New physics in $B_{d,s} - \bar{B}_{d,s}$ mixings and $B_{d,s} \rightarrow \mu^+ \mu^-$ decays

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Abstract A new way of probing new physics in the $B$ meson system is provided. We define double ratios for the observables of $B_{d,s} - \bar{B}_{d,s}$ mixings and $B_{d,s} \rightarrow \mu^+ \mu^-$ decays, and find simple relations between the observables. By using the relations we predict the yet-to-be-measured branching ratio of $B_d \rightarrow \mu^+ \mu^-$ to be $(0.809-1.03) \times 10^{-10}$, up to the new physics models.

1 Introduction

The recent discovery of a Higgs boson at the large hadron collider (LHC) opened a new era of high energy physics. It may take time to confirm whether the new particle is really the Higgs boson of the standard model (SM), but it looks more and more like the SM Higgs. The discovery of the Higgs boson would mean a completion of the SM. On the other hand, we have many reasons to believe that there must be new physics (NP) beyond the SM. Unfortunately, the LHC up to now has not reported any clues of NP. But it is too early to say that there is no NP at all. $B_{d,s}$ mesons are good test beds for NP. Especially, $B_{d,s} - \bar{B}_{d,s}$ mixings and $B_{d,s} \rightarrow \mu^+ \mu^-$ decays are loop-induced phenomena in the SM and very sensitive to NP effects. The current status of the experiments is well compatible with the SM predictions. For example, the LHCb and the CMS collaboration reported [1,2]

$$\text{Br}(B_s \rightarrow \mu^+ \mu^-) = (2.9^{+1.1}_{-1.0}) \times 10^{-9},$$
$$\text{Br}(B_d \rightarrow \mu^+ \mu^-) < 7.4 \times 10^{-10} \text{ (LHCb)},$$

(1)

$$\text{Br}(B_s \rightarrow \mu^+ \mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9},$$
$$\text{Br}(B_d \rightarrow \mu^+ \mu^-) < 1.1 \times 10^{-9} \text{ (CMS)}.$$  

The measured value is slightly smaller than the previous LHCb measurements [3]:

\[ \text{Br}(B_s \rightarrow \mu^+ \mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}, \]
\[ \text{Br}(B_d \rightarrow \mu^+ \mu^-) < 9.4 \times 10^{-10}. \]

For comparison: the SM predictions are [4,5]

\[ \text{Br}(B_s \rightarrow \mu^+ \mu^-) = (3.25 \pm 0.17) \times 10^{-9}, \]
\[ \text{Br}(B_d \rightarrow \mu^+ \mu^-) = (1.07 \pm 0.10) \times 10^{-10}. \]

But there is still some room for NP, as discussed in [4,6,7]. In this paper, we provide a very simple and quick way to probe NP in $B_{d,s} - \bar{B}_{d,s}$ mixings and $B_{d,s} \rightarrow \mu^+ \mu^-$ decays. The idea is that a double ratio for one observable between different flavors extracts the relevant couplings for NP, and they are directly related to the other observable. Schematically, for a physical observable $O_i^a$ with flavor $a$,

$$R_i^{ab} \equiv \frac{O_i^{a,\exp}}{O_i^{a,\SM}} \frac{O_i^{b,\exp}}{O_i^{b,\SM}} = f_i \left( \frac{c_i^a}{c_i^b} \right),$$

(6)

where the $c_i^a$ are the new couplings and $f_i$ is some function of $c_i^a/c_i^b$. For another observable $O_j$ we can define a similar quantity, $R_j^{ab}$, which would behave $\propto f_j(c_i^a/c_i^b)$. Consequently, $R_i^{ab}$ and $R_j^{ab}$ are related through the functions $f_i$ and $f_j$, and the relations are remarkably simplified when the new couplings belong to the category of the minimal flavor violation (MFV). In this way, we can establish simple relations between the observables of $B_{d,s} - \bar{B}_{d,s}$ mixings and $B_{d,s} \rightarrow \mu^+ \mu^-$ decays. The relations are very useful because $R_i^{ab}$ and $R_j^{ab}$ are directly connected, and the relations are different for various NP models. For example, we can predict $\text{Br}(B_d \rightarrow \mu^+ \mu^-)$ from other known observables such as $\Delta M$ of $B_{d,s} - \bar{B}_{d,s}$ mixings, without knowing the values of the new couplings. Or if we measure the branching ratio $\text{Br}(B_d \rightarrow \mu^+ \mu^-)$, we can find from the double ratio relations which NP is realized in $B$ physics. In this paper we specifically consider flavor changing scalar (un)particles and vector boson ($Z'$) scenarios. Actually it is already known that $\Delta M_q$ and $\text{Br}(B_q \rightarrow \mu^+ \mu^-)$ can be related to each other.

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In our approach, the $R_i^{sb}$ are directly proportional to the NP effects, so the resulting relations are solely those of NP. The relations might be different for various models, which makes it easier to see which kind of NP is realized.

The NP couplings adopted in this analysis are summarized as follows [4, 11]:

$$\mathcal{L}_{Z'} = \left[ \Delta_{L}^{bq}(Z')(\tilde{y}_\mu P_L b) + \Delta_{R}^{bq}(Z')(\tilde{y}_\mu P_R b) + \Delta_{L}^{bq}(Z')(\tilde{y}_\mu P_L \ell) + \Delta_{R}^{bq}(Z')(\tilde{y}_\mu P_R \ell) \right] Z^\mu, \quad (7)$$

$$\mathcal{L}_H = \left[ \Delta_{L}^{bq}(H)(\tilde{y}_\mu P_L b) + \Delta_{R}^{bq}(H)(\tilde{y}_\mu P_R b) + \Delta_{L}^{bq}(H)(\tilde{y}_\mu P_L \ell) + \Delta_{R}^{bq}(H)(\tilde{y}_\mu P_R \ell) \right] H, \quad (8)$$

$$\mathcal{L}_{UL} = \frac{c_{bq}}{\Lambda_{UL}^{d_2}} \tilde{y}_\mu (1 - \gamma_5)b \partial^\mu \mathcal{O}_{UL} + \frac{c_{bq}}{\Lambda_{UL}^{d_2}} \tilde{y}_\mu (1 - \gamma_5)\ell \partial^\mu \mathcal{O}_{UL}, \quad (9)$$

where $P_{L,R} = (1 \mp \gamma_5)/2$. In $\mathcal{L}_{UL}$ one can also include the right-handed coupplings, but here (and in [11]) only the minimal extension of the SM is considered for simplicity.

First consider the $B_{d,s} \to \bar{B}_{d,s}$ mixing. The mixing effect is parametrized as the following quantity:

$$\Delta M_q = \frac{G_F^2}{6\pi^2} M_W^2 m_{B_q} |V_{tb}^* V_{tq}|^2 F_{B_q}^2 \eta_B |S(B_q)|, \quad (10)$$

where

$$S(B_q) = S_0(x_t) + \Delta S(B_q) \equiv |S(B_q)| e^{i\delta^{bq}_q}, \quad (11)$$

and $x_t = m_t^2/m_W^2$. Here the loop function

$$S_0(x_t) = \frac{4x_t - 11x_t^2 + x_t^3}{4(1 - x_t)^2} - \frac{3x_t^2 \log x_t}{2(1 - x_t)^2}, \quad (12)$$

and

$$\Delta S(B_q) = [\Delta S(B_q)]_{V(S)LL} + [\Delta S(B_q)]_{V(S)RR}, \quad (13)$$

where the subscript $V(S)$ stands for $Z'(H)$ contributions. Explicitly [6, 7],

$$[S(B_q)]_{VLL} = \left[ \frac{\Delta_{L}^{bq}(Z')}{V_{tb}^* V_{tq}} \right]^2 \frac{4\tilde{\tau}}{M_{Z'}^2 g_{SM}^2}, \quad (14)$$

$$[S(B_q)]_{VRR} = \left[ \frac{\Delta_{R}^{bq}(Z')}{V_{tb}^* V_{tq}} \right]^2 \frac{4\tilde{\tau}}{M_{Z'}^2 g_{SM}^2}, \quad (15)$$

$$[S(B_q)]_{VLR} = \frac{\Delta_{L}^{bq}(Z') \Delta_{R}^{bq}(Z')}{T(B_q) M_{Z'}^2} \times \left[ C_1^{VLR}(\mu_Z)(Q_1^{VLR}(\mu_Z, B_q)) + C_2^{VLR}(\mu_Z)(Q_2^{VLR}(\mu_Z, B_q)) \right], \quad (16)$$

where

$$g_{SM} \equiv \frac{4G_F}{\sqrt{2}} \frac{\alpha}{2\pi \sin^2 \theta_W}, \quad (17)$$

$$T(B_q) \equiv \frac{G_F^2}{12\pi^2} F_{B_q}^2 \tilde{B}_{B_q} m_{B_q} M_W^2 |V_{tb}^* V_{tq}|^2 \eta_B, \quad (18)$$

and $\tilde{\tau} = 0.985$ for $M_{Z'} = 1$ TeV. For the scalar field,

$$\Delta S(B_q) = - \frac{[\Delta_{L}^{bq}(H)]^2}{T(B_q) M_H^2} \times \{ C_1^{VLL}(\mu_H)(Q_1^{VLL}(\mu_H, B_q)) + C_2^{VLL}(\mu_H)(Q_2^{VLL}(\mu_H, B_q)) \}, \quad (19)$$

$$\Delta S(B_q)_{VLL} = - \frac{[\Delta_{L}^{bq}(H)]^2}{T(B_q) M_H^2} \times \{ C_1^{VLL}(\mu_H)(Q_1^{VLL}(\mu_H, B_q)) + C_2^{VLL}(\mu_H)(Q_2^{VLL}(\mu_H, B_q)) \}. \quad (20)$$

The expectation values of the operators $Q_i^a$ are

$$\langle Q_i^a(\mu_M, B_q) \rangle = \frac{1}{3} m_{B_q} F_{B_q}^2 h_i^{a}(\mu_M, B_q). \quad (22)$$

For the case of $\Delta_{R}^{bq} = 0$,

$$\frac{\Delta M_q(Z')}{\Delta M_{SM}^2} \approx 1 + \frac{1}{S_0(x_t)} \text{Re} \left[ \frac{\Delta_{L}^{bq}(Z')}{V_{tb}^* V_{tq}} \right]^2 \frac{4\tilde{\tau}}{M_{Z'}^2 g_{SM}^2}, \quad (23)$$

up to the leading order of $\Delta_{L}^{bq}$. Now we define a double ratio $R_{\Delta M}^Z$ as

$$R_{\Delta M}^Z \equiv \frac{\Delta M_4(Z')/\Delta M_{SM} - 1}{\Delta M_4(Z')/\Delta M_{SM} - 1} = \frac{\text{Re} \left[ \Delta_{L}^{bq}(Z')/V_{ts} \right]^2}{\text{Re} \left[ \Delta_{L}^{bq}(Z')/V_{ts} \right]^2}, \quad (24)$$

where the result of Eq. (23) is applied. Similarly, for the scalar contribution (with $\Delta_{R}^{bq} = 0$),

$$R_{\Delta M}^H \equiv \frac{\Delta M_4(H)/\Delta M_{SM} - 1}{\Delta M_4(H)/\Delta M_{SM} - 1} = \frac{\text{Re} \left[ \Delta_{L}^{bq}(H)/V_{ts} \right]^2}{\text{Re} \left[ \Delta_{L}^{bq}(H)/V_{ts} \right]^2}. \quad (25)$$

We assumed here that the light-quark dependence on $P_{t}^a(\mu_H, B_q)$ is negligible [12], and thus $P_{t}^a(\mu_H, B_d) \approx P_{t}^a(\mu_H, B_d)$. \[\Box\]
In the scalar unparticle scenario [11],
\[
\frac{\Delta M_{\ell}^{D}}{\Delta M_{\ell}^{SM}} - 1 = |\Delta_{\ell}| - 1 = \text{Re}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q} \cot d_{U_{\ell}} \pi] + \text{Im}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q}] + O(c_{U_{\ell}L}^{A}).
\]
(26)

Here
\[
f_{U_{\ell}}^{q} = \frac{5}{24 M_{12}^{SM}} A_{d_{U_{\ell}}} \left( F_{R_{L}}^{2} \right) \left( \frac{m_{B_{L}}^{2}}{m_{B_{R}}^{2}} \right) \frac{d_{U_{\ell}}}{\Lambda_{1}},
\]
(27)
where \( M_{12}^{SM} \) is the SM contribution and
\[
A_{d_{U_{\ell}}} = \frac{16 \sqrt{2}}{(2\pi)^{6} \Delta_{1}^{2}} \frac{\Gamma(d_{U_{\ell}} + 1/2)}{(d_{U_{\ell}} - 1) \Gamma(2d_{U_{\ell}})},
\]
(28)
with \( d_{U_{\ell}} \) being the scaling dimension of the scalar unparticle operator. The double ratio for the scalar unparticle is
\[
\frac{\Delta M_{\ell}^{U_{\ell}}}{\Delta M_{\ell}^{SM}} - 1 \equiv |\Delta_{\ell}| - 1 = \text{Re}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q} \cot d_{U_{\ell}} \pi] + \text{Im}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q}] + O(c_{U_{\ell}L}^{A}).
\]

\[
\frac{R_{\Delta M}^{U_{\ell}}}{R_{\Delta M}^{SM}} = \frac{\text{Re}[c_{U_{\ell}L}^{bq} c_{U_{\ell}L}^{bq} \csc d_{U_{\ell}} \pi + \text{Im}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q}]^{2}]}{\text{Re}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q}]^{2} + \text{Im}[c_{U_{\ell}L}^{bq} f_{U_{\ell}}^{q}]^{2}}.
\]
(29)
where we put \( c_{U_{\ell}L}^{bq} = c_{U_{\ell}L}^{bq} \). For real \( c_{U_{\ell}L}^{bq} \), one has
\[
\frac{R_{\Delta M}^{U_{\ell}}}{R_{\Delta M}^{SM}} = \left( \frac{B_{R_{L}}}{B_{R_{L}}} \right) \left( \frac{m_{B_{L}}^{2}}{m_{B_{R}}^{2}} \right) \frac{d_{U_{\ell}} - 1}{d_{U_{\ell}}} \left( \frac{c_{U_{\ell}L}^{bq}}{c_{U_{\ell}L}^{bq}} \right)^{2}.
\]
(30)
If \( c_{U_{\ell}L}^{bq} \) is purely imaginary, one gets a similar result.

Now we move to \( B_{L,s} \rightarrow \mu^{+} \mu^{-} \) decays. The relevant effective Hamiltonian is given by
\[
H_{\text{eff}} = -\frac{G_{F} \alpha}{\sqrt{2} \pi} \sum_{i} (C_{i} O_{i} + C_{i}^{*} O_{i}^{*}) + \text{h.c.},
\]
(31)
where the operators \( O_{i} \) are
\[
O_{10} = (\bar{\nu}_{\mu} P_{L} l_{b})(\bar{\nu}_{\mu} \gamma_{5} l_{s}), \quad O_{10}^{*} = (\bar{\nu}_{\mu} P_{R} l_{b})(\bar{\nu}_{\mu} \gamma_{5} l_{s}).
\]
(32)
\[
O_{5} = m_{b}(\bar{\nu}_{b} P_{L} l_{b}), \quad O_{5}^{*} = m_{b}(\bar{\nu}_{b} P_{R} l_{b}),
\]
(33)
\[
O_{s} = m_{s}(\bar{\nu}_{s} P_{L} l_{b}), \quad O_{s}^{*} = m_{s}(\bar{\nu}_{s} P_{R} l_{b}),
\]
(34)
For \( B_{s} \) decay it is convenient to define [13,14]
\[
\text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-}) = \frac{1}{r(y_{s})} \text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-})_{\text{th}},
\]
(35)
and we have the asymmetric parameter
\[
A_{\Delta \Gamma} = \frac{R_{H} - R_{L}}{R_{H} + R_{L}}.
\]
(38)
where \( R_{H(L)} \exp[-\Gamma_{H(L)}] \) is the decay rate of the heavy (light) mass eigenstate. Here \( \text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-})_{\text{th}} \) is a theoretical prediction, while \( \text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-}) \) would be directly compared with the experimental results. In general,
\[
\text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-}) = \frac{1 + y_{s} A_{\Delta \Gamma}}{1 + y_{s}} (|P|^{2} + |S|^{2}),
\]
(39)
where
\[
P = \frac{C_{10} - C_{10}^{*}}{C_{10}^{SM}} + \frac{m_{B_{s}}}{2 m_{1} m_{b} + m_{s}} \frac{C_{s} - C_{s}^{*}}{C_{10}^{SM}} \left( \frac{m_{B_{s}}^{2}}{m_{B_{s}}^{2}} \right) \left( \frac{m_{B_{s}}^{2}}{m_{B_{s}}^{2}} \right),
\]
(40)
and
\[
S = \left[ 1 - \frac{4 m_{2}^{2}}{m_{B_{s}}^{2}} m_{b} m_{s} \right] \frac{C_{s} - C_{s}^{*}}{C_{10}^{SM}} \left( \frac{m_{B_{s}}^{2}}{m_{B_{s}}^{2}} \right) \left( \frac{m_{B_{s}}^{2}}{m_{B_{s}}^{2}} \right).
\]
(41)
The standard model contribution is
\[
C_{10}^{SM} = -\frac{1}{\sin^{2} \theta_{W}} \eta_{Y} Y_{0}(x_{t}),
\]
(42)
with \( \eta_{Y} = 1.012 \) and
\[
Y_{0}(x_{t}) = \frac{x_{t}}{8} \left[ \frac{x_{t} - 4}{x_{t} - 1} + 3 x_{t} \log x_{t} \right].
\]
(43)
For the \( Z' \) model,
\[
\sin^{2} \theta_{W} C_{10}(Z') = -\eta_{Y} Y_{0}(x_{t}) \frac{1}{\sin^{2} \theta_{W}} \frac{1}{M_{Z}^{2}} \frac{\Delta_{L}^{zh}(Z') \Delta_{A}^{zh}(Z')}{V_{t_{s}}^{*} V_{t_{b}}},
\]
(44)
\[
\sin^{2} \theta_{W} C_{10}(Z') = -\frac{1}{\sin^{2} \theta_{W}} \frac{1}{M_{Z}^{2}} \frac{\Delta_{L}^{zh}(Z') \Delta_{A}^{zh}(Z')}{V_{t_{s}}^{*} V_{t_{b}}},
\]
(45)
while the other coefficients are vanishing. Using \( \Delta_{L,R}^{zh}(Z') = \Delta_{L,R}^{zh}(Z')^{*} \), one has
\[
\text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-}) = \text{Br}(B_{s} \rightarrow \mu^{+} \mu^{-})_{\text{obs}} - 1 \simeq \frac{y_{s}}{1 + y_{s}} \left[ \cos(2\theta_{B_{s}}^{B_{s}}) + \theta_{B_{s}}^{B_{s}} \right] - 1
\]
\[
+ \frac{1}{1 + y_{s}} \frac{1}{\sqrt{2}} \frac{1}{g_{SM}^{2}} \frac{1}{2} \text{Re} \left[ \frac{\Delta_{L}^{zh}(Z') \Delta_{A}^{zh}(Z')}{V_{t_{s}}^{*} V_{t_{b}}},
\]
(46)
In this case we have the ratio \( \Delta_{\mu\mu} \) up to \( \Delta_{1} \), and the ratio
\[
\frac{R_{\mu\mu}^{Z'}}{R_{\mu\mu}^{Z}} = 1 + \frac{1}{1 + \psi} \left( \frac{\Delta_{L}^{bs}}{\Delta_{L}^{bd}} \right).
\]

For neutral scalar \( H \), the coefficients are
\[
C_{10}^{H}(H) = C_{10}^{SM},
\]
\[
C_{5}^{H}(H) = \frac{1}{m_{b} \sin^{2} \theta_{W}} \frac{1}{g_{SM}} \frac{1}{M_{H}^{2}} \frac{\Delta_{R}^{bs}(H) \Delta_{\mu\mu}^{L}(H)}{V_{tb}^{*} V_{tb}},
\]
\[
C_{5}^{P}(H) = \frac{1}{m_{b} \sin^{2} \theta_{W}} \frac{1}{g_{SM}} \frac{1}{M_{H}^{2}} \frac{V_{tb}^{*} V_{tb}}{\Delta_{\mu\mu}^{L}(H)},
\]
\[
C_{P}^{H}(H) = \frac{1}{m_{b} \sin^{2} \theta_{W}} \frac{1}{g_{SM}} \frac{1}{M_{H}^{2}} \frac{\Delta_{R}^{bs}(H) \Delta_{\mu\mu}^{L}(H)}{V_{tb}^{*} V_{tb}},
\]
\[
C_{P}^{P}(H) = \frac{1}{m_{b} \sin^{2} \theta_{W}} \frac{1}{g_{SM}} \frac{1}{M_{H}^{2}} \frac{V_{tb}^{*} V_{tb}}{\Delta_{\mu\mu}^{L}(H)}.
\]

One can define a double ratio \( R_{\mu\mu}^{H} \) similar to Eq. (48). For simplicity we assume that \( \Delta_{R} = 0 \) and \( \Delta_{L}^{bs} = \Delta_{L}^{bd} \) with real \( \Delta_{L}^{bd} \). Note that in this case
\[
R_{\mu\mu}^{H}(1 + y_{s}) = \sqrt{R_{\Delta_{L}}^{H}}.
\]

For the case of \( \Delta_{\mu\mu}^{L}(H) = 0 \), the double ratio reduces to
\[
R_{\mu\mu}^{H} = \frac{\text{Br}(B_{s} \rightarrow \mu^{+}\mu^{-})}{\text{Br}(B_{d} \rightarrow \mu^{+}\mu^{-})_{SM}} \left( \frac{\Delta_{R}^{bs} - \Delta_{R}^{bd}}{\Delta_{L}^{bd}} \right),
\]
\[
\text{V}_{id}^{*} V_{tb}^{*},
\]
\[
\left( \frac{m_{b}^{2} m_{d} + m_{d}}{m_{d}^{2}} \right)^{2} \left( \frac{\Delta_{L}^{bd}}{\Delta_{L}^{bd}} \right).
\]

On the other hand if \( \Delta_{\mu\mu}^{L} = 0 \),
\[
R_{\mu\mu}^{H} = \frac{1}{1 + y_{s}} \left( \frac{1}{1 + y_{s}} \right) \left( \frac{1 - 4m_{b}^{2} / m_{d}^{2}}{1 - 4m_{b}^{2} / m_{d}^{2}} \right) \left( \frac{\Delta_{L}^{bd}}{\Delta_{L}^{bd}} \right).
\]
We confirm that the simplified double ratio relations really hold, then we may conclude that NP is realized in a minimal way.

One point to be mentioned is that our double ratio becomes meaningless if there were no NP at all. In this case both numerator and denominator are vanishing and one cannot take a ratio. Thus the double ratio is not adequate to check whether there is any NP or not, but to see which kind of NP is involved once the observables turn out to be quite different from the SM predictions. The current status of NP searches in the case of the $B$ meson is not so pessimistic. According to [16], the relative size of NP in $\Delta M_{d,s} (= h_{d,s})$ is currently $\lesssim 0.2\%$, and would be $\lesssim 1$ in the near future (“Stage I” where the LHCb will end). As for $B_d \to \mu^+\mu^-$, the current upper bound is almost an order of magnitude larger than the SM prediction. It is predicted in [17] that at $2\sigma, 0.3 \times 10^{-10} \lesssim Br(B_d \to \mu^+\mu^-) \lesssim 1.8 \times 10^{-10}$. If the measured branching ratio does not lie within this window, it would be a clear indication of NP. It is also found in [17] that although the measured value of $Br(B_s \to \mu^+\mu^-)$ provides constraints on NP, there are still sizable regions allowed for $C_S - C_S'$ and $C_P - C_P'$ parameter space.

Besides the current status of NP searches, we need NP for various reasons (dark matter for example). Although there have been no smoking-gun signals for NP up to now, we believe that the SM is not (and should not be) the full story of particle physics. In this context the double ratio analysis might be very promising with the coming flavor precision era, and it can also be applied to $K$ meson systems.

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