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

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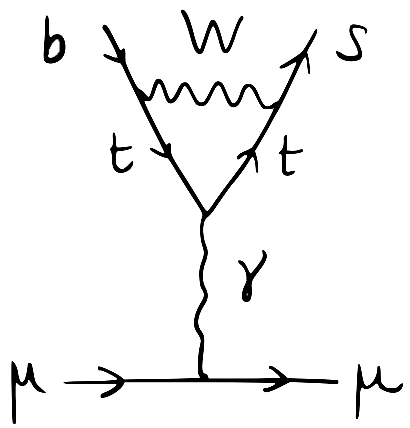
based on ongoing work with G.Isidori, M.König, S. Liechti, P. Owen, N.Serra

$B^+ \to K^+\mu^+\mu^-$

Key channel for indirect NP searches

- FCNC, hence suppressed in SM
- NP could modify decay rates, angular distributions…



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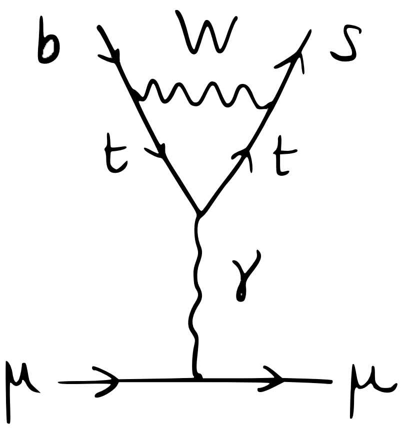

Flavour anomalies several $b \to s\mu\mu$ observables in tension with SM

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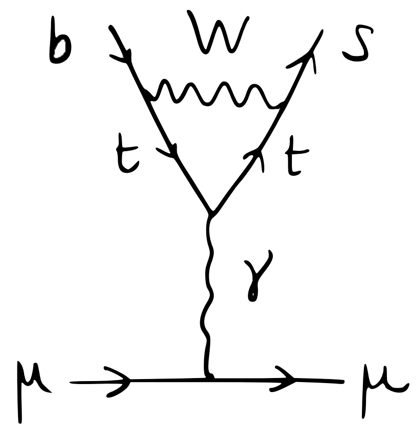

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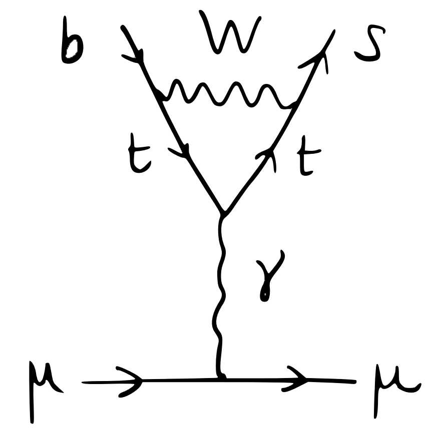

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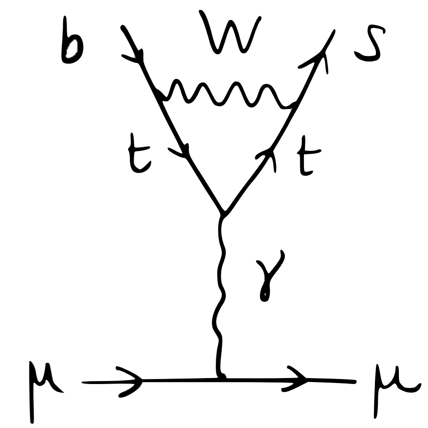

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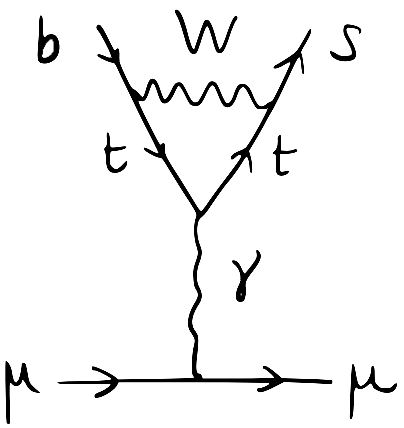

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Can we improve its description at experiments?

Can we use it to extract bounds on NP in $b \to s\tau\tau$?

Effective field theory description

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

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

SM

$$\begin{cases} O_9^{\mu} = \dfrac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu \mu) & O_{10}^{\mu} = \dfrac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu \gamma_5 \mu) \\ O_7 = \dfrac{e}{16\pi^2} m_b\,(\bar{s}\sigma_{\mu\nu} P_R b)\, F^{\mu\nu} & O_{1-6}, O_8 \end{cases}$$

NP $\quad C_i^{\text{SM}} \to C_i^{\text{SM}} + \delta C_i^{NP}$ and/or new operators

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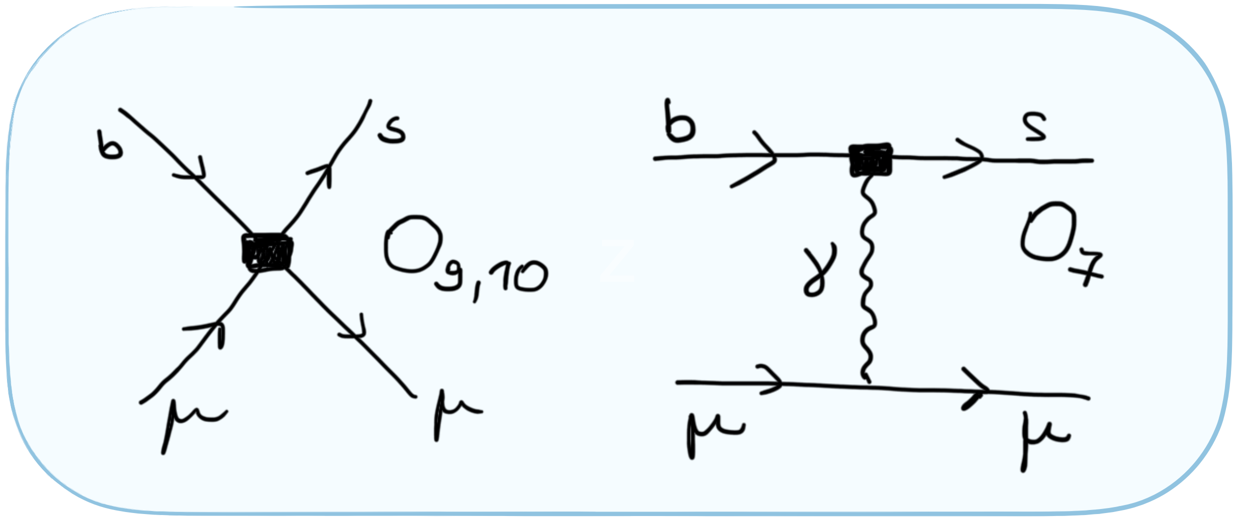

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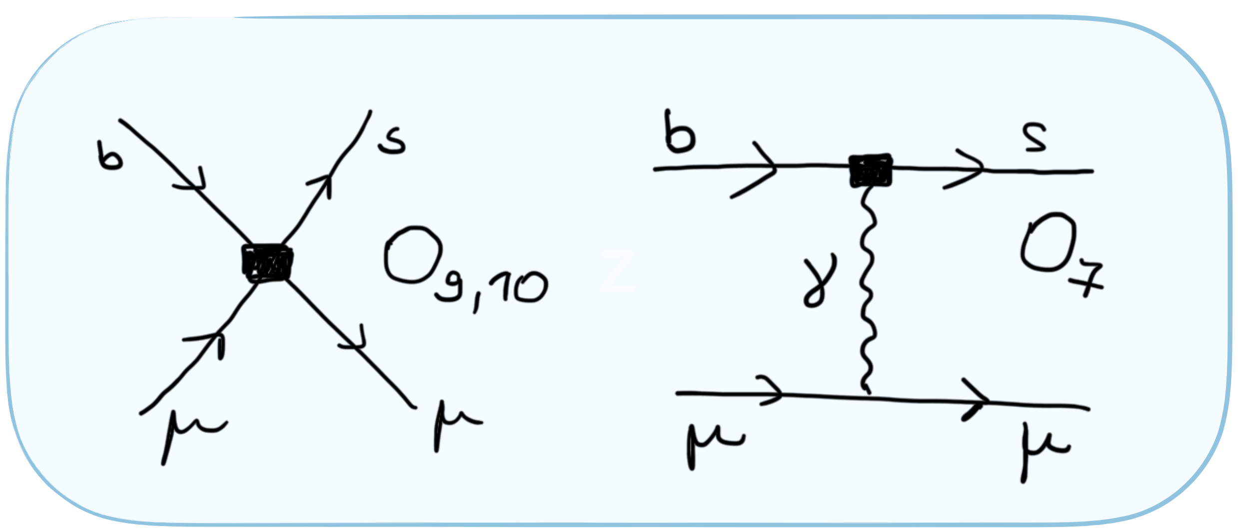

- C_i^{SM}
- f_+, f_0, f_T for $B \to K$

Non-local effects: the charm loop

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

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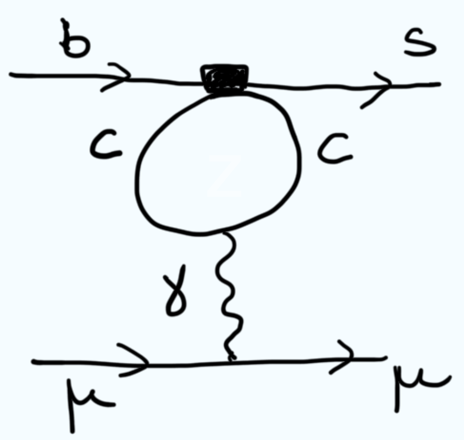

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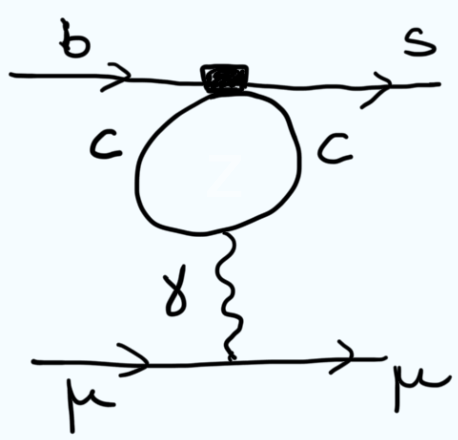

[Semi]perturbative approach valid at low q^2:

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

[Khodjamirian et al., 1212.0234]

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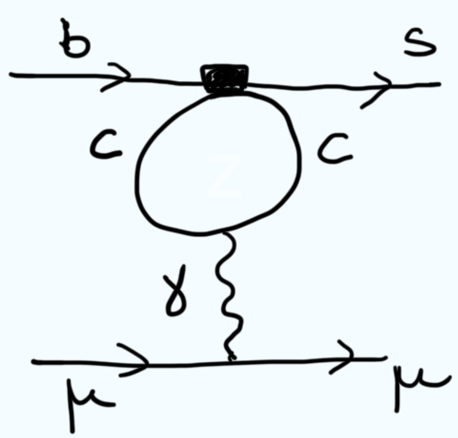

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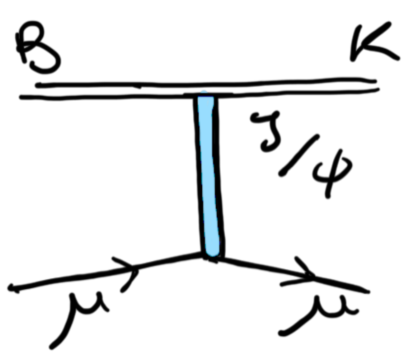
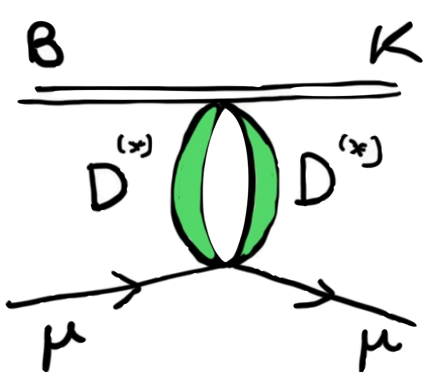


$q^2 > m_{J/\psi}^2$



$q^2 > 4\, m_D^2$

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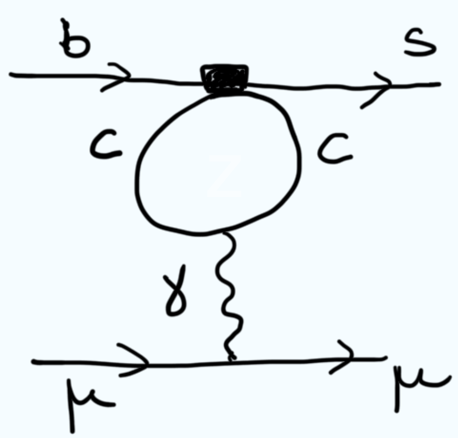

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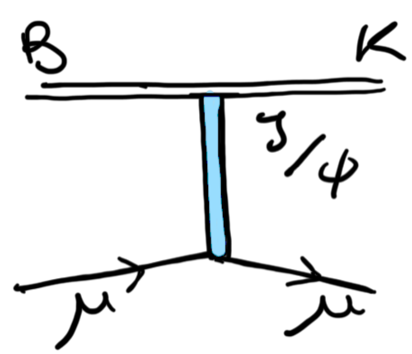

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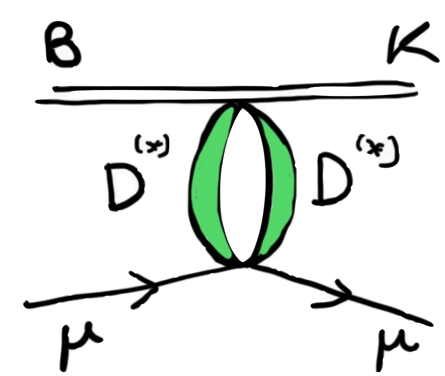

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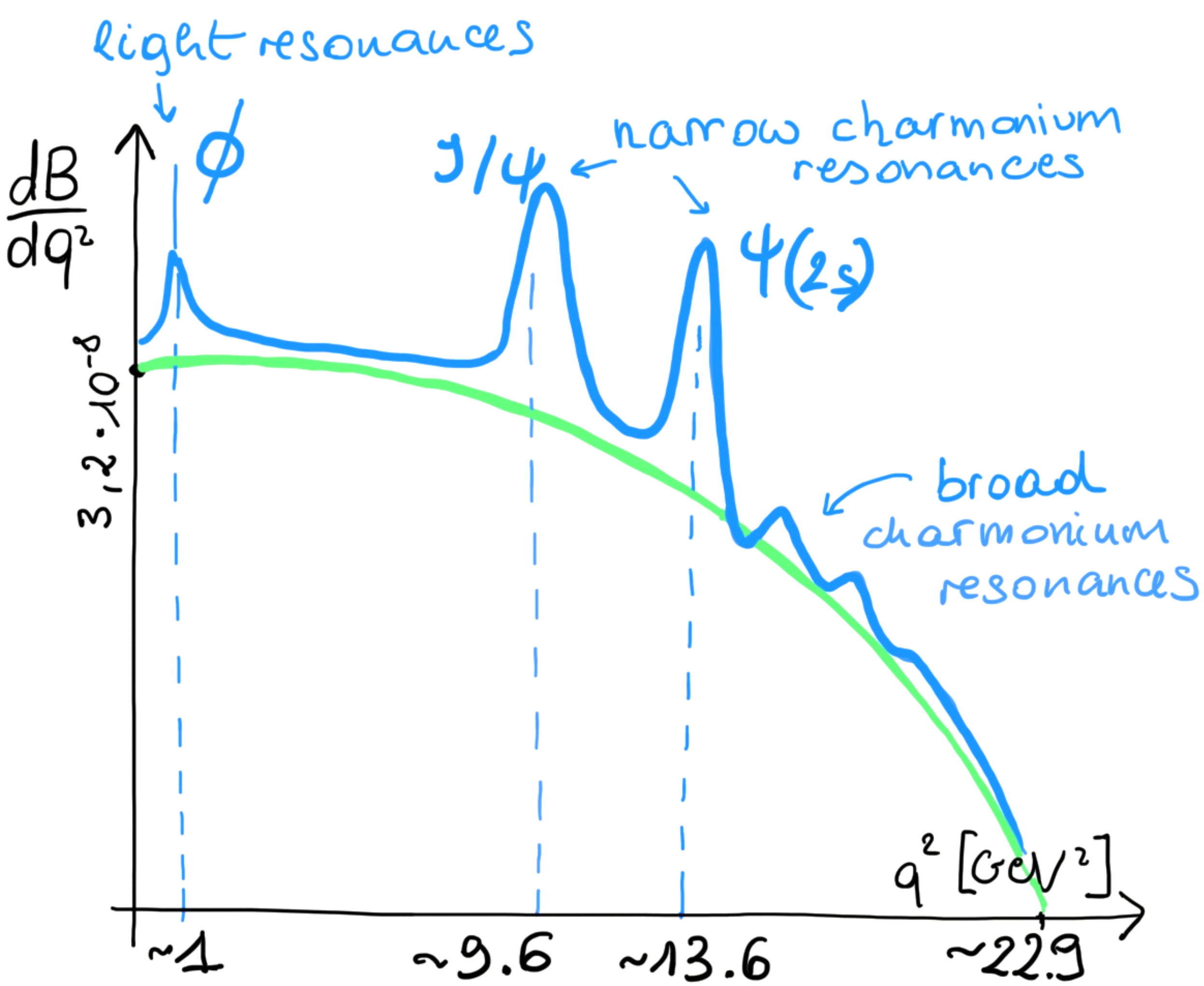
Goal: model long-distance effects at experiments, in the entire spectrum.

Long-distance effects at experiments



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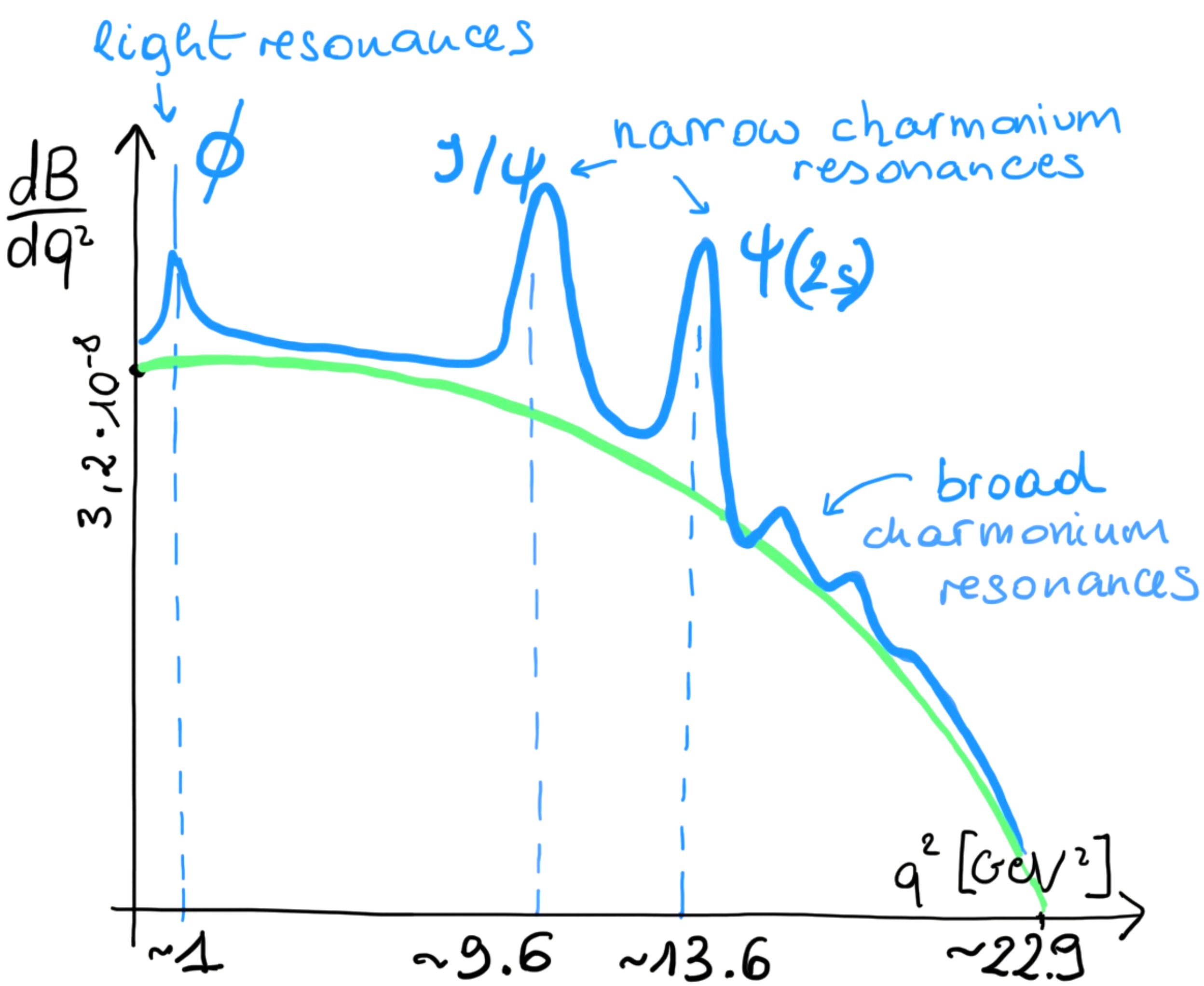

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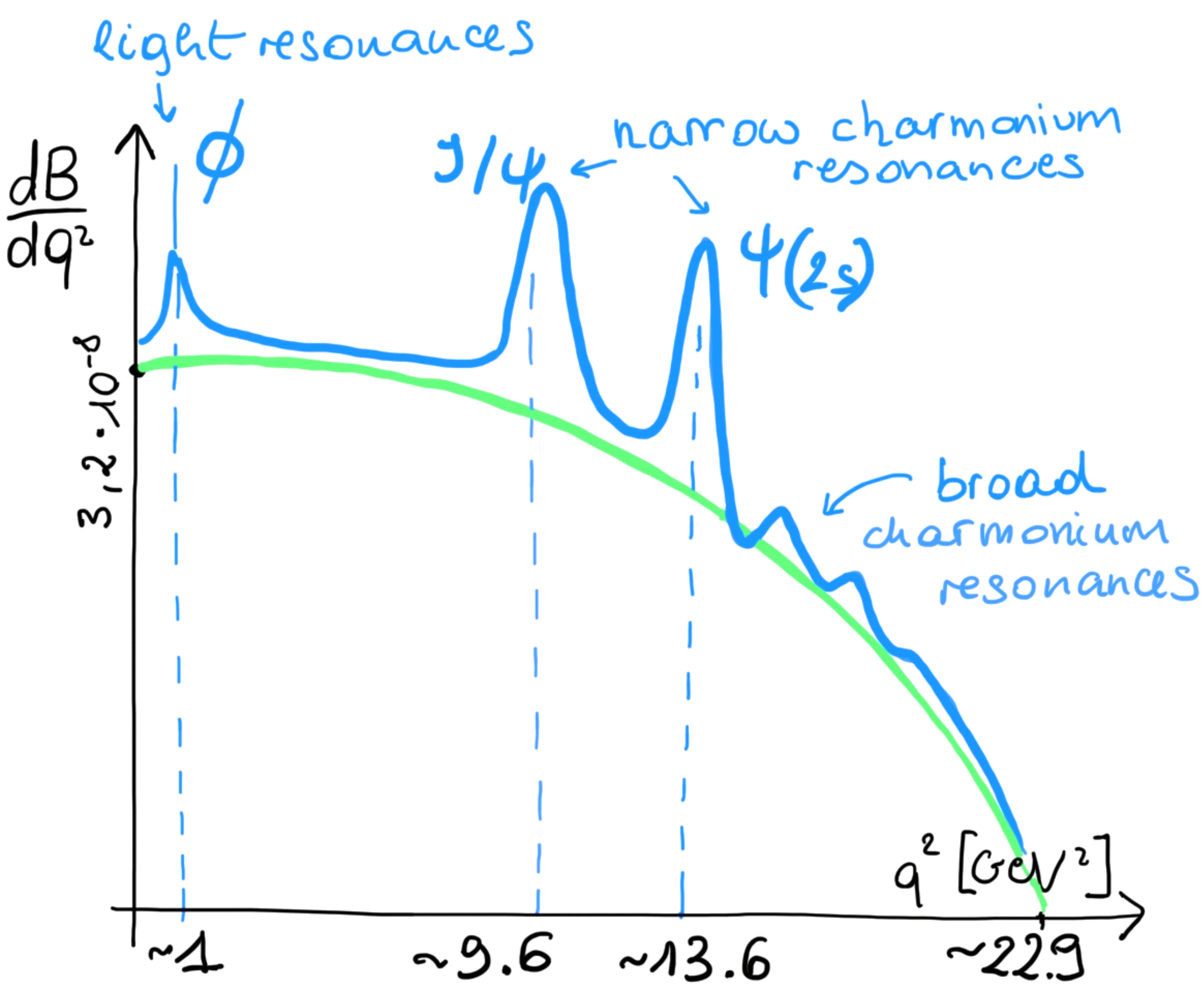

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fit parameters

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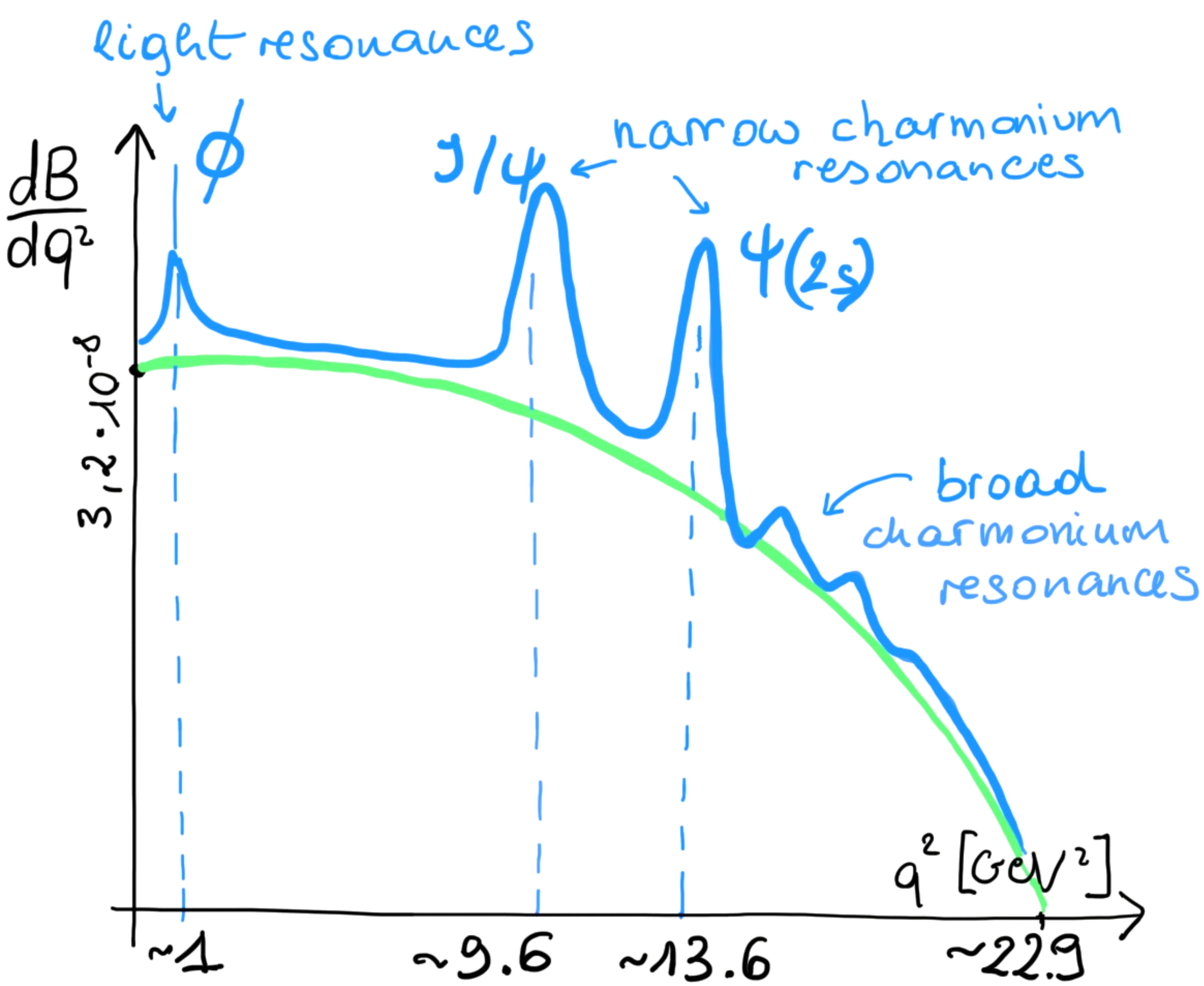

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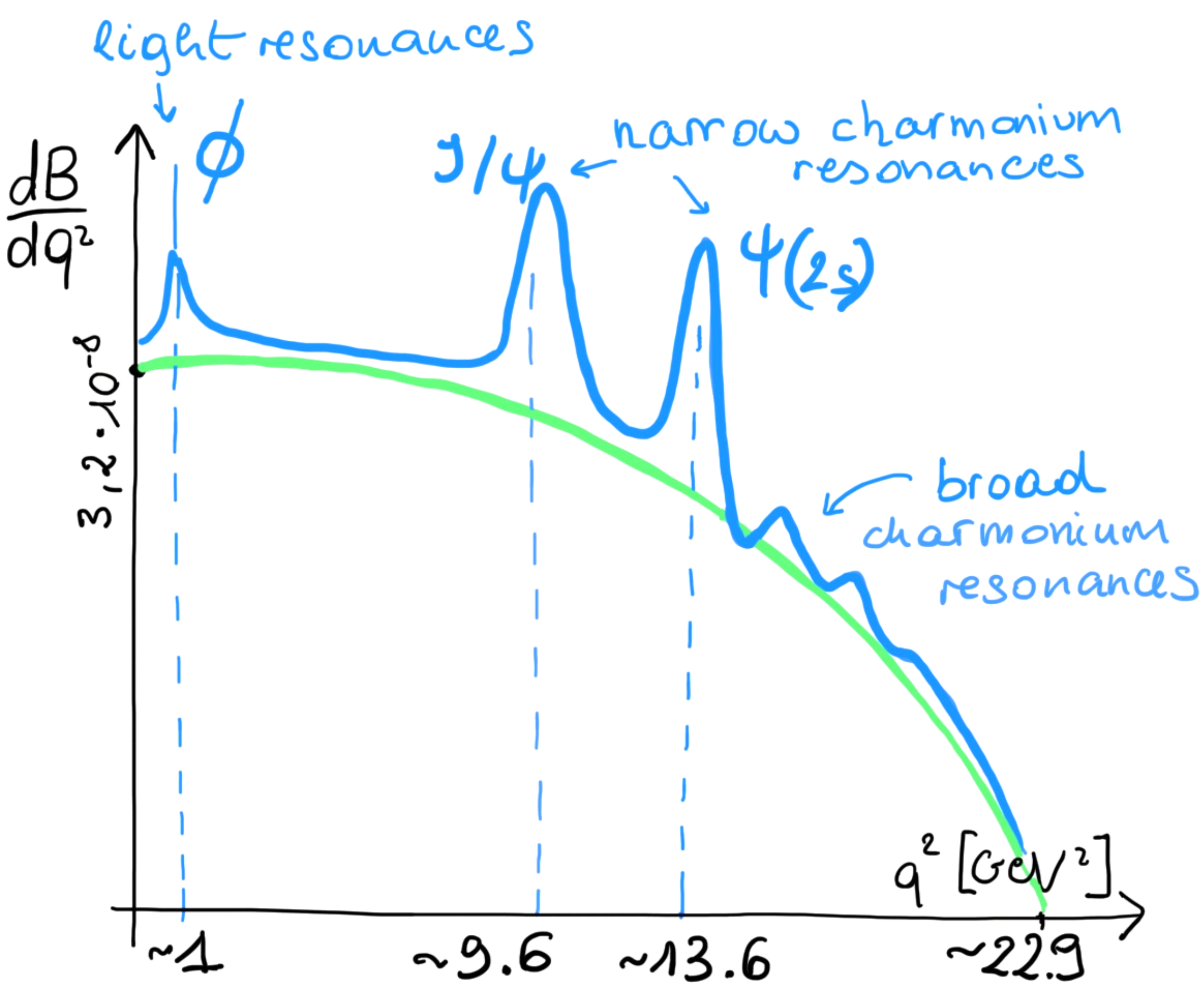

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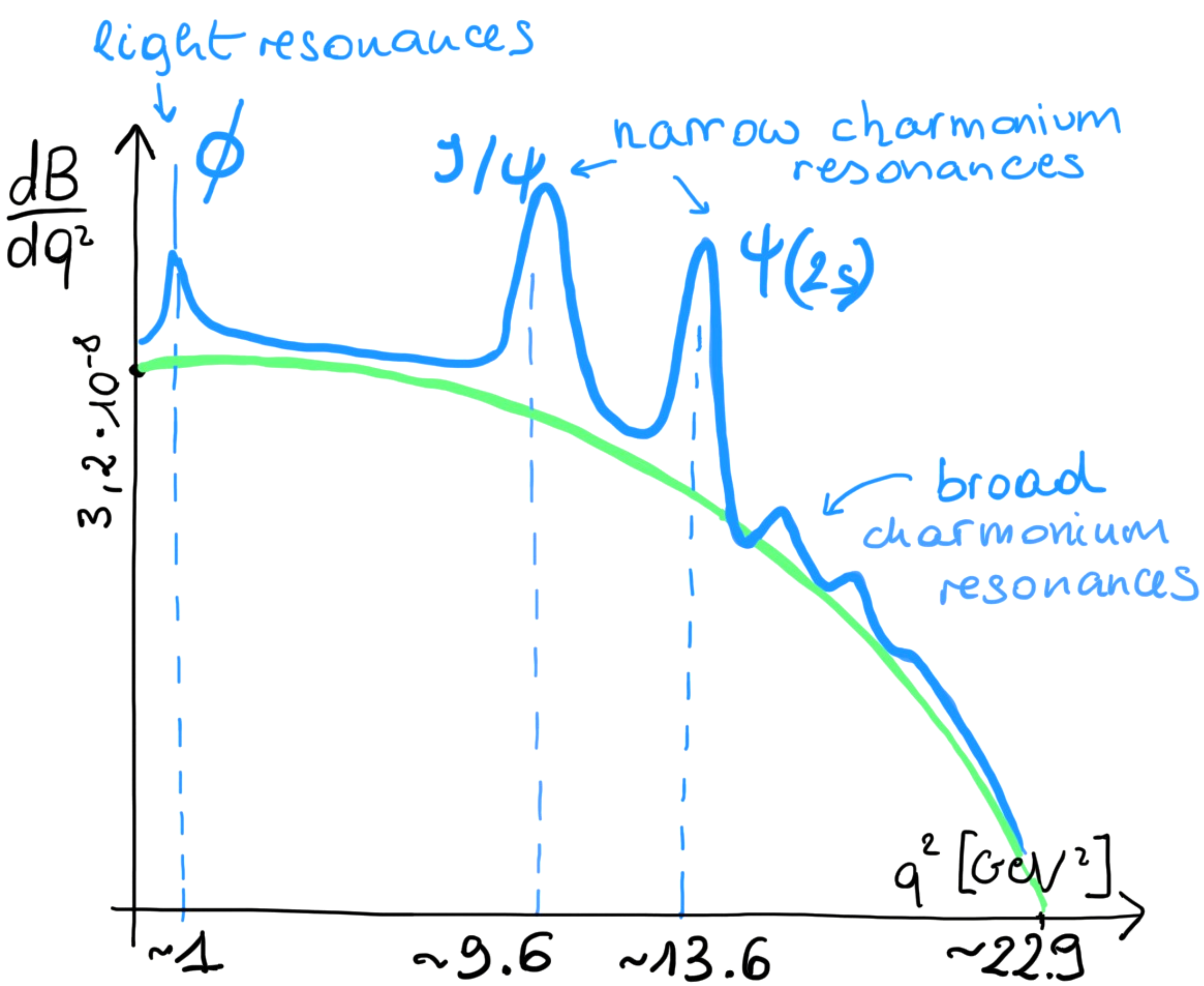

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- access long-distance info unaccessible from first principles [e.g. phases]
- extract reliable short-distance info [hence NP!]

Our proposal in a nutshell

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

$$C_9^{\text{eff}}(q^2) = C_9 + Y(q^2)\,, \qquad Y(q^2) = Y_0 + \overbrace{\underbrace{\Delta C_{q\bar{q}}^{1\text{P}}(q^2)}_{\text{up}} + \mathrlap{\underbrace{\phantom{\Delta C_{c\bar{c}}^{1\text{P}}(q^2) + \Delta C_{c\bar{c}}^{2\text{P}}(q^2)}}_{\text{charm}}}\Delta C_{c\bar{c}}^{1\text{P}}(q^2)}^{\text{1P exchange}} + \overbrace{\Delta C_{c\bar{c}}^{2\text{P}}(q^2)}^{\text{2P exchange}}$$

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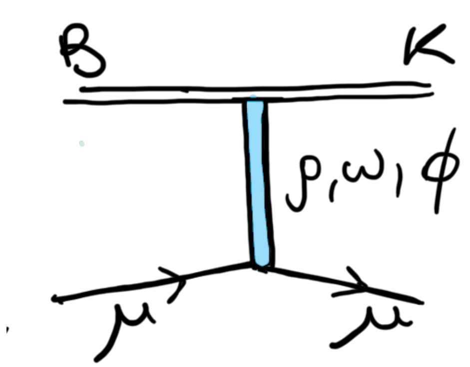
Light resonances (ρ, ω, ϕ)



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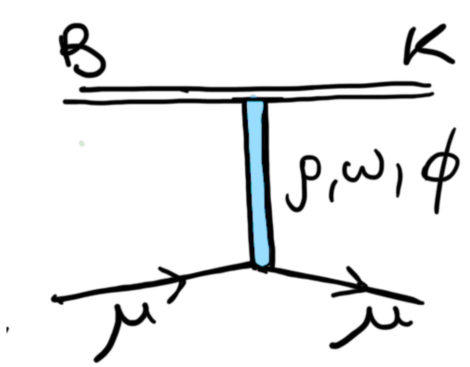

$$\Delta C_{q\bar q}^{\text{1P}}(q^2) = \sum_j \eta_j \, e^{i\delta_j} A_j^{\text{res}}(q^2)$$

constraint: $|\Delta C_{\bar q q}^{\text{1P}}(0)| = \mathcal{O}\left(\frac{\Lambda_{QCD}}{m_b}\right) \cdot$ CKM suppression ≈ 0

Charm contribution

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

Two-particle $\bar{c}c$ states $(D\,D, D^*\,D^*, DD^*)$

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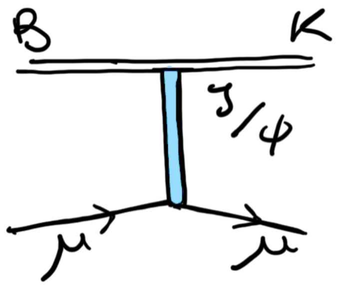

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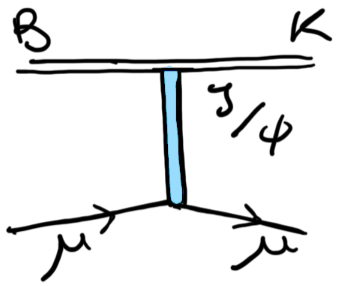

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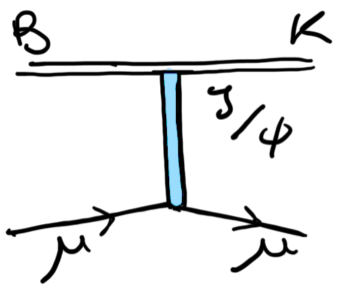

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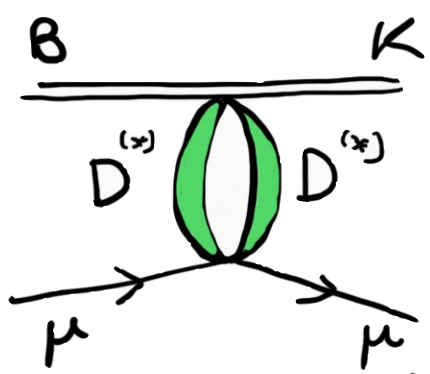
$\rho(s) = \mathrm{Im} \Bigg\{$  $\Bigg\}$

$$\sim \begin{cases} \left(1 - \dfrac{4m_D^2}{s}\right)^{3/2} & D\,D \\ \left(1 - \dfrac{4m_{D^*}^2}{s}\right)^{3/2} & D^*D^* \\ \left(1 - \dfrac{4m_{\bar{D}}^2}{s}\right)^{1/2} & D^*D \end{cases}$$

Charm contribution

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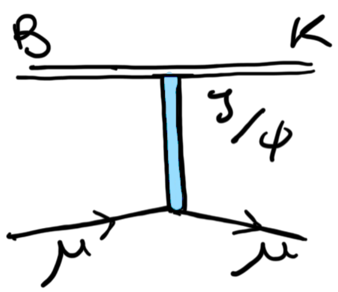

$$\Delta C^{1\mathrm{P}}_{c\bar{c}}(q^2) = \sum_j \eta_j\, e^{i\delta_j} \frac{q^2}{m_j^2} A^{\mathrm{res}}_j(q^2)\,,$$

Two-particle $\bar{c}c$ states $(D\,D, D^*\,D^*, DD^*)$

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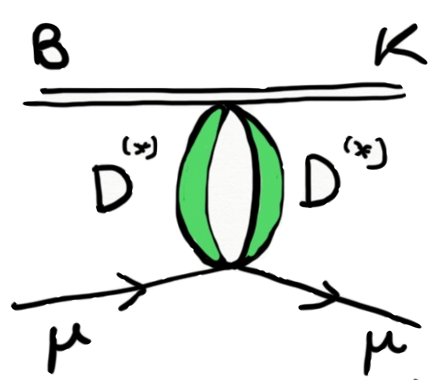
$\rho(s)$ = Im $\Big\{$  $\Big\}$

$$\sim \begin{cases} \left(1 - \frac{4m_D^2}{s}\right)^{3/2} & D\,D \\ \left(1 - \frac{4m_{D^*}^2}{s}\right)^{3/2} & D^* D\,^* \\ \left(1 - \frac{4m_{\bar{D}}^2}{s}\right)^{1/2} & D^* D \end{cases}$$

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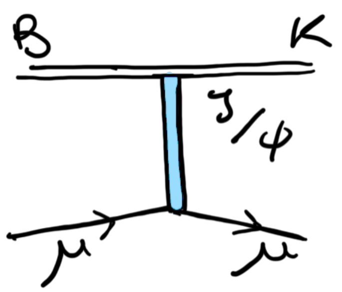

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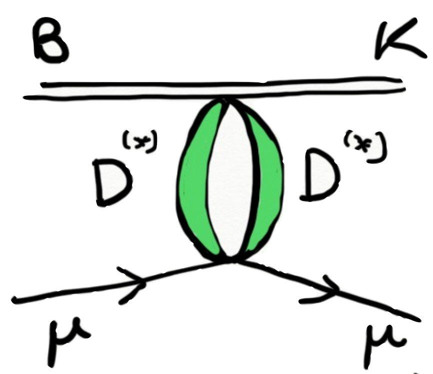
$\rho(s)$ = Im $\Bigg\{$  $\Bigg\}$

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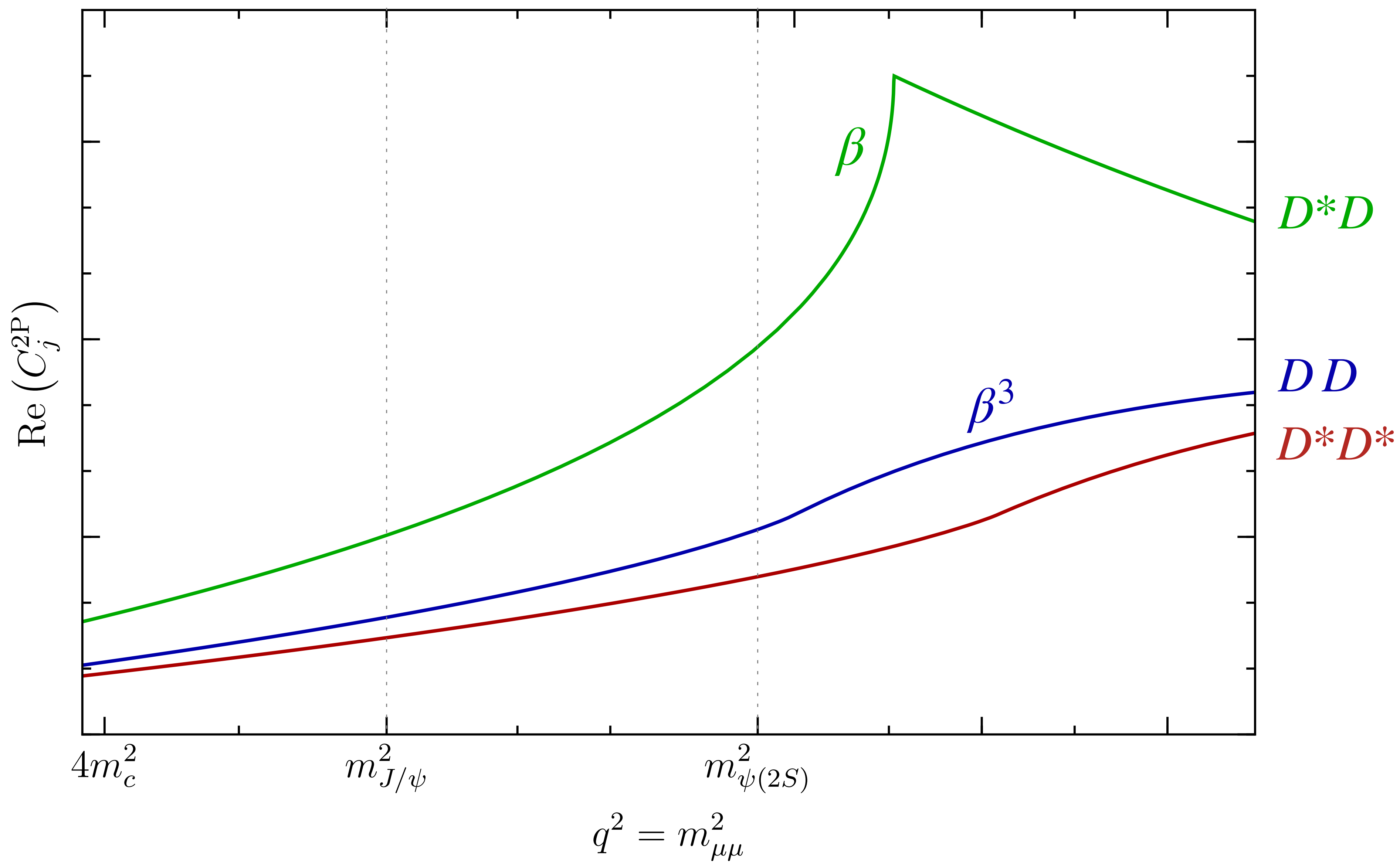
constraint: $q^2 \ll m_c^2 \qquad \Delta C^{1\mathrm{P}}_{c\bar{c}}(q^2) + \Delta C^{2\mathrm{P}}_{c\bar{c}}(q^2) = \Delta C^{\mathrm{pert}}_{c\bar{c}}(q^2)$

Two-particle intermediate states: cusps

Contributions from two-particle intermediate states present a “**cusp**” at the kinematical threshold for on-shell production:



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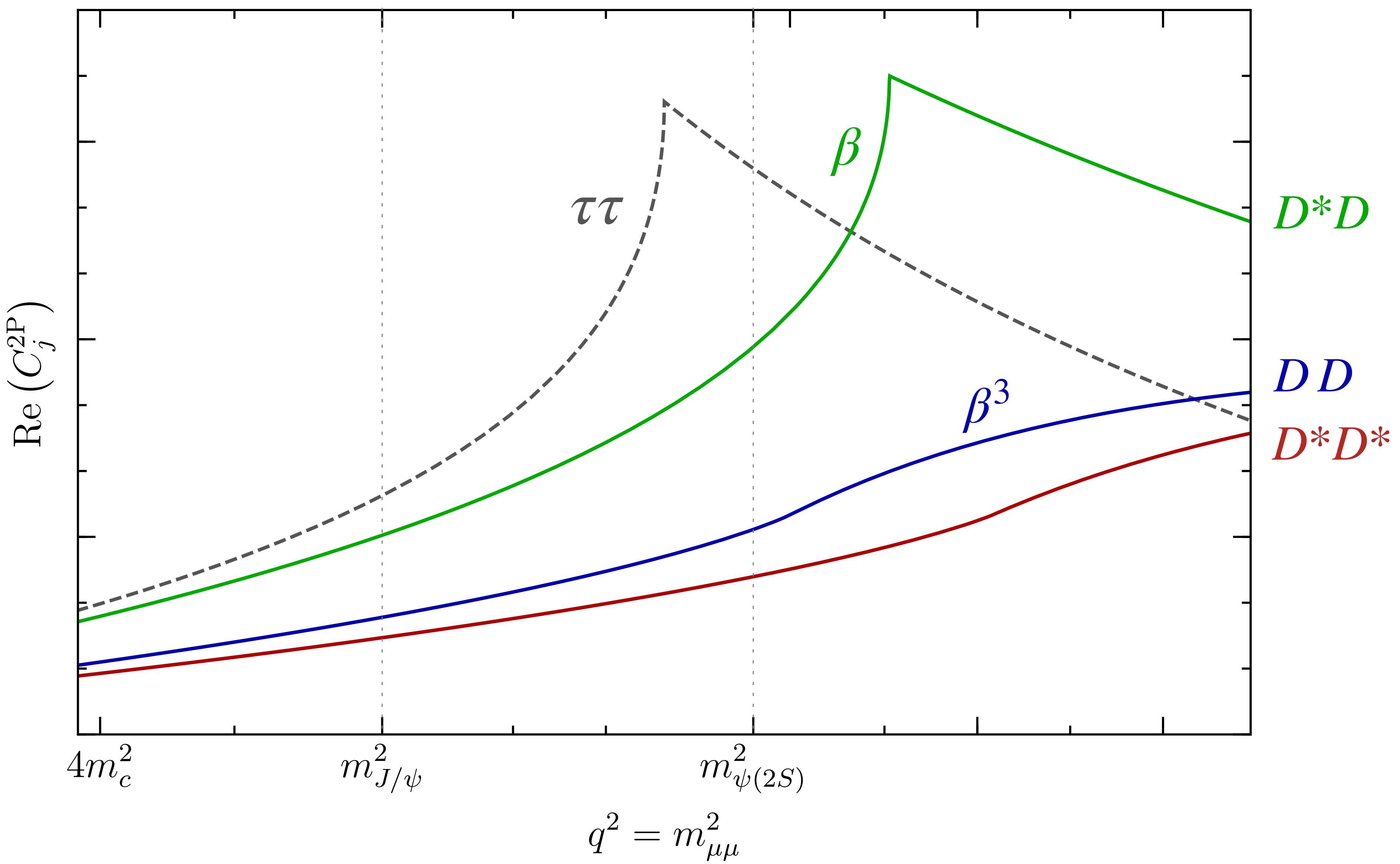
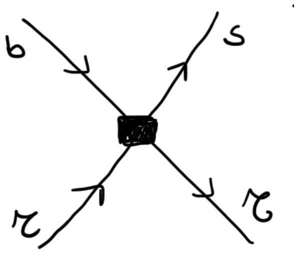


Constraining NP in taus…from muons?

Consider a NP scenario where a large C_{9_τ} 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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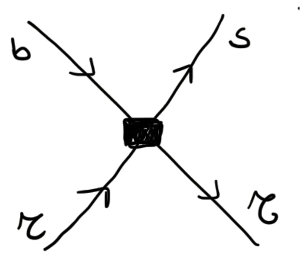

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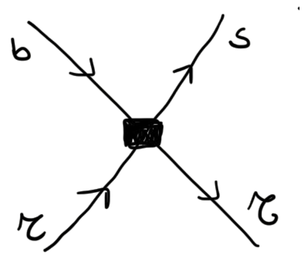

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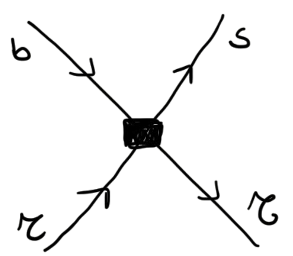

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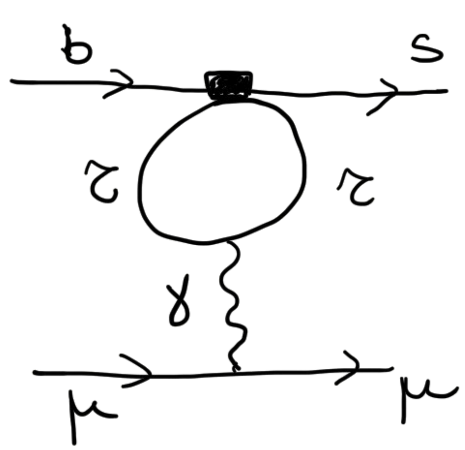

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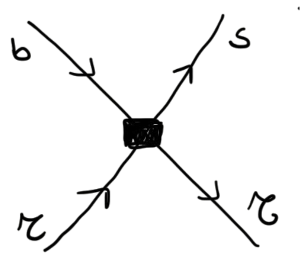

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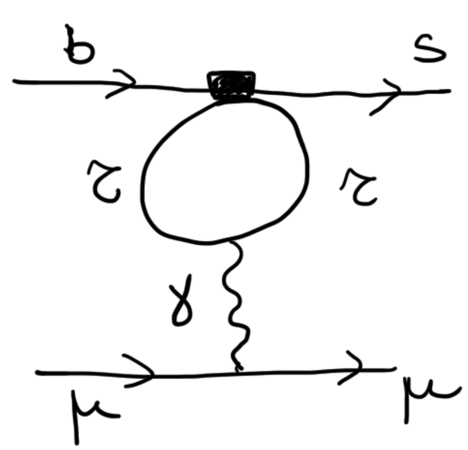

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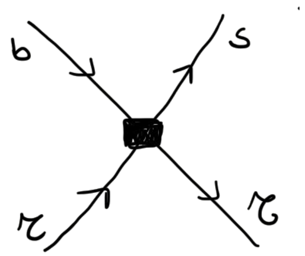

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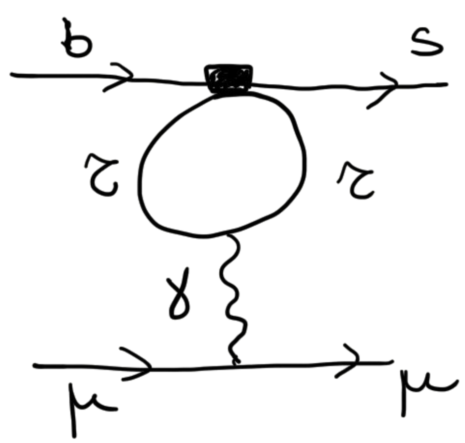

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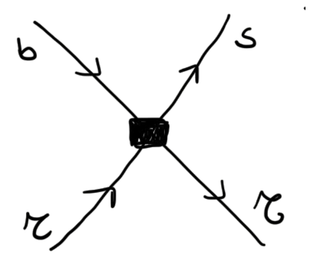

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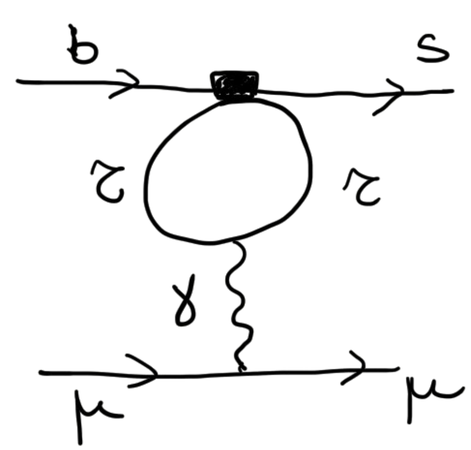

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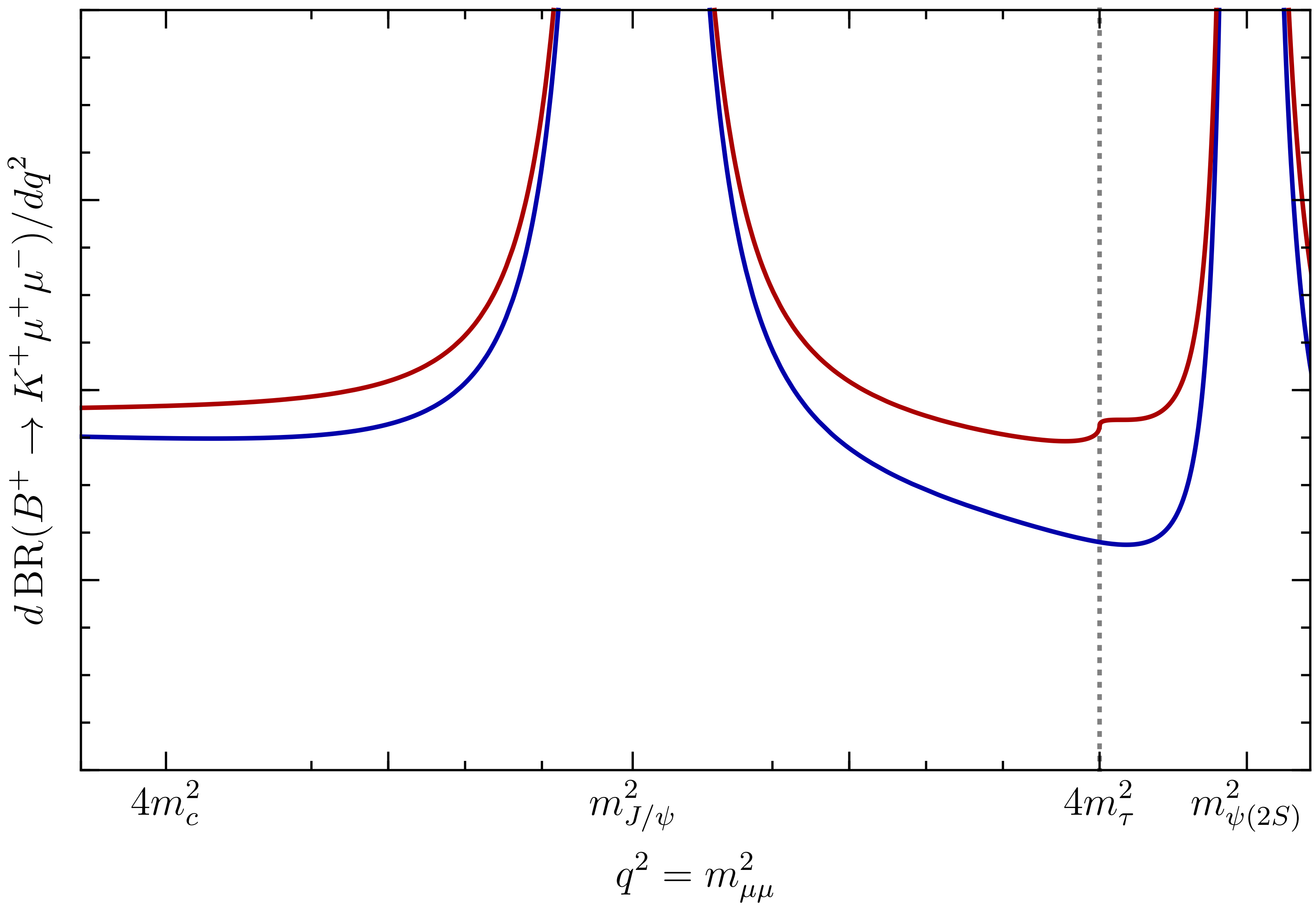
Preliminary sensitivity @ LHCb [with Run 2 statistics]: $\boldsymbol{\mathscr{B}(B^+ \to K^+\tau^+\tau^-) \lesssim \mathcal{O}(10^{-4})}$

The $\tau - \tau$ cusp



resonances only

res. parameters from

[LHCb 1612.06764]

resonances + $\tau\tau$

assuming $\mathscr{B}(B^+ \to K^+\tau^+\tau^-) =$ Babar upper limit (for illustration)

Conclusions and outlook

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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!