# Hunting $\tau$-loops in $B^{+} \rightarrow K^{+} \mu^{+} \mu^{-}$ 

Matthias König
Physik-Institut
Universität Zürich
"7th Workshop on rare semileptonic B-Decays" Lyon, Sep 6, 2019


## Universität Zürich ${ }^{\text {VZH }}$

## FNTMF

Anomalies in semileptonic $B$-decays:

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

FCNC ( $\rightarrow$ loop level) process in the Standard Model


Anomalies in semileptonic $B$-decays:

$$
\begin{array}{ll}
\underline{B \rightarrow K \mu^{+} \mu^{-}} & \text {FCNC }(\rightarrow \text { loop level }) \text { process in the } \\
\text { Standard Model }
\end{array}
$$


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


Anomalies in semileptonic $B$-decays:

$$
\begin{array}{ll}
B \rightarrow K \mu^{+} \mu^{-} & \begin{array}{l}
\text { FCNC }(\rightarrow \text { loop level }) \text { process in the } \\
\text { Standard Model }
\end{array}
\end{array}
$$


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


New physics explanations favor NP mostly in the third generation, possible connection to the SM flavor puzzle!
$\rightarrow$ large effects in $\tau$, smaller effects in $\mu$

In these cases, one expects large effects from $\tau$ in $B \rightarrow K$ as well!
What's the sitaution on $b \rightarrow s \tau \tau$ ?

In these cases, one expects large effects from $\tau$ in $B \rightarrow K$ as well!
What's the sitaution on $b \rightarrow s \tau \tau$ ?
■ $B \rightarrow K \tau^{+} \tau^{-}$experimentally challenging:

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<2.25 \cdot 10^{-3}
$$

$$
\operatorname{Br}_{\mathrm{SM}}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)=1.2 \cdot 10^{-7}
$$

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

In these cases, one expects large effects from $\tau$ in $B \rightarrow K$ as well!
What's the sitaution on $b \rightarrow s \tau \tau$ ?

- $B \rightarrow K \tau^{+} \tau^{-}$experimentally challenging:

$$
\begin{aligned}
& \operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<2.25 \cdot 10^{-3} \\
& \operatorname{Br}_{\mathrm{SM}}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)=1.2 \cdot 10^{-7}
\end{aligned}
$$

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

- $B_{s} \rightarrow \tau^{+} \tau^{-}$likewise:

$$
\operatorname{Br}\left(B_{s} \rightarrow \tau^{+} \tau^{-}\right)<6.8 \cdot 10^{-3}
$$

$\operatorname{Br}_{\mathrm{SM}}\left(B_{s} \rightarrow \tau^{+} \tau^{-}\right)=7.73 \cdot 10^{-7}$
[LHCb (2017), Phys.Rev.Lett. 118 no.25, 251802]

In these cases, one expects large effects from $\tau$ in $B \rightarrow K$ as well!
What's the sitaution on $b \rightarrow s \tau \tau$ ?

- $B \rightarrow K \tau^{+} \tau^{-}$experimentally challenging:

$$
\begin{aligned}
& \operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<2.25 \cdot 10^{-3} \\
& \operatorname{Br}_{\mathrm{SM}}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)=1.2 \cdot 10^{-7}
\end{aligned}
$$

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

- $B_{s} \rightarrow \tau^{+} \tau^{-}$likewise:

$$
\operatorname{Br}\left(B_{s} \rightarrow \tau^{+} \tau^{-}\right)<6.8 \cdot 10^{-3}
$$

$\operatorname{Br}_{\mathrm{SM}}\left(B_{s} \rightarrow \tau^{+} \tau^{-}\right)=7.73 \cdot 10^{-7}$
[LHCb (2017), Phys.Rev.Lett. 118 no.25, 251802]
There is a lot of room for new physics!

In these cases, one expects large effects from $\tau$ in $B \rightarrow K$ as well!
What's the sitaution on $b \rightarrow s \tau \tau$ ?

- $B \rightarrow K \tau^{+} \tau^{-}$experimentally challenging:

$$
\begin{aligned}
& \operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<2.25 \cdot 10^{-3} \\
& \operatorname{Br}_{\mathrm{SM}}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)=1.2 \cdot 10^{-7}
\end{aligned}
$$

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

- $B_{s} \rightarrow \tau^{+} \tau^{-}$likewise:

$$
\operatorname{Br}\left(B_{s} \rightarrow \tau^{+} \tau^{-}\right)<6.8 \cdot 10^{-3}
$$

$\operatorname{Br}_{\mathrm{SM}}\left(B_{s} \rightarrow \tau^{+} \tau^{-}\right)=7.73 \cdot 10^{-7}$
[LHCb (2017), Phys.Rev.Lett. 118 no.25, 251802 ]
There is a lot of room for new physics!
Also: Lots of data on $b \rightarrow s \mu \mu$ !

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

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

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


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

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


## Based on:

Hunting for $B \rightarrow K \tau^{+} \tau^{-}$imprints on the $B \rightarrow K \mu^{+} \mu^{-}$dimuon spectrum
C. Cornella, G. Isidori, MK, S. Liechti, P. Owen, N. Serra

1 EFT description of $B \rightarrow K \ell \ell$

2 Long-distance hadronic effects
$3 \tau$-loops in $b \rightarrow s \mu \mu$

4 Sensitivity and future projections

5 Conclusions

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

Weak effective Lagrangian: $\quad \mathcal{L}_{\text {eff }}=\frac{4 G_{F}}{\sqrt{2}} V_{t b} V_{t s}^{*} \sum_{i} \mathcal{C}_{i}(\mu) \mathcal{O}_{i}$
FCNC operators:

$$
\begin{array}{ll}
\mathcal{O}_{7}=\frac{e}{16 \pi^{2}} m_{b}\left(\bar{s} \sigma_{\mu \nu} P_{R} b\right) F^{\mu \nu} \\
\mathcal{O}_{9}^{l}=\frac{e^{2}}{16 \pi^{2}}\left(\bar{s} \gamma_{\mu} P_{L} b\right)\left(\bar{l} \gamma^{\mu} l\right) & \mathcal{O}_{10}^{l}=\frac{e^{2}}{16 \pi^{2}}\left(\bar{s} \gamma_{\mu} P_{L} b\right)\left(\bar{l} \gamma^{\mu} \gamma_{5} l\right)
\end{array}
$$

Weak effective Lagrangian: $\quad \mathcal{L}_{\text {eff }}=\frac{4 G_{F}}{\sqrt{2}} V_{t b} V_{t s}^{*} \sum_{i} \mathcal{C}_{i}(\mu) \mathcal{O}_{i}$
FCNC operators:

$$
\mathcal{O}_{7}=\frac{e}{16 \pi^{2}} m_{b}\left(\bar{s} \sigma_{\mu \nu} P_{R} b\right) F^{\mu \nu}
$$

$$
\mathcal{O}_{9}^{l}=\frac{e^{2}}{16 \pi^{2}}\left(\bar{s} \gamma_{\mu} P_{L} b\right)\left(\bar{l} \gamma^{\mu} l\right) \quad \mathcal{O}_{10}^{l}=\frac{e^{2}}{16 \pi^{2}}\left(\bar{s} \gamma_{\mu} P_{L} b\right)\left(\bar{l} \gamma^{\mu} \gamma_{5} l\right)
$$

Four-quark operators:


$$
\mathcal{O}_{1}^{q}=\left(\bar{s} \gamma_{\mu} P_{L} q\right)\left(\bar{q} \gamma_{\mu} P_{L} b\right)
$$

$$
\mathcal{O}_{2}^{q}=\left(\bar{s}^{\alpha} \gamma_{\mu} P_{L} q^{\beta}\right)\left(\bar{q}^{\beta} \gamma_{\mu} P_{L} b^{\alpha}\right)
$$



Differential decay rate:

$$
\begin{aligned}
\frac{d \Gamma}{d q^{2}}=\frac{\alpha_{\mathrm{em}}^{2} G_{F}^{2}\left|V_{t b} V_{t s}^{*}\right|^{2}}{128 \pi^{5}} \kappa \beta\{ & \frac{2}{3} \kappa^{2} \beta^{2}\left|\mathcal{C}_{10}^{\mu} f_{+}\left(q^{2}\right)\right|^{2}+\frac{4 m_{\mu}^{2}\left(m_{B}^{2}-m_{K}^{2}\right)^{2}}{q^{2} m_{B}^{2}}\left|\mathcal{C}_{10}^{\mu} f_{0}\left(q^{2}\right)\right|^{2} \\
& \left.+\kappa^{2}\left(1-\frac{1}{3} \beta\right)\left|\mathcal{C}_{9}^{\mu} f_{+}\left(q^{2}\right)+2 \mathcal{C}_{7} \frac{m_{b}+m_{s}}{m_{B}+m_{K}} f_{T}\left(q^{2}\right)\right|^{2}\right\},
\end{aligned}
$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_{i}(\mu)$

■ Hadronic matrix elements: form factors $f_{i}\left(q^{2}\right) \quad$ [see talk by N. Gubermari]

Differential decay rate:

$$
\begin{aligned}
\frac{d \Gamma}{d q^{2}}=\frac{\alpha_{\mathrm{em}}^{2} G_{F}^{2}\left|V_{t b} V_{t s}^{*}\right|^{2}}{128 \pi^{5}} \kappa \beta\{ & \frac{2}{3} \kappa^{2} \beta^{2}\left|\mathcal{C}_{10}^{\mu} f_{+}\left(q^{2}\right)\right|^{2}+\frac{4 m_{\mu}^{2}\left(m_{B}^{2}-m_{K}^{2}\right)^{2}}{q^{2} m_{B}^{2}}\left|\mathcal{C}_{10}^{\mu} f_{0}\left(q^{2}\right)\right|^{2} \\
& \left.+\kappa^{2}\left(1-\frac{1}{3} \beta\right)\left|\mathcal{C}_{9}^{\mu} f_{+}\left(q^{2}\right)+2 \mathcal{C}_{7} \frac{m_{b}+m_{s}}{m_{B}+m_{K}} f_{T}\left(q^{2}\right)\right|^{2}\right\},
\end{aligned}
$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_{i}(\mu)$
- Hadronic matrix elements: form factors $f_{i}\left(q^{2}\right) \quad$ [see talk by $N$. Gubernari]

Real world more complicated than that. Introduce:

$$
\mathcal{C}_{9}^{\mu} \rightarrow \mathcal{C}_{9}^{\mathrm{eff}}\left(q^{2}\right)=\mathcal{C}_{9}^{\mu}+Y_{i}\left(q^{2}\right)
$$

Differential decay rate:

$$
\begin{aligned}
\frac{d \Gamma}{d q^{2}}=\frac{\alpha_{\mathrm{em}}^{2} G_{F}^{2}\left|V_{t b} V_{t s}^{*}\right|^{2}}{128 \pi^{5}} \kappa \beta\{ & \frac{2}{3} \kappa^{2} \beta^{2}\left|\mathcal{C}_{10}^{\mu} f_{+}\left(q^{2}\right)\right|^{2}+\frac{4 m_{\mu}^{2}\left(m_{B}^{2}-m_{K}^{2}\right)^{2}}{q^{2} m_{B}^{2}}\left|\mathcal{C}_{10}^{\mu} f_{0}\left(q^{2}\right)\right|^{2} \\
& \left.+\kappa^{2}\left(1-\frac{1}{3} \beta\right)\left|\mathcal{C}_{9}^{\mu} f_{+}\left(q^{2}\right)+2 \mathcal{C}_{7} \frac{m_{b}+m_{s}}{m_{B}+m_{K}} f_{T}\left(q^{2}\right)\right|^{2}\right\},
\end{aligned}
$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_{i}(\mu)$

■ Hadronic matrix elements: form factors $f_{i}\left(q^{2}\right) \quad$ [see talk by N. Gubermari]
Real world more complicated than that. Introduce:

$$
\mathcal{C}_{9}^{\mu} \rightarrow \mathcal{C}_{9}^{\mathrm{eff}}\left(q^{2}\right)=\mathcal{C}_{9}^{\mu}+Y_{i}\left(q^{2}\right)
$$

short-distance SM/NP

Differential decay rate:

$$
\begin{aligned}
\frac{d \Gamma}{d q^{2}}=\frac{\alpha_{\mathrm{em}}^{2} G_{F}^{2}\left|V_{t b} V_{t s}^{*}\right|^{2}}{128 \pi^{5}} \kappa \beta\{ & \frac{2}{3} \kappa^{2} \beta^{2}\left|\mathcal{C}_{10}^{\mu} f_{+}\left(q^{2}\right)\right|^{2}+\frac{4 m_{\mu}^{2}\left(m_{B}^{2}-m_{K}^{2}\right)^{2}}{q^{2} m_{B}^{2}}\left|\mathcal{C}_{10}^{\mu} f_{0}\left(q^{2}\right)\right|^{2} \\
& \left.+\kappa^{2}\left(1-\frac{1}{3} \beta\right)\left|\mathcal{C}_{9}^{\mu} f_{+}\left(q^{2}\right)+2 \mathcal{C}_{7} \frac{m_{b}+m_{s}}{m_{B}+m_{K}} f_{T}\left(q^{2}\right)\right|^{2}\right\},
\end{aligned}
$$

Ingredients for the description:

- Perturbative short distance: matching coefficients $\mathcal{C}_{i}(\mu)$
- Hadronic matrix elements: form factors $f_{i}\left(q^{2}\right)$ [see talk by N. Gubernari]

Real world more complicated than that. Introduce:


## 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.

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

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 $\left(k^{2} \sim m_{c}^{2}\right)$
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 $\left(k^{2} \sim m_{c}^{2}\right)$
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; see talk by Nico]

Universität

Leading contribution: Intermediate charmonium resonances.


Leading contribution: Intermediate charmonium resonances.


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

$$
\Delta Y_{c \bar{c}}^{1 P}(s)=\eta_{V} e^{i \delta_{V}} \frac{s}{m_{V}^{2}} \frac{m_{V} \Gamma_{V}}{s-m_{V}^{2}+i m_{V} \Gamma_{V}}
$$

## Charm loops - two-particle states

Two-particle intermediate states:


Two-particle intermediate states:

$q^{2}$ dependence through subtracted hadronic dispersion relation:

$$
\begin{aligned}
\Delta Y_{c \bar{c}}^{2 \mathrm{P}}(s)= & \frac{s}{\pi} \sum_{V} \int_{\tau_{V}}^{\infty} \frac{d \tilde{s}}{\tilde{s}} \frac{\rho_{V}(\tilde{s})}{\tilde{s}-s} \\
& V \in\left\{D D, D^{*} D, D^{*} D^{*}\right\}
\end{aligned}
$$

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

Two-particle intermediate states:

$q^{2}$ dependence through subtracted hadronic dispersion relation:

$$
\begin{aligned}
\Delta Y_{c \bar{c}}^{2 \mathrm{P}}(s)= & \frac{s}{\pi} \sum_{V} \int_{\tau_{V}}^{\infty} \frac{d \tilde{s}}{\tilde{s}} \frac{\rho_{V}(\tilde{s})}{\tilde{s}-s} \\
& V \in\left\{D D, D^{*} D, D^{*} D^{*}\right\}
\end{aligned}
$$

[Khodjamirian et al. (2010), JHEP 1009 089; Khodjamirian et al. (2013), JHEP 1302 010]
What are the various $\rho_{V}(s) ? \quad \rightarrow$ 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 $V V^{\prime} \rightarrow \mu \mu$ using helicity arguments.

## Charm loops - two-particle states

First-principle calculation of the spectral densities $\rho_{V}(s)$ not viable.

$\rightarrow$ Can estimate $\rho_{V}(s)$ from $V V^{\prime} \rightarrow \mu \mu$ using helicity arguments.

From this we find: $\rho_{V}=\sum_{n} c_{n}^{V} \beta^{n}\left(4 m_{V}^{2} / s\right), \quad \beta(\tau)=\sqrt{1-\tau}$

First-principle calculation of the spectral densities $\rho_{V}(s)$ not viable.

$\rightarrow$ Can estimate $\rho_{V}(s)$ from $V V^{\prime} \rightarrow \mu \mu$ using helicity arguments.

From this we find: $\rho_{V}=\sum_{n} c_{n}^{V} \beta^{n}\left(4 m_{V}^{2} / s\right), \quad \beta(\tau)=\sqrt{1-\tau}$
Keeping only the leading partial waves:

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



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

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.
$\rightarrow$ We limit ourselves to single-particle contributions.

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.
$\rightarrow$ We limit ourselves to single-particle contributions.


$$
Y_{\text {light }}^{1 \mathrm{P}}(s)=\sum_{V} \eta_{V} e^{i \delta_{V}} \frac{m_{V} \Gamma_{V}}{s-m_{V}^{2}+i m_{V} \Gamma_{V}}
$$

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.

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:

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

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

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:

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

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:

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

At low $q^{2}$, the slope of the perturbative charm contribution is:

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

This yields the following set of constraints:
$\operatorname{Re}\left[\sum_{j=\Psi(1 S), \ldots} \eta_{j} e^{i \delta_{j}} \frac{\Gamma_{j}}{m_{j}^{3}}+\eta_{\bar{D}} e^{i \delta_{j}} \frac{1}{6 m_{\bar{D}}^{2}}+\sum_{j=D, D^{*}} \eta_{j} e^{i \delta_{j}} \frac{1}{10 m_{j}^{2}}\right]=(1.7 \pm 2.2) \cdot 10^{-2} \mathrm{GeV}^{-2}$

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

At low $q^{2}$, the slope of the perturbative charm contribution is:

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

This yields the following set of constraints:
$\operatorname{Re}\left[\sum_{j=\Psi(1 S), \ldots} \eta_{j} e^{i \delta_{j}} \frac{\Gamma_{j}}{m_{j}^{3}}+\eta_{\bar{D}} e^{i \delta_{j}} \frac{1}{6 m_{\bar{D}}^{2}}+\sum_{j=D, D^{*}} \eta_{j} e^{i \delta_{j}} \frac{1}{10 m_{j}^{2}}\right]=(1.7 \pm 2.2) \cdot 10^{-2} \mathrm{GeV}^{-2}$
$\left|\sum_{j=\Psi(1 S), \ldots} \eta_{j} e^{i \delta_{j}} \frac{\Gamma_{j}}{m_{j}^{3}}+\eta_{\bar{D}} e^{i \delta_{j}} \frac{1}{6 m_{\bar{D}}^{2}}+\sum_{j=D, D^{*}} \eta_{j} e^{i \delta_{j}} \frac{1}{10 m_{j}^{2}}\right| \leq 5 \cdot 10^{-2} \mathrm{GeV}^{-2}$
Similarly, we can put an upper limit on the $\eta$ from $\Delta Y$ directly:

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

$\tau$-loops in $b \rightarrow s \mu \mu$

The $\tau$ loops enter as a contribution to $\mathcal{C}_{9}^{\text {eff }}\left(q^{2}\right)$ :

$$
Y_{\tau \bar{\tau}}\left(q^{2}\right)=-\frac{\alpha}{2 \pi} \mathcal{C}_{9}^{\tau}\left[h_{s}\left(m_{\tau}^{2}, q^{2}\right)-\frac{1}{3} h_{p}\left(m_{\tau}^{2}, q^{2}\right)\right]
$$

Intriguing channel because:
■ It has an $s$-wave contribution $\rightarrow$ large

The $\tau$ loops enter as a contribution to $\mathcal{C}_{9}^{\text {eff }}\left(q^{2}\right)$ :

$$
Y_{\tau \bar{\tau}}\left(q^{2}\right)=-\frac{\alpha}{2 \pi} \mathcal{C}_{9}^{\tau}\left[h_{s}\left(m_{\tau}^{2}, q^{2}\right)-\frac{1}{3} h_{p}\left(m_{\tau}^{2}, q^{2}\right)\right]
$$

Intriguing channel because:

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

The $\tau$ loops enter as a contribution to $\mathcal{C}_{9}^{\text {eff }}\left(q^{2}\right)$ :

$$
Y_{\tau \bar{\tau}}\left(q^{2}\right)=-\frac{\alpha}{2 \pi} \mathcal{C}_{9}^{\tau}\left[h_{s}\left(m_{\tau}^{2}, q^{2}\right)-\frac{1}{3} h_{p}\left(m_{\tau}^{2}, q^{2}\right)\right]
$$

Intriguing channel because:
■ It has an $s$-wave contribution $\rightarrow$ large

- A large enhancement over the SM is well-motivated by NP explanations to $B$-anomalies
- Current direct bounds are rather weak, implying $\mathcal{C}_{9}^{\tau} \lesssim 580$

The $\tau$ loops enter as a contribution to $\mathcal{C}_{9}^{\text {eff }}\left(q^{2}\right)$ :

$$
Y_{\tau \bar{\tau}}\left(q^{2}\right)=-\frac{\alpha}{2 \pi} \mathcal{C}_{9}^{\tau}\left[h_{s}\left(m_{\tau}^{2}, q^{2}\right)-\frac{1}{3} h_{p}\left(m_{\tau}^{2}, q^{2}\right)\right]
$$

Intriguing channel because:

- It has an $s$-wave contribution $\rightarrow$ 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 $q^{2}=4 m_{\tau}^{2}$

The $\tau$ loops enter as a contribution to $\mathcal{C}_{9}^{\text {eff }}\left(q^{2}\right)$ :

$$
Y_{\tau \bar{\tau}}\left(q^{2}\right)=-\frac{\alpha}{2 \pi} \mathcal{C}_{9}^{\tau}\left[h_{s}\left(m_{\tau}^{2}, q^{2}\right)-\frac{1}{3} h_{p}\left(m_{\tau}^{2}, q^{2}\right)\right]
$$

Intriguing channel because:

- It has an $s$-wave contribution $\rightarrow$ 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 $q^{2}=4 m_{\tau}^{2}$

■ Again: LHCb has lots of data on $B \rightarrow K \mu \mu$ !






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:

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right) \lesssim 8.1 \cdot 10^{-4} @ 95 \% \mathrm{CL}
$$

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

## Preliminary sensitivity and future

## Preliminary sensitivity:

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right) \lesssim 8.1 \cdot 10^{-4} @ 95 \% \mathrm{CL}
$$

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

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<7.6 \cdot 10^{-4} \quad @ 95 \% \mathrm{CL}
$$

assuming FF uncertainty reduced to $30 \%$

Preliminary sensitivity:

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right) \lesssim 8.1 \cdot 10^{-4} @ 95 \% \mathrm{CL}
$$

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

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<7.6 \cdot 10^{-4} \quad @ 95 \% \mathrm{CL}
$$

assuming FF uncertainty reduced to $30 \%$
Numbers preliminary! Full fit with resonance parameters $\left(\eta_{i}, \delta_{i}\right)$ underway!

## Preliminary sensitivity:

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right) \lesssim 8.1 \cdot 10^{-4} \quad @ 95 \% \mathrm{CL}
$$

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

$$
\operatorname{Br}\left(B^{+} \rightarrow K^{+} \tau^{+} \tau^{-}\right)<7.6 \cdot 10^{-4} \quad @ 95 \% \mathrm{CL}
$$

assuming FF uncertainty reduced to $30 \%$
Numbers preliminary! Full fit with resonance parameters $\left(\eta_{i}, \delta_{i}\right)$ underway!

Competitive with the projected bounds from Belle!


Competitive with the projected bounds from Belle!
[see talk by S. Wehler]

## Conclusions

## Conclusions

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

■ If the anomalies in semileptonic $B$ decays hold any water, $B \rightarrow K \tau \tau$ 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 $\psi$ and $\psi^{\prime}$ resonances!
- If the anomalies in semileptonic $B$ decays hold any water, $B \rightarrow K \tau \tau$ 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 $\psi$ and $\psi^{\prime}$ resonances!
- Sufficient understanding of the SM background required, especially the long-distance QCD with their respective phases.
- If the anomalies in semileptonic $B$ decays hold any water, $B \rightarrow K \tau \tau$ 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 $\psi$ and $\psi^{\prime}$ 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.
- If the anomalies in semileptonic $B$ decays hold any water, $B \rightarrow K \tau \tau$ 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 $\psi$ and $\psi^{\prime}$ 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 $B \rightarrow K \tau \tau$ !
- If the anomalies in semileptonic $B$ decays hold any water, $B \rightarrow K \tau \tau$ 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 $\psi$ and $\psi^{\prime}$ 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 $B \rightarrow K \tau \tau$ !

■ Future perspective: Bound will tighten with more statistics, better hadronic form factors.

- If the anomalies in semileptonic $B$ decays hold any water, $B \rightarrow K \tau \tau$ 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!

are floating parameters in the fit.

- Bound competitive with $B \rightarrow K \tau \tau$ !
- Future perspective: Bound will tighten with more statistics, better hadronic form factors.


## Bonus slides

