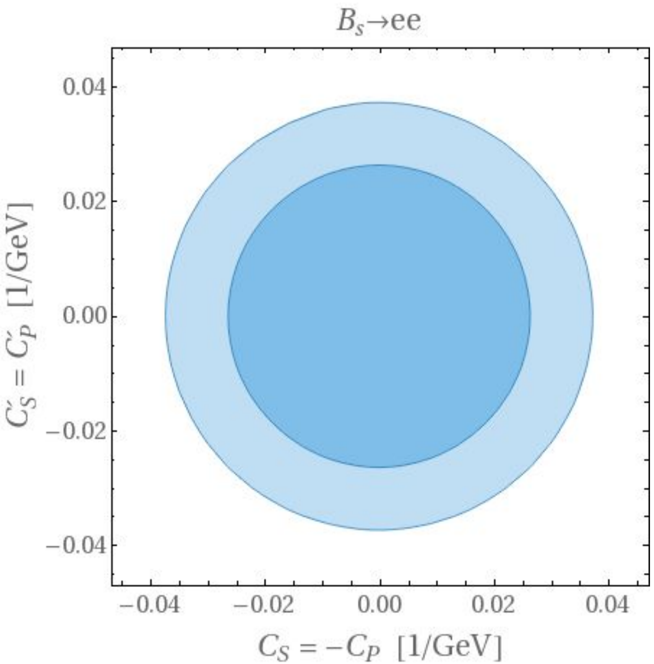
- $A_{FB} \backsimeq 0$ in the Standard Model
- Could become sizeable if both (pseudo)scalar and tensor operators are present at the same time

Scalar Operators in $B_s \to ll$ and $B \to Kll$

$$O_S^{(\prime)} = m_b(\bar{s}_{L(R)} b_{R(L)})(\bar{\mu}\mu), \quad O_P^{(\prime)} = m_b(\bar{s}_{L(R)} b_{R(L)})(\bar{\mu}\gamma_5\mu),$$

- Scalar operators are strongly constrained by BR($B_s \to ll$), if SMEFT relations are imposed [Alonso et al. 1407.7044]

$C_S = -C_P \quad C'_S = C'_P$



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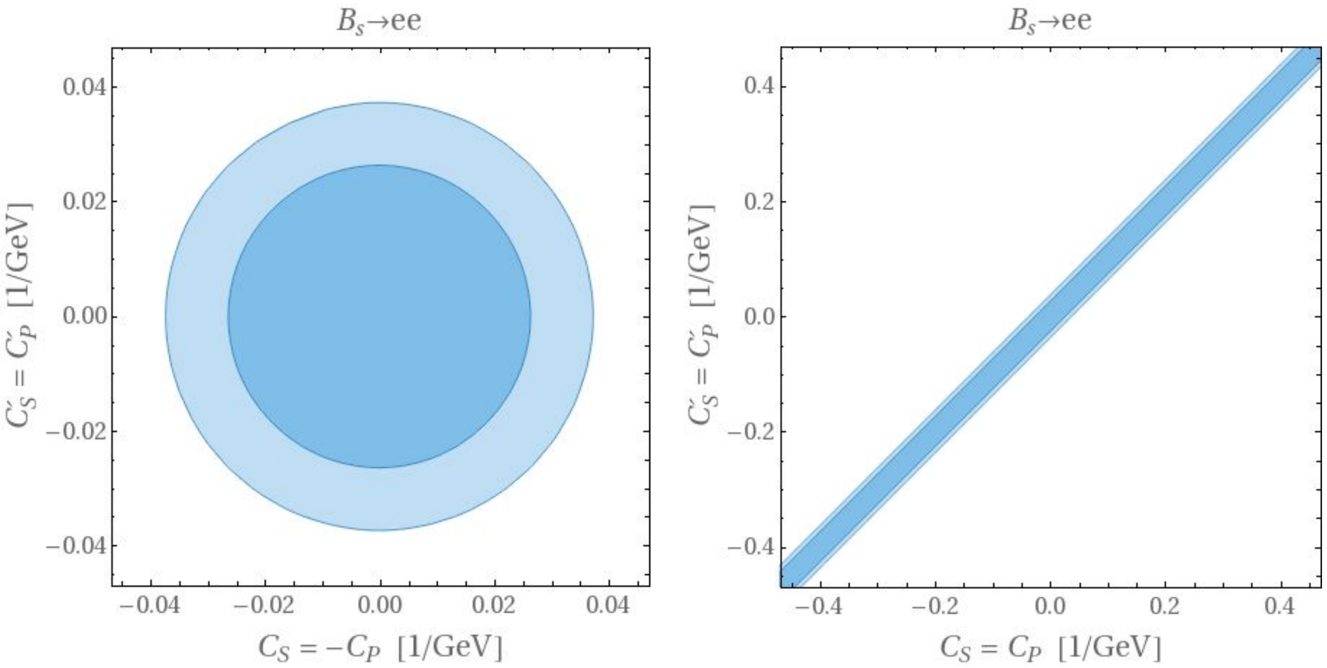
- Beyond SMEFT, there are "blind directions" in Wilson coefficient space that are not probed by the purely leptonic decays [Becirevic et al 1205.5811]



Modification of the B→Kll Angular Distribution and effect on R(K)

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_l) + \frac{1}{2}F_H + A_{FB}\cos\theta_l$$

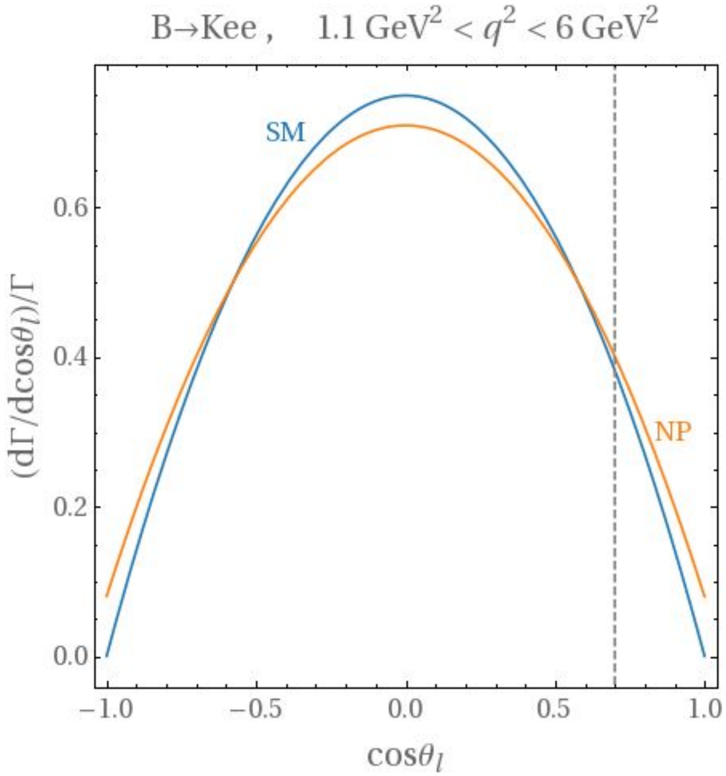
- Example benchmark point with R(K)= 0.85

  $C_S=C_P=C'_S=C'_P= 0.35/\mathrm{GeV}$

  (equality of the Wilson coefficients has to hold at the 10% level to escape the bound from B_s→ee)

- B→Kee efficiency is slightly reduced (~2%) in the new physics example => true R(K) is ~2% lower
  [note: using a cut $\cos(\theta_l)<0.7$]

  (The new physics scenario is contrived, but I don't think it is excluded)



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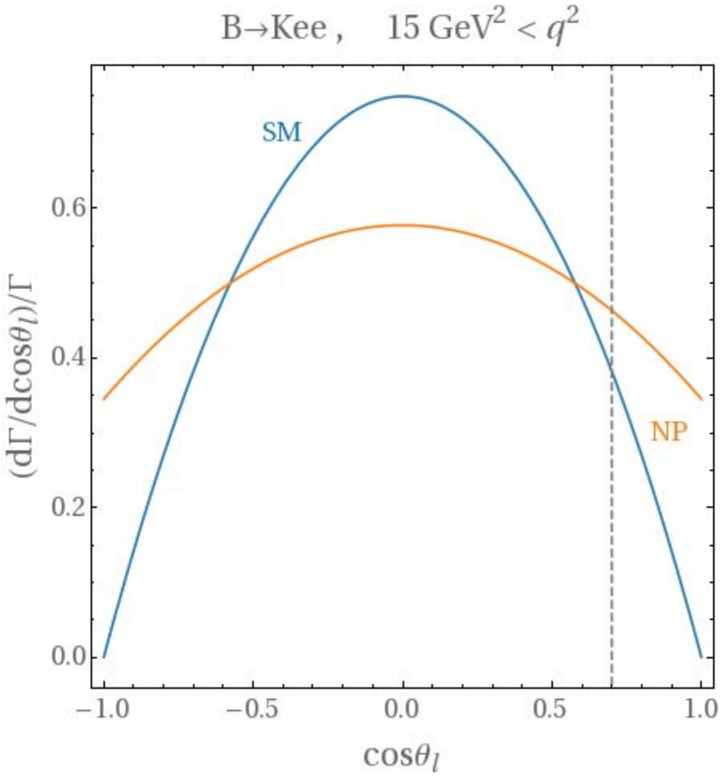
  [note: using a cut $\cos(\theta_l)<0.7$]

- The effect of scalar operators is more pronounced at high q^2 (~7% in this example)

  (The new physics scenario is contrived, but I don't think it is excluded)



The B→K*ll Angular Distribution

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\mu} = \frac{3}{4}F_L(1-\cos^2\theta_\mu) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\mu) + A_{FB}\cos\theta_\mu$$

- The $\cos(\theta_l)$ distribution depends on:
  1. the longitudinal polarization fraction of the K*
  2. the forward backward asymmetry

- F_L and A_{FB} can be modified by the usual semi-leptonic operators

$$O_9^{bs\ell\ell} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad O_9'^{bs\ell\ell} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,,$$

$$O_{10}^{bs\ell\ell} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,, \qquad O_{10}'^{bs\ell\ell} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)\,,$$

Modification of the B→K*ll Angular Distribution and effect on R(K*)

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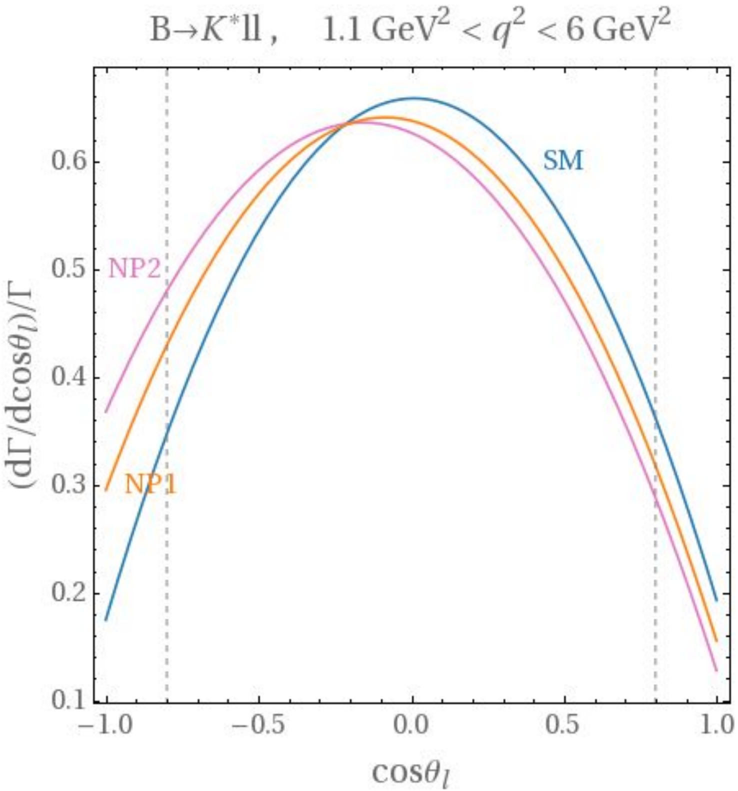
- Two new physics examples
  1) $C_9^{bs\mu\mu} = -1.0$ -> R(K*)=0.85
  2) $C_9^{bsee} = C_{10}^{bsee} = -1.5$ -> R(K*)=0.66

- At low q^2: $1.1\ \mathrm{GeV}^2 < q^2 < 6\ \mathrm{GeV}^2$

  In new physics example 1, the B→K*μμ efficiency is ~1% smaller => true R(K*) is ~1% higher

  In new physics example 2, the B→K*ee efficiency is ~2% smaller => true R(K*) is ~2% lower



Modification of the B➜K*ll Angular Distribution and effect on R(K*)

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- At low q^2: $4\ GeV^2 < q^2 < 6\ GeV^2$

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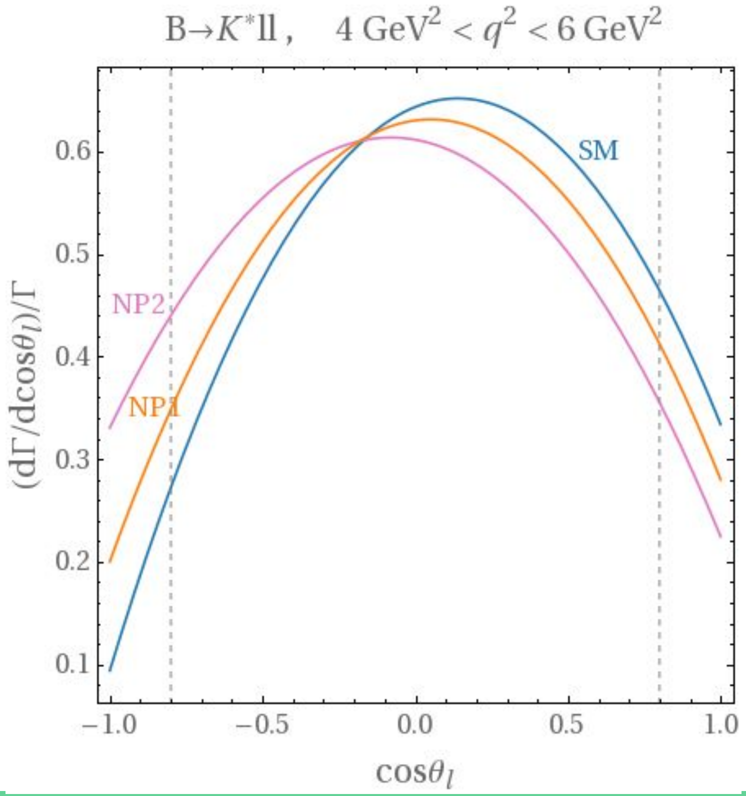

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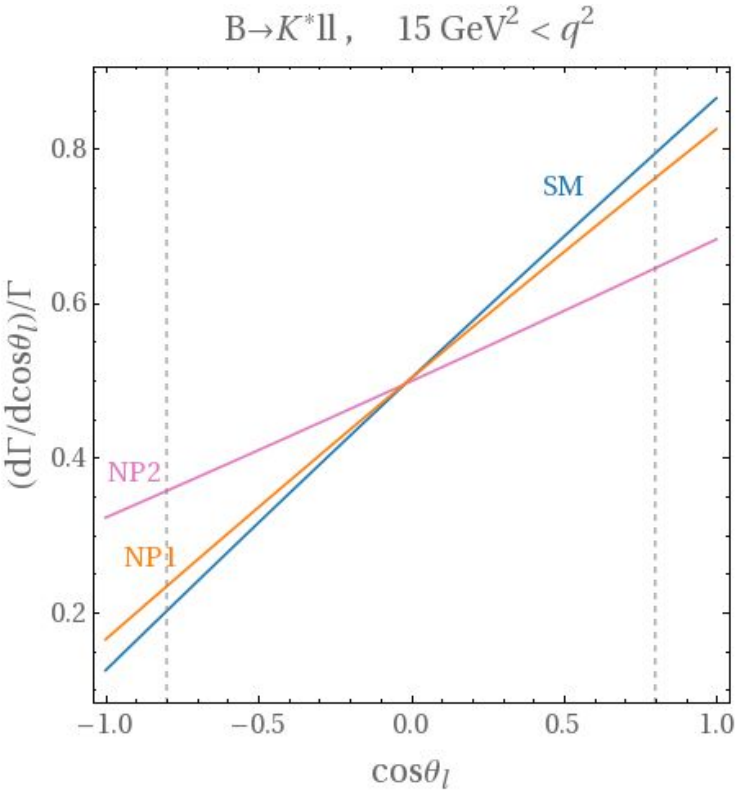
- At high q^2: 15 GeV^2 < q^2

  In new physics example 1, the B→K*μμ efficiency is ~unchanged => true R(K*) is ~unchanged

  In new physics example 2, the B→K*ee efficiency is ~unchanged => true R(K*) is ~unchanged



Light New Physics?

- Can light new physics that is not covered by the effective Hamiltonian formalism affect the measurements of R(K) and R(K*) ? (dark photons, axions, light Z' bosons, ...)
  [Sala, Straub 1704.06188; Datta et al. 1705.08423; WA, Baker, Gori, Harnik, Pospelov, Thamm 1711.07494]

- Typically one would expect a prominent bump in the q^2-spectrum.

- No new physics resonance is seen in B→K*X, X→μμ and B→KX, X→μμ

- What about electrons?

[LHCb 1508.04094, 1612.07818]

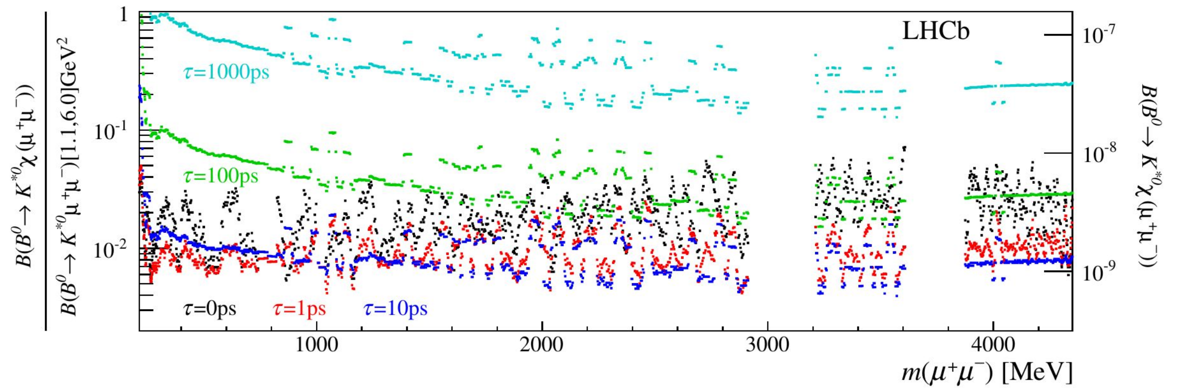


Figure 7: Upper limits at 95% CL for (left axis) $\mathcal{B}(B^0 \to K^{*0}\chi(\mu^+\mu^-))/\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)$, with $B^0 \to K^{*0}\mu^+\mu^-$ in $1.1 < m^2(\mu^+\mu^-) < 6.0\,\mathrm{GeV}^2$, and (right axis) $\mathcal{B}(B^0 \to K^{*0}\chi(\mu^+\mu^-))$. Same as Fig. 4 in the Letter but including the $\tau = 0$ and $1\,\mathrm{ps}$ limits.

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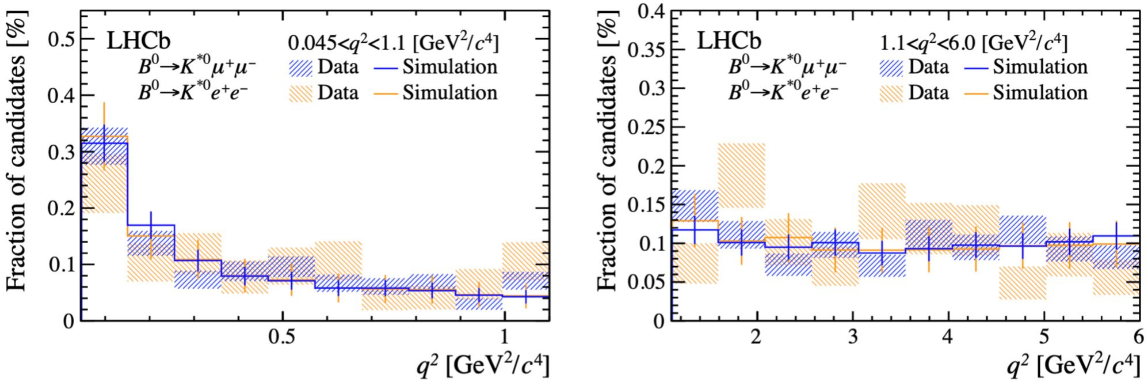
[LHCb, JHEP 08 (2017) 055]



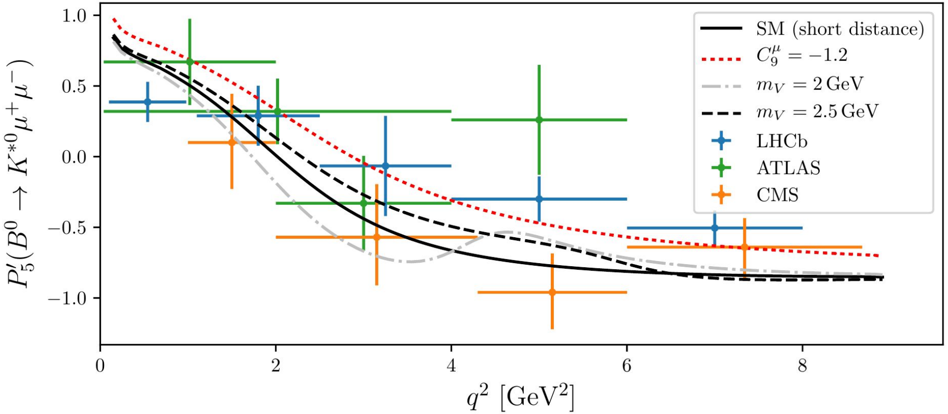
Light New Physics and the Angular Distribution

The constraints from the q^2 Spectrum can be avoided in several ways:

↓ increasing "exoticness"

- Hide the light new physics particle behind QCD resonances.
- Put the new particle close to thresholds.
- Give the new particle a very large width.
- Introduce many resonances with mass splitting of the order of the invariant mass resolution.
- Consider an ``unparticle continuum''.

[Sala, Straub 1704.06188



Could light new physics lead to an ``exotic'' distortion of the angular distribution and affect the R(K) or R(K*) efficiencies in a peculiar way?

Some other thoughts...

- C/C' interplay for different helicity amplitudes?

$$C + C': \quad K, K^*_\perp, \ldots$$

$$C - C': \quad K_0(1430), K^*_{0,\parallel}, \ldots$$

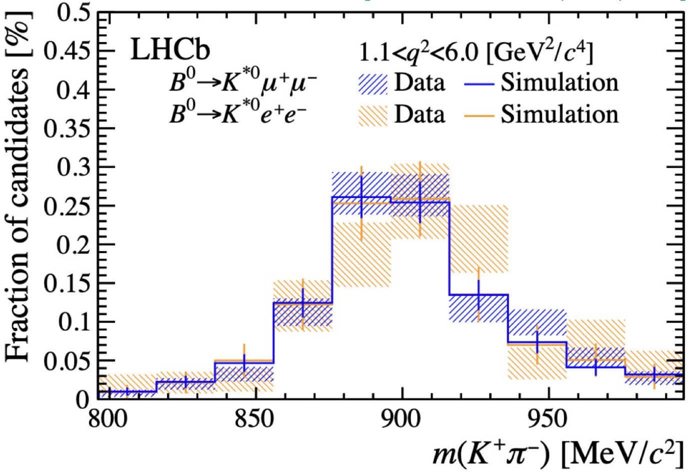
[Hiller, Schmaltz, JHEP 02 (2015) 055]

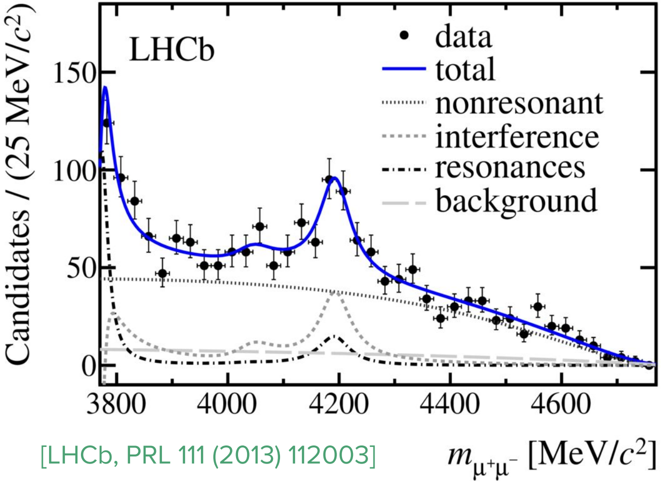
- Impact of S-wave on B->K^{*0}ll - not separated in R_{K^*}
    - measured in $B^0 \to K\pi\mu\mu$ to be ~10% [LHCb, JHEP 04 (2017) 142]
    - higher waves?

      [No significant D-wave in $B^0 \to K\pi\mu\mu$ at high m(Kπ)] [LHCb, JHEP 04 (2017) 142]

- For LFU at high q2: What is the impact of resonances?
    - How to include these bins in global fits?

[LHCb, JHEP 08 (2017) 055]





[LHCb, PRL 111 (2013) 112003]