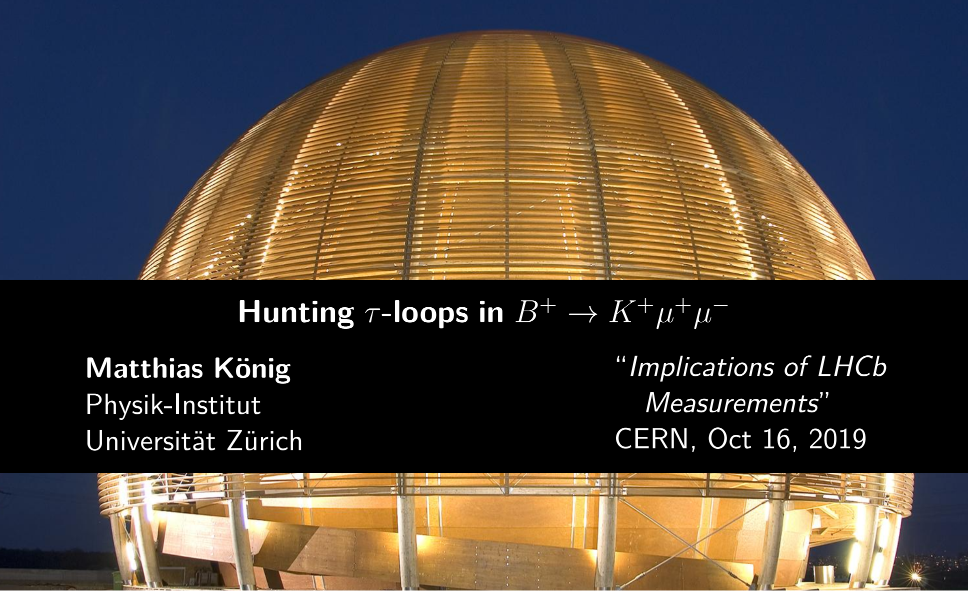


Hunting τ-loops in $B^+ \to K^+\mu^+\mu^-$

Matthias König
Physik-Institut
Universität Zürich

"*Implications of LHCb Measurements*"
CERN, Oct 16, 2019

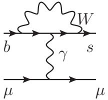
Universität Zürich UZH

FNSNF
Schweizerischer Nationalfonds
zur Förderung der wissenschaftlichen Forschung

Invitation

Anomalies in semileptonic B-decays:

$\underline{B \to K\mu^+\mu^-}$ FCNC ($\to$ loop level) process in the Standard Model

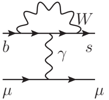


Invitation

Anomalies in semileptonic B-decays:

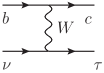
$\underline{B \to K\mu^+\mu^-}$

FCNC (→ loop level) process in the Standard Model



$\underline{B \to D\tau\nu}$

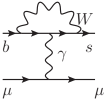
Charged current (→ tree level) process in the Standard Model



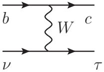
Invitation

Anomalies in semileptonic B-decays:

$\underline{B \to K\mu^+\mu^-}$ FCNC ($\to$ loop level) process in the Standard Model



$\underline{B \to D\tau\nu}$ Charged current ($\to$ tree level) process in the Standard Model



<u>New physics</u> explanations favor NP mostly in the **third generation**, possible connection to the SM flavor puzzle!
→ large effects in τ, smaller effects in μ

Invitation

In these cases, one expects **large effects** from τ in $B \to K$ as well!

What's the sitaution on $b \to s\tau\tau$?

Invitation

In these cases, one expects **large effects** from τ in $B \to K$ as well!

What's the sitaution on $b \to s\tau\tau$?

- $B \to K\tau^+\tau^-$ experimentally **challenging**:
  $\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) < 2.25 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B^+ \to K^+\tau^+\tau^-) = 1.2 \cdot 10^{-7}$

[BaBar (*2017*), Phys.Rev.Lett. 118 no.3, 031802]

Invitation

In these cases, one expects **large effects** from τ in $B \to K$ as well!

What's the sitaution on $b \to s\tau\tau$?

- $B \to K\tau^+\tau^-$ experimentally **challenging**:
  $\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) < 2.25 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B^+ \to K^+\tau^+\tau^-) = 1.2 \cdot 10^{-7}$

[BaBar (*2017*), Phys.Rev.Lett. 118 no.3, 031802]

- $B_s \to \tau^+\tau^-$ likewise:
  $\mathrm{Br}(B_s \to \tau^+\tau^-) < 6.8 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B_s \to \tau^+\tau^-) = 7.73 \cdot 10^{-7}$

[LHCb (*2017*), Phys.Rev.Lett. 118 no.25, 251802]

Invitation

In these cases, one expects **large effects** from τ in $B \to K$ as well!

What's the sitaution on $b \to s\tau\tau$?

- $B \to K\tau^+\tau^-$ experimentally **challenging**:
  $\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) < 2.25 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B^+ \to K^+\tau^+\tau^-) = 1.2 \cdot 10^{-7}$

[BaBar (*2017*), Phys.Rev.Lett. 118 no.3, 031802]

- $B_s \to \tau^+\tau^-$ likewise:
  $\mathrm{Br}(B_s \to \tau^+\tau^-) < 6.8 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B_s \to \tau^+\tau^-) = 7.73 \cdot 10^{-7}$

[LHCb (*2017*), Phys.Rev.Lett. 118 no.25, 251802]

There is **a lot** of room for **new physics**!

Invitation

In these cases, one expects **large effects** from τ in $B \to K$ as well!

What's the sitaution on $b \to s\tau\tau$?

- $B \to K\tau^+\tau^-$ experimentally **challenging**:
  $\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) < 2.25 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B^+ \to K^+\tau^+\tau^-) = 1.2 \cdot 10^{-7}$

[BaBar (*2017*), Phys.Rev.Lett. 118 no.3, 031802]

- $B_s \to \tau^+\tau^-$ likewise:
  $\mathrm{Br}(B_s \to \tau^+\tau^-) < 6.8 \cdot 10^{-3}$
  $\mathrm{Br}_{\mathrm{SM}}(B_s \to \tau^+\tau^-) = 7.73 \cdot 10^{-7}$

[LHCb (*2017*), Phys.Rev.Lett. 118 no.25, 251802]

There is **a lot** of room for **new physics**!

Also: **Lots of data** on $b \to s\mu\mu$!

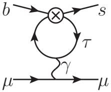
Invitation

Idea: Can we probe $b \to s\tau\tau$ through its **loop-contribution** to the $b \to s\mu\mu$ spectrum?

Invitation

Idea: Can we probe $b \to s\tau\tau$ through its **loop-contribution** to the $b \to s\mu\mu$ spectrum?

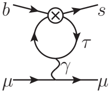
Electroweak loop, but **large enhancements** motivated by NP and allowed by current bounds!



Invitation

Idea: Can we probe $b \to s\tau\tau$ through its **loop-contribution** to the $b \to s\mu\mu$ spectrum?

Electroweak loop, but **large enhancements** motivated by NP and allowed by current bounds!



Based on:

Hunting for $B \to K\tau^+\tau^-$ imprints on the $B \to K\mu^+\mu^-$ dimuon spectrum

C. Cornella, G. Isidori, MK, S. Liechti, P. Owen, N. Serra

[in preparation]

Outline

1. EFT description of $B \to K\ell\ell$
2. Long-distance hadronic effects
3. τ-loops in $b \to s\mu\mu$
4. Sensitivity and future projections
5. Conclusions

EFT description of $B \to K\ell\ell$

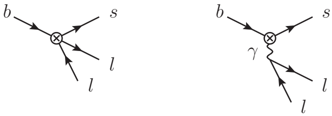
EFT description

Weak effective Lagrangian: $\mathcal{L}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i(\mu)\mathcal{O}_i$

FCNC operators:

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu}$$

$$\mathcal{O}_9^l = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l) \qquad \mathcal{O}_{10}^l = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l)$$



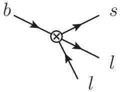
EFT description

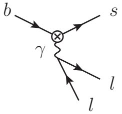
Weak effective Lagrangian: $\mathcal{L}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i(\mu)\mathcal{O}_i$

FCNC operators:

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu}$$

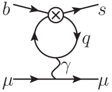
$$\mathcal{O}_9^l = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l) \qquad \mathcal{O}_{10}^l = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l)$$





Four-quark operators:

$$\mathcal{O}_1^q = (\bar{s}\gamma_\mu P_L q)(\bar{q}\gamma_\mu P_L b) \qquad \mathcal{O}_2^q = (\bar{s}^\alpha \gamma_\mu P_L q^\beta)(\bar{q}^\beta \gamma_\mu P_L b^\alpha)$$



EFT description

Differential decay rate:

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{\rm em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa\beta\left\{\frac{2}{3}\kappa^2\beta^2\left|\mathcal{C}_{10}^{\mu}f_+(q^2)\right|^2+\frac{4m_\mu^2(m_B^2-m_K^2)^2}{q^2\,m_B^2}\left|\mathcal{C}_{10}^{\mu}f_0(q^2)\right|^2\right.$$
$$\left.+\kappa^2\left(1-\frac{1}{3}\beta\right)\left|\mathcal{C}_9^{\mu}f_+(q^2)+2\mathcal{C}_7\frac{m_b+m_s}{m_B+m_K}f_T(q^2)\right|^2\right\},$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_i(\mu)$
- Hadronic matrix elements: form factors $f_i(q^2)$

EFT description

Differential decay rate:

$$\frac{d\Gamma}{dq^2} = \quad \frac{\alpha_{\rm em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa\beta \left\{ \frac{2}{3}\kappa^2\beta^2 \left|\mathcal{C}_{10}^{\mu} f_+(q^2)\right|^2 + \frac{4m_\mu^2(m_B^2 - m_K^2)^2}{q^2\, m_B^2}\left|\mathcal{C}_{10}^{\mu} f_0(q^2)\right|^2 \right.$$
$$\left. +\kappa^2\left(1-\frac{1}{3}\beta\right)\left|\mathcal{C}_9^{\mu} f_+(q^2) + 2\mathcal{C}_7 \frac{m_b+m_s}{m_B+m_K} f_T(q^2)\right|^2 \right\},$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_i(\mu)$
- Hadronic matrix elements: form factors $f_i(q^2)$

Real world more complicated than that. Introduce:

$$\mathcal{C}_9^{\mu} \to \mathcal{C}_9^{\rm eff}(q^2) = \mathcal{C}_9^{\mu} + Y_i(q^2)$$

EFT description

Differential decay rate:

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{\rm em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa\beta\left\{\frac{2}{3}\kappa^2\beta^2\left|\mathcal{C}_{10}^{\mu} f_+(q^2)\right|^2 + \frac{4m_\mu^2(m_B^2-m_K^2)^2}{q^2\,m_B^2}\left|\mathcal{C}_{10}^{\mu} f_0(q^2)\right|^2 \right.$$
$$\left. +\kappa^2\left(1-\frac{1}{3}\beta\right)\left|\mathcal{C}_9^{\mu} f_+(q^2) + 2\mathcal{C}_7\frac{m_b+m_s}{m_B+m_K}f_T(q^2)\right|^2\right\},$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_i(\mu)$
- Hadronic matrix elements: form factors $f_i(q^2)$

Real world more complicated than that. Introduce:

$$\mathcal{C}_9^{\mu} \to \mathcal{C}_9^{\rm eff}(q^2) = \mathcal{C}_9^{\mu} + Y_i(q^2)$$

short-distance SM/NP

EFT description

Differential decay rate:

$$\frac{d\Gamma}{dq^2} = \frac{\alpha_{\rm em}^2 G_F^2 |V_{tb}V_{ts}^*|^2}{128\,\pi^5}\kappa\beta\left\{\frac{2}{3}\kappa^2\beta^2\left|\mathcal{C}_{10}^{\mu} f_+(q^2)\right|^2 + \frac{4m_\mu^2(m_B^2-m_K^2)^2}{q^2\,m_B^2}\left|\mathcal{C}_{10}^{\mu} f_0(q^2)\right|^2 \right.$$
$$\left. +\kappa^2\left(1-\frac{1}{3}\beta\right)\left|\mathcal{C}_9^{\mu} f_+(q^2) + 2\mathcal{C}_7\frac{m_b+m_s}{m_B+m_K}f_T(q^2)\right|^2\right\},$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_i(\mu)$
- Hadronic matrix elements: form factors $f_i(q^2)$

Real world more complicated than that. Introduce:

$$\mathcal{C}_9^{\mu} \to \mathcal{C}_9^{\rm eff}(q^2) = \mathcal{C}_9^{\mu} + Y_i(q^2)$$

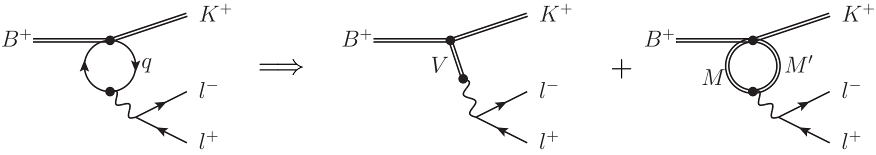
short-distance SM/NP

long-distance QCD

Long-distance hadronic effects

Long-distance hadronic effects

Leave it to QCD to make live interesting:

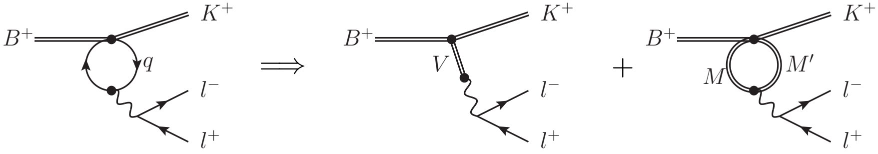


Depending on q^2, the intermediate state live at **non-perturbative** scales

$\Rightarrow$ Hadronic intermediate states rather than quarks.

Long-distance hadronic effects

Leave it to QCD to make live interesting:



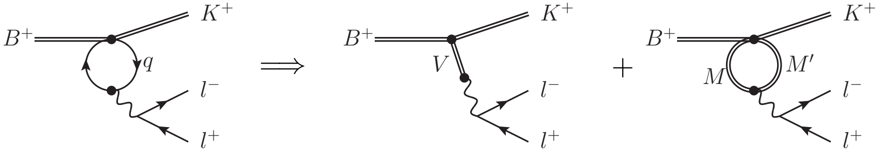
Depending on q^2, the intermediate state live at **non-perturbative** scales

$\Rightarrow$ Hadronic intermediate states rather than quarks.

To extract bounds on a q^2-dependent signal, we need to **understand the shape** of the SM spectrum.

Long-distance hadronic effects

Leave it to QCD to make live interesting:



Depending on q^2, the intermediate state live at **non-perturbative** scales

$\Rightarrow$ Hadronic intermediate states rather than quarks.

To extract bounds on a q^2-dependent signal, we need to **understand the shape** of the SM spectrum.

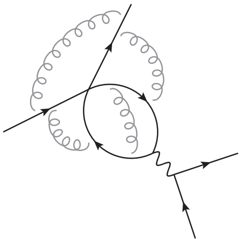
Not a straightforward computation by first principles.

Long-distance hadronic effects

The way around: Find a region in q^2, where the intermediate state is **dominated by short-distance** physics.

Long-distance hadronic effects

The way around: Find a region in q^2, where the intermediate state is **dominated by short-distance** physics.



Example: Charm-quark loop at $q^2 \sim 0$

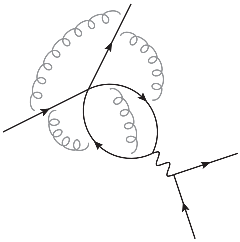
Charm quarks hard ($k^2 \sim m_c^2$)

Can compute QCD corrections using the established bag of tricks

(factorizable/non-factorizable corrections, ...)

Long-distance hadronic effects

The way around: Find a region in q^2, where the intermediate state is **dominated by short-distance** physics.



Example: Charm-quark loop at $q^2 \sim 0$

Charm quarks hard ($k^2 \sim m_c^2$)

Can compute QCD corrections using the established bag of tricks

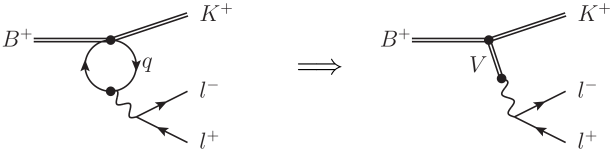
(factorizable/non-factorizable corrections, ...)

Then: Extrapolate to high-q^2 region using analyticity of amplitude.

[Khodjamirian et al. (*2010*), JHEP 1009 089; Khodjamirian et al. (*2013*), JHEP 1302 010]

Charm loops - resonances

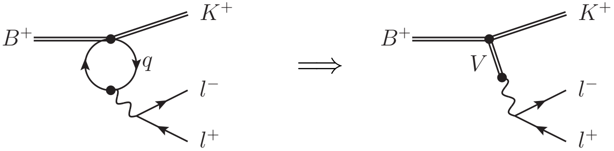
Leading contribution: Intermediate charmonium resonances.



$$V \in \left\{ \begin{array}{ccc} J/\psi, & \psi(2S), & \psi(3770), \\ \psi(4040), & \psi(4160), & \psi(4415) \end{array} \right\}$$

Charm loops - resonances

Leading contribution: Intermediate charmonium resonances.



$$V \in \left\{ \begin{array}{ccc} J/\psi, & \psi(2S), & \psi(3770), \\ \psi(4040), & \psi(4160), & \psi(4415) \end{array} \right\}$$

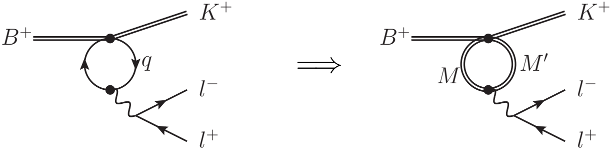
The q^2-dependence is described by a relativistic Breit-Wigner.

$$\Delta Y_{c\bar{c}}^{1P}(s) = \eta_V e^{i\delta_V} \frac{s}{m_V^2} \frac{m_V \Gamma_V}{s - m_V^2 + i m_V \Gamma_V}$$

[Lyon & Zwicky (2014); LHCb (*2017*), Eur.Phys.J. C77 161]

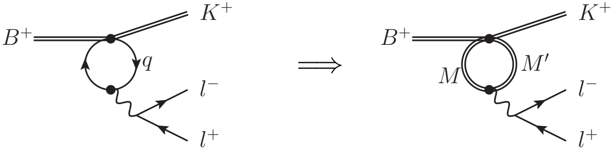
Charm loops - two-particle states

Two-particle intermediate states:



Charm loops - two-particle states

Two-particle intermediate states:



q^2 dependence through subtracted hadronic dispersion relation:

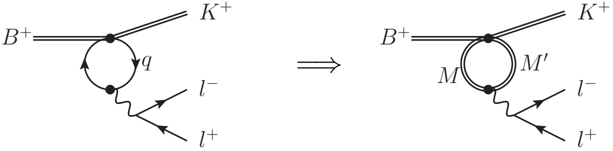
$$\Delta Y_{c\bar{c}}^{2\mathrm{P}}(s) = \frac{s}{\pi} \sum_{V} \int_{\tau_V}^{\infty} \frac{d\tilde{s}}{\tilde{s}} \frac{\rho_V(\tilde{s})}{\tilde{s} - s}$$

$$V \in \{DD,\, D^* D,\, D^* D^*\}$$

[Khodjamirian et al. (*2010*), JHEP 1009 089; Khodjamirian et al. (*2013*), JHEP 1302 010]

Charm loops - two-particle states

Two-particle intermediate states:



q^2 dependence through subtracted hadronic dispersion relation:

$$\Delta Y^{\mathrm{2P}}_{c\bar{c}}(s) = \frac{s}{\pi} \sum_V \int_{\tau_V}^{\infty} \frac{d\tilde{s}}{\tilde{s}} \frac{\rho_V(\tilde{s})}{\tilde{s} - s}$$

$$V \in \{DD,\, D^* D,\, D^* D^*\}$$

[Khodjamirian et al. (*2010*), JHEP 1009 089; Khodjamirian et al. (*2013*), JHEP 1302 010]

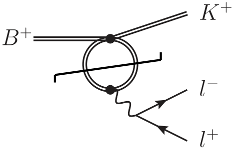
What are the various $\rho_V(s)$? → estimate!

Charm loops - two-particle states

First-principle calculation of the spectral densities $\rho_V(s)$ not viable.

Charm loops - two-particle states

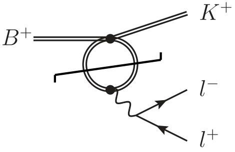
First-principle calculation of the spectral densities $\rho_V(s)$ not viable.



$\rightarrow$ Can estimate $\rho_V(s)$ from $VV' \rightarrow \mu\mu$ using helicity arguments.

Charm loops - two-particle states

First-principle calculation of the spectral densities $\rho_V(s)$ not viable.

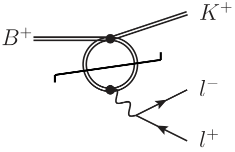


→ Can estimate $\rho_V(s)$ from $VV' \to \mu\mu$ using helicity arguments.

From this we find: $\rho_V = \sum_n c_n^V \, \beta^n(4m_V^2/s)\,, \qquad \beta(\tau) = \sqrt{1-\tau}$

Charm loops - two-particle states

First-principle calculation of the spectral densities $\rho_V(s)$ not viable.



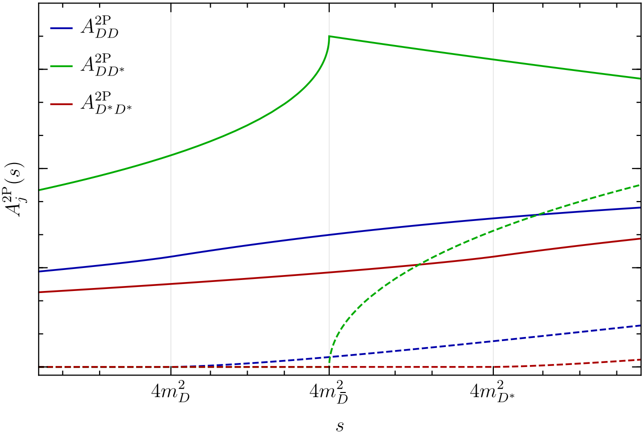
$\rightarrow$ Can estimate $\rho_V(s)$ from $VV' \rightarrow \mu\mu$ using helicity arguments.

From this we find: $\rho_V = \sum_n c_n^V \, \beta^n(4m_V^2/s)\,, \qquad \beta(\tau) = \sqrt{1-\tau}$

Keeping only the **leading** partial waves:

$$\rho_{DD} = \left(1 - \frac{4m_D^2}{s}\right)^{3/2} \quad \rho_{DD^*} = \left(1 - \frac{4m_{DD^*}^2}{s}\right)^{1/2} \quad \rho_{D^*D^*} = \left(1 - \frac{4m_D^{*2}}{s}\right)^{3/2}$$

Charm loops - two-particle states



$$\rho_{DD} = \left(1 - \frac{4m_D^2}{s}\right)^{3/2} \qquad \rho_{DD^*} = \left(1 - \frac{4m_{DD^*}^2}{s}\right)^{1/2} \qquad \rho_{D^*D^*} = \left(1 - \frac{4m_D^{*2}}{s}\right)^{3/2}$$

Light resonances

While the **charm-contributions** are the largest ones, light quarks still need to be accounted for.

Light resonances

While the **charm-contributions** are the largest ones, light quarks still need to be accounted for.

They are strongly CKM-suppressed with respect to the leading charm.

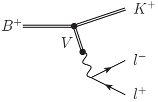
→ We limit ourselves to single-particle contributions.

Light resonances

While the **charm-contributions** are the largest ones, light quarks still need to be accounted for.

They are strongly CKM-suppressed with respect to the leading charm.

→ We limit ourselves to single-particle contributions.



$$Y^{\mathrm{1P}}_{\mathrm{light}}(s) = \sum_V \eta_V e^{i\delta_V} \frac{m_V \Gamma_V}{s - m_V^2 + i m_V \Gamma_V}$$

with $V = \rho, \omega, \phi$.

Constraints

In our approach, we only fix the q^2-shape of the contributions.

Constraints

In our approach, we only fix the q^2-shape of the contributions.

Magnitudes and phases are floating parameters in the fit.

Constraints

In our approach, we only fix the q^2-shape of the contributions.

Magnitudes and phases are floating parameters in the fit.

The hadronic long-distance contributions are written as:

$$Y_{\rm hadr}(s) = \Delta Y_{c\bar{c}}^{\rm 1P}(s) + \Delta Y_{c\bar{c}}^{\rm 2P}(s) + Y_{\rm light}^{\rm 1P}(s)$$

All $\Delta Y_{c\bar{c}}^{i}(0) = 0$ by construction!

Constraints

In our approach, we only fix the q^2-shape of the contributions.

Magnitudes and phases are floating parameters in the fit.

The hadronic long-distance contributions are written as:

$$Y_{\rm hadr}(s) = \Delta Y_{c\bar{c}}^{\rm 1P}(s) + \Delta Y_{c\bar{c}}^{\rm 2P}(s) + Y_{\rm light}^{\rm 1P}(s)$$

All $\Delta Y_{c\bar{c}}^{i}(0) = 0$ by construction!

We can constrain our fit by requiring $\Delta Y_{c\bar{c}}^{i}(0)$ to be close to the perturbative result.

Constraints

At low q^2, the slope of the **perturbative** charm contribution is:

$$\frac{d}{dq^2}\Delta Y_{c\bar{c}}^{\text{pert}}\bigg|_{q^2=0} = \frac{4}{15m_c^2}\left(\mathcal{C}_2 + \frac{1}{3}\mathcal{C}_1\right) \approx (1.7 \pm 1.7)\cdot 10^{-2}\,\text{GeV}^{-2}$$

Constraints

At low q^2, the slope of the **perturbative** charm contribution is:

$$\frac{d}{dq^2}\Delta Y_{c\bar{c}}^{\text{pert}}\bigg|_{q^2=0} = \frac{4}{15m_c^2}\left(\mathcal{C}_2 + \frac{1}{3}\mathcal{C}_1\right) \approx (1.7 \pm 1.7)\cdot 10^{-2}\,\text{GeV}^{-2}$$

This yields the following set of constraints:

$$\text{Re}\left[\sum_{j=\Psi(1S),\ldots}\eta_j e^{i\delta_j}\frac{\Gamma_j}{m_j^3} + \eta_{\bar{D}}e^{i\delta_j}\frac{1}{6m_{\bar{D}}^2} + \sum_{j=D,D*}\eta_j e^{i\delta_j}\frac{1}{10m_j^2}\right] = (1.7 \pm 2.2)\cdot 10^{-2}\ \text{GeV}^{-2}$$

$$\left|\sum_{j=\Psi(1S),\ldots}\eta_j e^{i\delta_j}\frac{\Gamma_j}{m_j^3} + \eta_{\bar{D}}e^{i\delta_j}\frac{1}{6m_{\bar{D}}^2} + \sum_{j=D,D*}\eta_j e^{i\delta_j}\frac{1}{10m_j^2}\right| \leq 5\cdot 10^{-2}\ \text{GeV}^{-2}$$

Constraints

At low q^2, the slope of the **perturbative** charm contribution is:

$$\frac{d}{dq^2}\Delta Y_{c\bar{c}}^{\text{pert}}\bigg|_{q^2=0} = \frac{4}{15m_c^2}\left(\mathcal{C}_2 + \frac{1}{3}\mathcal{C}_1\right) \approx (1.7 \pm 1.7)\cdot 10^{-2}\,\text{GeV}^{-2}$$

This yields the following set of constraints:

$$\text{Re}\left[\sum_{j=\Psi(1S),\dots} \eta_j e^{i\delta_j}\frac{\Gamma_j}{m_j^3} + \eta_{\bar{D}}e^{i\delta_j}\frac{1}{6m_{\bar{D}}^2} + \sum_{j=D,D*}\eta_j e^{i\delta_j}\frac{1}{10m_j^2}\right] = (1.7 \pm 2.2)\cdot 10^{-2}\ \text{GeV}^{-2}$$

$$\left|\sum_{j=\Psi(1S),\dots} \eta_j e^{i\delta_j}\frac{\Gamma_j}{m_j^3} + \eta_{\bar{D}}e^{i\delta_j}\frac{1}{6m_{\bar{D}}^2} + \sum_{j=D,D*}\eta_j e^{i\delta_j}\frac{1}{10m_j^2}\right| \leq 5\cdot 10^{-2}\ \text{GeV}^{-2}$$

Similarly, we can put an upper limit on the η from ΔY directly:

$$\left|\eta_{D,D^*,\bar{D}}\right| \leq 0.2\,.$$

τ-loops in $b \to s\mu\mu$

Tau effects in the spectrum

The τ loops enter as a contribution to $\mathcal{C}_9^{\text{eff}}(q^2)$:

$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha}{2\pi}\mathcal{C}_9^{\tau}\left[h_s\left(m_\tau^2, q^2\right) - \frac{1}{3}h_p\left(m_\tau^2, q^2\right)\right]$$

Intriguing channel because:

- It has an s-wave contribution → large

Tau effects in the spectrum

The τ loops enter as a contribution to $\mathcal{C}_9^{\text{eff}}(q^2)$:

$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha}{2\pi}\mathcal{C}_9^{\tau}\left[h_s\left(m_\tau^2, q^2\right) - \frac{1}{3}h_p\left(m_\tau^2, q^2\right)\right]$$

Intriguing channel because:

- It has an s-wave contribution → large
- A large enhancement over the SM is well-motivated by NP explanations to B-anomalies

Tau effects in the spectrum

The τ loops enter as a contribution to $\mathcal{C}_9^{\text{eff}}(q^2)$:

$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha}{2\pi}\mathcal{C}_9^{\tau}\left[h_s\left(m_\tau^2, q^2\right) - \frac{1}{3}h_p\left(m_\tau^2, q^2\right)\right]$$

Intriguing channel because:

- It has an s-wave contribution → large
- A large enhancement over the SM is well-motivated by NP explanations to B-anomalies
- Current direct bounds are rather weak, implying $\mathcal{C}_9^{\tau} \lesssim 580$

Tau effects in the spectrum

The τ loops enter as a contribution to $\mathcal{C}_9^{\text{eff}}(q^2)$:

$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha}{2\pi}\mathcal{C}_9^{\tau}\left[h_s\left(m_\tau^2, q^2\right) - \frac{1}{3}h_p\left(m_\tau^2, q^2\right)\right]$$

Intriguing channel because:

- It has an s-wave contribution → large
- A large enhancement over the SM is well-motivated by NP explanations to B-anomalies
- Current direct bounds are rather weak, implying $\mathcal{C}_9^{\tau} \lesssim 580$
- Very distinct shape of the spectrum, with a "cusp" at $q^2 = 4m_\tau^2$

Tau effects in the spectrum

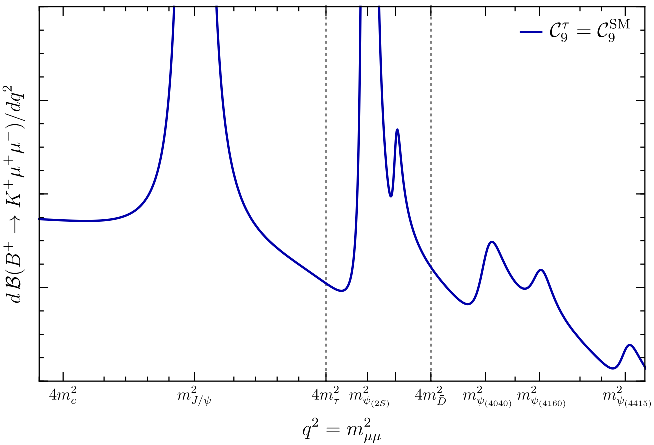
The τ loops enter as a contribution to $\mathcal{C}_9^{\text{eff}}(q^2)$:

$$Y_{\tau\bar{\tau}}(q^2) = -\frac{\alpha}{2\pi}\mathcal{C}_9^{\tau}\left[h_s\left(m_\tau^2, q^2\right) - \frac{1}{3}h_p\left(m_\tau^2, q^2\right)\right]$$

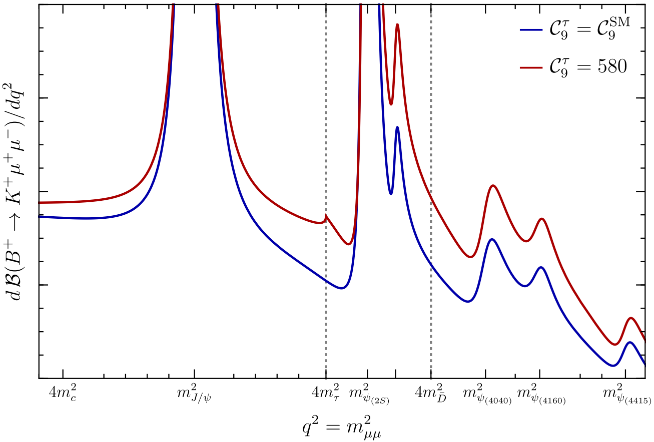
Intriguing channel because:

- It has an s-wave contribution → large
- A large enhancement over the SM is well-motivated by NP explanations to B-anomalies
- Current direct bounds are rather weak, implying $\mathcal{C}_9^{\tau} \lesssim 580$
- Very distinct shape of the spectrum, with a “cusp” at $q^2 = 4m_\tau^2$
- Again: LHCb has **lots** of data on $B \to K\mu\mu$!

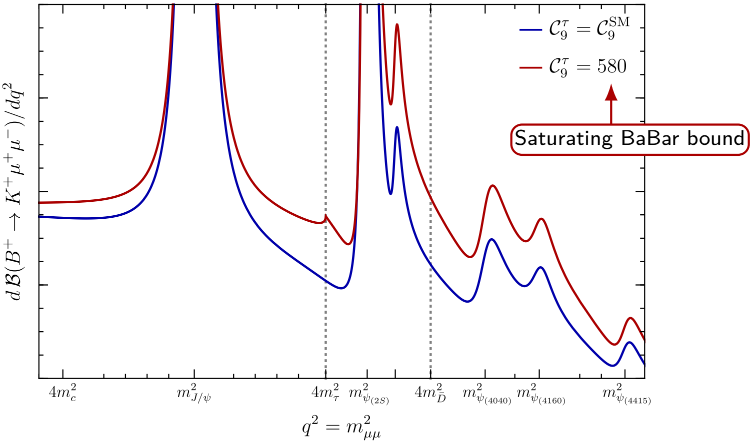
Tau effects in the spectrum



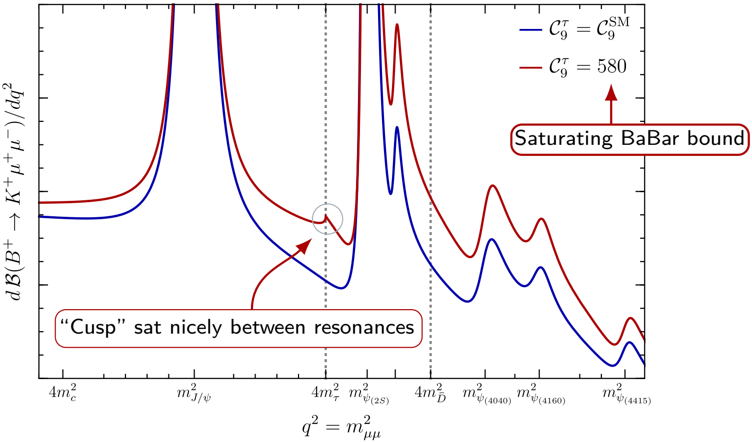
Tau effects in the spectrum



Tau effects in the spectrum



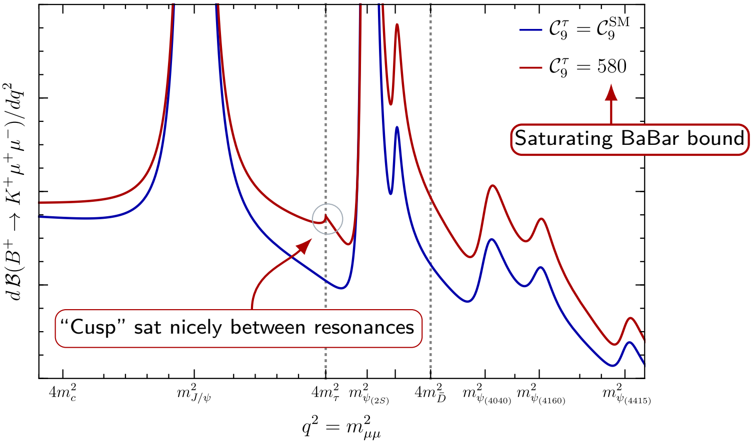
Tau effects in the spectrum



Saturating BaBar bound

“Cusp” sat nicely between resonances

Tau effects in the spectrum



Saturating BaBar bound

“Cusp” sat nicely between resonances

With the amount of data LHCb has, we can find a bound competitive to the current one!

Preliminary sensitivity and future

Preliminary sensitivity:

Preliminary sensitivity and future

Preliminary sensitivity:

$$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \lesssim 2.3 \cdot 10^{-3} \quad @\ 95\%\mathrm{CL}$$

using $9\ \mathrm{fb}^{-1}$ of pseudodata (40k events after cutting resonances).

Preliminary sensitivity and future

Preliminary sensitivity:

$$\mathrm{Br}(B^+ \to K^+ \tau^+ \tau^-) \lesssim 2.3 \cdot 10^{-3} \quad @\ 95\%\mathrm{CL}$$

using $9\ \mathrm{fb}^{-1}$ of pseudodata (40k events after cutting resonances).

Numbers preliminary! Full fit with resonance parameters (η_i, δ_i) can look different!

Preliminary sensitivity and future

Preliminary sensitivity:

$$\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \lesssim 2.3 \cdot 10^{-3} \quad @\ 95\%\mathrm{CL}$$

using $9\ \mathrm{fb}^{-1}$ of pseudodata (40k events after cutting resonances).

Numbers preliminary! Full fit with resonance parameters (η_i, δ_i) can look different!

Equivalent to the bound from BaBar, to improve with higher statistics.

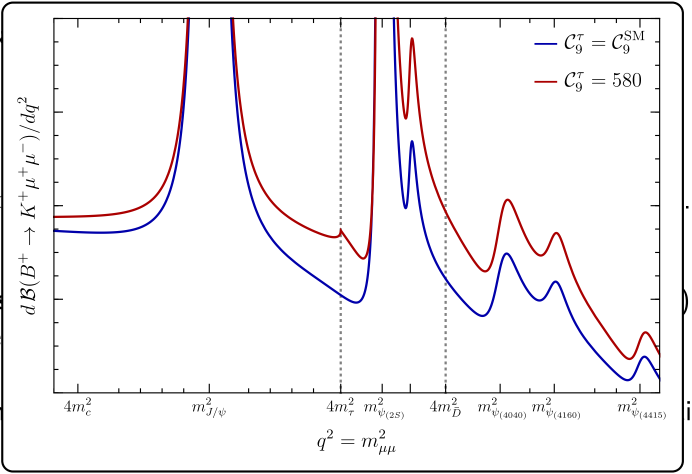
Preliminary sensitivity and future

Prelimin

using 9 fb
.

Numbers
) can
look diffe

Equivalen
istics.



Conclusions

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.
- Tau loops lead to a **distinct distortion** of the q^2 spectrum, with a cusp nicely set between the ψ and ψ' resonances!

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.
- Tau loops lead to a **distinct distortion** of the q^2 spectrum, with a cusp nicely set between the ψ and ψ' resonances!
- Sufficient understanding of the SM background required, especially the **long-distance** QCD with their respective phases.

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.
- Tau loops lead to a **distinct distortion** of the q^2 spectrum, with a cusp nicely set between the ψ and ψ' resonances!
- Sufficient understanding of the SM background required, especially the **long-distance** QCD with their respective phases.
- We fix the q^2-shape of the contributions. **Magnitudes and phases are floating** parameters in the fit.

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.
- Tau loops lead to a **distinct distortion** of the q^2 spectrum, with a cusp nicely set between the ψ and ψ' resonances!
- Sufficient understanding of the SM background required, especially the **long-distance** QCD with their respective phases.
- We fix the q^2-shape of the contributions. **Magnitudes and phases are floating** parameters in the fit.
- Bound competitive with $B \to K\tau\tau$!

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.
- Tau loops lead to a **distinct distortion** of the q^2 spectrum, with a cusp nicely set between the ψ and ψ' resonances!
- Sufficient understanding of the SM background required, especially the **long-distance** QCD with their respective phases.
- We fix the q^2-shape of the contributions. **Magnitudes and phases are floating** parameters in the fit.
- Bound competitive with $B \to K\tau\tau$!
- Future perspective: Bound will tighten with more statistics, better hadronic form factors.

Conclusions

- If the anomalies in semileptonic B decays hold any water, $B \to K\tau\tau$ should exhibit a **large enhancement**.
- Direct measurements are **tough**, current bounds allow for large enhancements over the SM value.
- Tau loops lead to a **distinct distortion** of the q^2 spectrum, with a

Thank you for your attention!

- We fix the q^2-shape of the contributions. **Magnitudes and phases are floating** parameters in the fit.
- Bound competitive with $B \to K\tau\tau$!
- Future perspective: Bound will tighten with more statistics, better hadronic form factors.

Bonus slides