Charm and tau loop effects in $B^+ \rightarrow K^+ \mu^+ \mu^-$

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based on ongoing work with G.Isidori, M.König, S. Liechti, P. Owen, N.Serra
Key channel for indirect NP searches

- FCNC, hence suppressed in SM
- NP could modify decay rates, angular distributions…
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Flavour anomalies several $b \to s\mu\mu$ observables in tension with SM
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**Lots of data available**  (LHCb, Belle II)
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Can we improve its description at experiments?
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Dimuon spectrum of $B^+ \rightarrow K^+\mu^+\mu^-$:
Can we improve its description at experiments?
Can we use it to extract bounds on NP in $b \rightarrow s\tau\tau$?
Effective field theory description

**EFT** for $b \to s\mu\mu$:

$$\mathcal{L}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i C_i(\mu) O_i,$$

\[
\begin{align*}
O_9^\mu &= \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu P_L b)(\bar{\mu} \gamma^\mu \mu) \\
O_7 &= \frac{e}{16\pi^2} m_b (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu} \\
O_{10}^\mu &= \frac{e^2}{16\pi^2} (\bar{s} \gamma_\mu P_L b)(\bar{\mu} \gamma^\mu \gamma_5 \mu)
\end{align*}
\]

**SM**

$$O_9^\mu, O_7, O_{10}^\mu, O_{1-6}, O_8$$

**NP**

$$C_i^{\text{SM}} \to C_i^{\text{SM}} + \delta C_i^{\text{NP}}$$ and/or new operators
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**Local** (short distance)
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**Local** (short distance)

- $C_i^{\text{SM}}$
- $f_+, f_0, f_T$ for $B \rightarrow K$
Non-local effects: the charm loop

**Non-local** (long distance) effects arise via 4-quark + chromomagnetic operator, and are included via

\[ C_9 \rightarrow C_9^{\text{eff}}(q^2) = C_9 + Y(q^2) \]
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[Semi]perturbative approach valid at low \( q^2 \):

Pert. contribution + expansion in \( \Lambda_{QCD}^2/(q^2 - 4m_c^2) \)

[Khodjamirian et al., 1212.0234]

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**Goal**: model long-distance effects at experiments, in the entire spectrum.
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- Standard approach: exclude events close to resonances
  [Babar, Belle, CDF, CMS, LHCb…]
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- LHCb [2016] first fit to full spectrum, including resonances: [LHCb 1612.06764] [Lyon, Zwicky 1406.0566]

\[ Y(q^2) = \sum_j \eta_j e^{i\delta_j} A_j^{\text{res}}(q^2) \]

fit parameters Breit Wigner
Long-distance effects at experiments

Why working towards a better parametrisation?

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Breit Wigner
Long-distance effects at experiments

Why working towards a better parametrisation?

- access long-distance info unaccessible from first principles [e.g. phases]
- extract reliable short-distance info [hence NP!]

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Bret Wigner
Our proposal in a nutshell

We propose the following parametrisation of hadronic long-distance contributions:

\[ C_9^{\text{eff}}(q^2) = C_9 + Y(q^2), \quad Y(q^2) = Y_0 + \Delta C_{qq}^{1P}(q^2) + \Delta C_{cc}^{1P}(q^2) + \Delta C_{cc}^{2P}(q^2) \]

1P exchange

2P exchange

up

ccharm
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Light resonances \((\rho, \omega, \phi)\)

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Light resonances \((\rho, \omega, \phi)\)

\[
\Delta C_{q\bar{q}}^{1P}(q^2) = \sum_j \eta_j e^{i\delta_j} A_j^{\text{res}}(q^2)
\]

constraint: \(|\Delta C_{q\bar{q}}^{1P}(0)| = \mathcal{O} \left( \frac{\Lambda_{QCD}}{m_b} \right) \). CKM suppression \(\approx 0\)
Charm contribution

Charmonium resonances \((J/\psi, \psi(2S), \ldots)\)

Two-particle \(\bar{c}c\) states \((DD, D^* D^*, DD^*)\)
Charmonium resonances \((J/\psi, \psi(2S), \ldots)\)

\[
\Delta C_{c\bar{c}}^{1P}(q^2) = \sum_j \eta_j e^{i\delta_j} \frac{q^2}{m_j^2} A_{j}^{\text{res}}(q^2),
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\[
\rho(s) = \text{Im} \left\{ \frac{g}{\kappa} \frac{\bar{c}c}{D^{(w)}_{D^{(w)}}} \right\} \sim \left\{ \begin{array}{l} \left(1 - \frac{4m_D^2}{s}\right)^{3/2} \text{ } D D \\ \left(1 - \frac{4m_{D^*}^2}{s}\right)^{3/2} \text{ } D^* D^* \\ \left(1 - \frac{4m_D^2}{s}\right)^{1/2} \text{ } D^* D \end{array} \right. 
\]

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\rho(s) = \text{Im} \left\{ \frac{B}{D} \right\} \sim \left\{ \begin{array}{l}
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\end{array} \right\} \text{ dominant contribution}
\]

\(\bar{c}c\) dominant contribution
Charmonium resonances \((J/\psi, \psi(2S), ...)\)

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dominant contribution

constraint: \(q^2 \ll m_c^2\)  \(\Delta C_{cc\bar{c}}^{1P}(q^2) + \Delta C_{cc\bar{c}}^{2P}(q^2) = \Delta C_{cc\bar{c}}^{\text{pert}}(q^2)\)
Contributions from two-particle intermediate states present a “cusp” at the kinematical threshold for on-shell production:
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Consider a NP scenario where a large $C_{9\tau}$ is generated:

\[ O_9^\tau \sim (\bar{s} \gamma_\mu P_L b)(\bar{\tau} \gamma^\mu \tau) \]

[e.g. combined expl. of B anomalies...]
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Probing $b \to s\tau\tau$ directly is experimentally challenging…

$$\mathcal{B}_{\exp}(B^{+} \to K^{+}\tau^{+}\tau^{-}) < 2.25 \cdot 10^{-3} \quad \text{[Babar]}$$

$$\mathcal{B}_{\text{SM}}(B^{+} \to K^{+}\tau^{+}\tau^{-}) = 1.2 \cdot 10^{-7}$$
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…can we get a competitive bound from the $B^{+} \rightarrow K^{+}\mu^{+}\mu^{-}$ spectrum?
Constraining NP in taus…from muons?

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\text{alter } q^2 \text{ dependence above/below threshold}
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...can we get a competitive bound from the $B^+ \rightarrow K^+\mu^+\mu^-$ spectrum?

$$\Delta C_{\bar{\tau}\tau}^{2p}(q^2) =$$

- cusp at $q^2 = 4m_\tau^2$
- alter $q^2$ dependence above/below threshold

Preliminary sensitivity @ LHCb [with Run 2 statistics]: $\mathcal{B}(B^+ \rightarrow K^+\tau^+\tau^-) \lesssim \mathcal{O}(10^{-4})$
The $\tau - \tau$ cusp

**resonances only**

res. parameters from

[LHCb 1612.06764]

**resonances + $\tau\tau$**

assuming $\mathcal{B}(B^+ \rightarrow K^+\tau^+\tau^-) = \text{Babar upper limit (for illustration)}$
Conclusions and outlook
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A precise description of the $q^2$ spectrum at experiments is crucial to extract reliable information. We propose an improved parameterisation of long-distance effects, including the contribution from 1 and 2-particle intermediate states.
Conclusions and outlook

Preliminary studies of the expected sensitivity at LHCb with Run II statistics suggest the possibility of constraining NP in $b \to s\tau\tau$ through its imprint on the spectrum of $B^+ \to K^+\mu^+\mu^-$. A precise description of the $q^2$ spectrum at experiments is crucial to extract reliable information. We propose an improved parameterisation of long-distance effects, including the contribution from 1 and 2-particle intermediate states.

In progress:
- detailed study on realistic sensitivity expected at LHCb with Run II statistics (and possibly beyond)
- extensions to other channels, e.g. $B \to K^*\mu^+\mu^-$
Thank you!