Probing new physics in \( B \rightarrow D \ell^+ \ell^- \) decays by using angular asymmetries

C. S. Kim and Dibyakrupa Sahoo

Department of Physics and IPAP, Yonsei University, Seoul 120-749, Korea

(Dated: October 2, 2018)

We present the fully general, model independent study of a few rare semileptonic \( B \) decays that get dominant contributions from \( W \)-annihilation and \( W \)-exchange diagrams, in particular \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \), where \( \ell = e, \mu \). We consider the most general Lagrangian for the decay, and define three angular asymmetries in the Gottfried-Jackson frame, which are sensitive to new physics. We show how these angular asymmetries can be easily extracted from the distribution of events in the Dalitz plot for \( B \rightarrow D \ell^+ \ell^- \) decays. Especially a non-zero forward-backward asymmetry within the frame would give the very first hint of possible new physics. These observations are also true for related decay modes, such as \( B^+ \rightarrow D^+ \ell^+ \ell^- \) and \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \). Moreover, these asymmetry signatures are not affected by either \( B^0 \rightarrow \bar{B}^0 \) or \( D^0 \rightarrow \bar{D}^0 \) mixings. This therefore allows us to combine the data sets for the decay modes \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \), \( B^0 \rightarrow D^0 \ell^+ \ell^- \) and their CP conjugate modes and do a search for the signatures of new physics with more statistics. We are hopeful that our results would further motivate the experimentalists to look for these decays in the various ongoing and upcoming particle physics experiments, such as LHCb and Belle II.

This paper is organised as follows: In section II we provide the model-independent form of the most general Lagrangian which then dictates the form of the decay amplitude. This is followed by a discussion on the relevant kinematics in the Gottfried-Jackson frame. Using the most general amplitude, we find out the angular distribution in section III A. We also provide the necessary angular asymmetries which are sensitive to specific parts of the angular distribution. Finally, we analyse the angular asymmetries in detail and show in section III B how they can be used to decipher the signature of any new physics contributing to the processes under consideration. In section III C we show how these asymmetries can be very easily obtained from the distribution of events inside the Dalitz plots for \( B \rightarrow D \ell^+ \ell^- \) decays. In section III D we note that the signatures of new physics are independent of \( B^0 \rightarrow \bar{B}^0 \) and \( D^0 \rightarrow \bar{D}^0 \) mixing. Then we conclude in section IV emphasizing all the essential aspects of our analysis.

I. INTRODUCTION

It is very well known that despite having enormous success in explaining an astounding amount of experimental observations, the Standard Model (SM) of particle physics has many glaring lacunae. On the other hand, with little direct experimental validation, there exists a vast possibility of physics beyond the SM. In addition to the direct collider searches, experimenters and theorists alike have tried to look for physics beyond the SM in various meson decays, most notably in the \( B \rightarrow K \ell^+ \ell^- \) decays [1–9], where \( \ell = e, \mu \). In such exciting times for new physics (NP), we present the most general, model independent study of a few hitherto unseen [10], very rare, semileptonic decays of the \( B \) meson, namely \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \), \( B^+ \rightarrow D^+ \ell^+ \ell^- \) and \( B^0 \rightarrow D^0 \ell^+ \ell^- \), which are promising candidates to probe new physics. We note that some of the previous works, which dealt with decay modes similar to those we consider now, are given in [11–14]. Unlike previous works, we provide a completely model-independent study of \( B \rightarrow D \ell^+ \ell^- \) decays by using the effective field theory framework. These decay modes are primarily facilitated by \( W \)-annihilation and \( W \)-exchange diagrams and are hence, in general, highly suppressed. However, for large Wilson coefficients such decays (especially \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \)) can have sizeable branching ratios in the SM, \( O(10^{-5}) \) [15], such that they can be observed and studied experimentally. The decays \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \) and \( B^+ \rightarrow D^+ \ell^+ \ell^- \) being CKM suppressed [1] have smaller branching ratios in the SM, \( O(10^{-9}–10^{-11}) \), which has been estimated without considering the photon pole contribution [11, 14]. However, assuming that these rare decays can be observed experimentally in near future, we provide angular observables which are easy to study in experiments and show how they can be utilised to unearth any underlying new physics in these decay modes. It is also notable that the signatures of new physics, considered later in this work, are unaffected by \( B^0 \rightarrow \bar{B}^0 \) or \( D^0 \rightarrow \bar{D}^0 \) mixings. This therefore allows us to combine the data sets for the decay modes \( B^0 \rightarrow D^{0*} \ell^+ \ell^- \), \( B^0 \rightarrow D^0 \ell^+ \ell^- \) and their CP conjugate modes and do a search for the signatures of new physics with more statistics. We are hopeful that our results would further motivate the experimentalists to look for these decays in the various ongoing and upcoming particle physics experiments, such as LHCb and Belle II.

II. THE MOST GENERAL LAGRANGIAN AND AMPLITUDE

The model-independent effective Lagrangian contributing to the \( B \rightarrow D \ell^+ \ell^- \) decays can be written as follows,

\[
  \mathcal{L}_{\text{eff}} = J_S \left( \bar{\ell} \gamma_5 \ell \right) + J_P \left( \bar{\ell} \gamma_5 \ell \right) + (J_{V})_{\alpha \beta} \left( \bar{\ell} \gamma_{\alpha} \gamma_{\beta} \ell \right) + (J_{A})_{\alpha} \left( \bar{\ell} \gamma_5 \gamma_{\alpha} \ell \right) + (J_{T_{\alpha \beta}})_{\alpha \beta} \left( \bar{\ell} \sigma_{\alpha \beta} \gamma_5 \ell \right),
\]

(1)
where \( J_s, J_P, (J_T)_a, (J_A)_a, (J_{T_1})_{a\beta}, (J_{T_2})_{a\beta} \) are the different effective hadronic currents which effectively describe the quark-level transitions from \( B \) to \( D \) meson. In the SM, only the vector and axial vector currents contribute. So all other terms in Eq. (1) except \((J_V)_a\) and \((J_A)_a\) are possible only in case of some specific NP scenarios. In this work, we are not concerned about which particular kind of NP model would give rise to such terms, though such model-dependent approaches are also fruitful. While specific NP models would give specific signatures of NP, we are interested in finding out the generic signature of NP in this work, starting with Eq. (1).

It must be noted that NP can also modify both \((J_V)_a\) and \((J_A)_a\) from their SM expressions.

In order to get the most general amplitude, we need to go from the effective quark-level description of Eq. (1) to the meson level description by defining appropriate form factors. It is easy to write down the most general form of the amplitude for \( B \rightarrow D^{\pm} \ell^- \) as shown below,

\[
M(B \rightarrow D^{\pm} \ell^-) = F_S \left( \overline{\ell} \hat{1} \ell \right) + F_T \left( \overline{\ell} \gamma^5 \ell \right) + \left( F^+_v p_a + F^-_v q_a \right) \left( \overline{\ell} \gamma^\mu \ell \right) + \left( F^+_A p_a + F^-_A q_a \right) \left( \overline{\ell} \gamma^\mu \gamma^5 \ell \right) + F_{T_1} \gamma_\mu p_a q_\beta \left( \overline{\ell} \gamma_\nu \gamma^\rho \gamma^\sigma \ell \right) + F_{T_2} \gamma_\mu p_a q_\beta \left( \overline{\ell} \gamma_\nu \gamma^\rho \gamma^\sigma \gamma^5 \ell \right),
\]

where \( F_S, F_T, F^+_v, F^-_v, F^+_A, F^-_A, F_{T_1} \) and \( F_{T_2} \) are the relevant form factors, and are defined as follows,

\[
\langle D | J_3 | B \rangle = F_S, \quad \langle D | J_P | B \rangle = F_T, \quad \langle D | (J_V)_a | B \rangle = F^+_v p_a + F^-_v q_a, \quad \langle D | (J_A)_a | B \rangle = F^+_A p_a + F^-_A q_a, \quad \langle D | (J_{T_1})_{a\beta} | B \rangle = F_{T_1} \gamma_\mu p_a q_\beta, \quad \langle D | (J_{T_2})_{a\beta} | B \rangle = F_{T_2} \gamma_\mu p_a q_\beta,
\]

with

\[
p \equiv p_B + p_D, \quad q \equiv p_B - p_D,
\]

in which \( p_B \) and \( p_D \) are the 4-momenta of the \( B \) meson and \( D \) meson respectively. All the form factors appearing in the amplitude are complex, in general, and contain all information regarding any new physics. Terms containing \( F_V \) and \( F_A \) are the ones allowed in the SM. As noted before NP can also alter \( F_V \) and \( F_A \) in addition to introducing other form factors. We shall use the angular distribution of \( B \rightarrow D^{\pm} \ell^- \) decays to find out the various signatures of NP.

We shall discuss the decay \( B \rightarrow D^{\pm} \ell^- \) in the Gottfried-Jackson frame, which is shown in Fig. 1. In this frame the \( B \) meson flies along the positive \( z \)-direction with 4-momentum \( p_B = (E_B, p_B) \) and decays to a \( D \) meson which flies along the positive \( z \)-direction with 4-momentum \( p_D = (E_D, p_D) \) to \( \ell^+, \ell^- \) which fly back-to-back with 4-momenta \( p_+ = (E_+, p_+) \) and \( p_- = (E_-, p_-) \) respectively, such that by conservation of 4-momentum we get, \( p_+ + p_- = 0 \), \( p_a = p_D \), and \( E_B = E_D + E_+ + E_- \). The \( \ell^- \) flies outwards subtending an angle \( \theta \) with respect to the direction of flight of the \( B \) meson, in the Gottfried-Jackson frame. Let us also denote the three invariant mass-squares as follows,

\[
s = (p_+ + p_-)^2 = (p_B - p_D)^2, \quad t = (p_D + p_-)^2 = (p_B - p_+)^2, \quad u = (p_D + p_+)^2 = (p_B - p_-)^2.
\]

It is easy to show that \( s + t + u = m_B^2 + m_D^2 + 2m_\ell^2 \), where \( m_i \) denotes the mass of particle \( i \). In the Gottfried-Jackson frame, the expressions for \( t \) and \( u \) are given by

\[
t = a - b \cos \theta, \quad u = a + b \cos \theta,
\]

where

\[
a = \left( m_B^2 + m_D^2 + 2m_\ell^2 - s \right) / 2, \quad b = \sqrt{\lambda (m_B^2, m_D^2, s) \left( 1 - 4m_\ell^2 / s \right) / 2},
\]

with the Källén function \( \lambda (x, y, z) \) defined as

\[
\lambda (x, y, z) = x^2 + y^2 + z^2 - 2 (xy + yz + zx).
\]

It is clear that both \( a \) and \( b \) are functions of \( s \) only. We would also like to emphasize that the angular distribution given later in section III involves the angle \( \theta \) which is the angle between the directions of flight of \( \ell^- \) and \( D \) measured in the Gottfried-Jackson frame, as shown in Fig. 1.

![Fig. 1. Decay of \( B^0 \to \overline{D}^{*} \ell^+ \ell^- \) in the Gottfried-Jackson frame.](image-url)

### III. THE MODEL-INDEPENDENT OBSERVABLES AND SIGNATURES OF NEW PHYSICS

#### A. Angular distribution and various observables

Using the most general form of the amplitude as given in Eq. (2) we can write down the following expression for the most general angular distribution for the \( B \rightarrow D^{\pm} \ell^- \) decays.

\[
d^2 \Gamma / ds \ d\cos \theta = \frac{b \sqrt{s} (T_0 + T_1 \cos \theta + T_2 \cos^2 \theta)}{128 \pi^3 m_B^5 (m_B^2 - m_D^2 + s)},
\]

where

\[
T_0 = \frac{s^2}{4m_B^2}, \quad T_1 = \frac{s^3 - 5m_B^2 s}{4m_B^4}, \quad T_2 = \frac{s^4 - 10m_B^2 s^2}{4m_B^6}.
\]
where we note again that the angle $\theta$ is measured in the Gottfried-Jackson frame as shown in Fig. 1, and

$$T_0 = 8a^2 \left[ |F_A|^2 + 4m_e^2 \left( |F_{T_0}|^2 m_e - \text{Im}(F_{T_0}F_{V}^*) + |F_{V}^*|^2 \right) \right]$$

$$- 16a \left[ |F_A|^2 \left( m_D^2 - m_B^2 \right) \right]$$

$$- m_e^2 \left[ |F_{T_0}|^2 \left( m_D^2 + m_B^2 \right) \left( \text{Im}(F_{T_0}F_{V}^*) - |F_{T_0}|^2 m_e \right) \right]$$

$$+ 2m_e \text{Re}(F_A^*F_{V}^*) + \text{Re}(F_A^*F_{V}^*) + |F_{V}^*|^2 \left( m_D^2 + m_B^2 \right) \right]$$

$$+ 2s \left[ 4 \left( |m_e^2| \left( |F_{T_0}|^2 + 2\text{Re}(F_A^*F_{V}^*) \right) \right]$$

$$+ 4m_e^2 \left( \text{Im}(F_{T_0}F_{V}^*) - |F_{T_0}|^2 m_e \right) + \text{Re}(F_A^*F_{V}^*) \right]$$

$$+ 8 \left[ |F_{T_0}^*|^2 \left( m_D^2 + m_B^2 \right) \left( m_D^2 + m_B^2 + 3m_e^2 - s \right) \right]$$

$$+ 8m_e \left[ |F_{T_0}^*|^2 \left( m_D^2 + m_B^2 \right) \right]$$

where $a$ and $b$ are as given in Eq. (7). In the limit of $m_e \to 0$ (which is a reasonable approximation to make at the B meson mass scale), we get

$$T_0 \bigg|_{m_e=0} = 8b^2 \left( |F_A|^2 + |F_{V}^*|^2 \right) + 2 \left( |F_{T_0}|^2 + |F_{S}|^2 \right)$$

where we have used the fact that $b^2 = a^2 - m_D^2 \left( 2a + s - m_D^2 \right)$. It is easy to notice that in the approximation of massless electrons and muons, it is the $T_1$ term which carries the interference terms. We shall define three asymmetries $A_j$ ($j = 0, 1, 2$) which would be proportional to the terms $T_j$ in Eq. (9).

$$A_0 = -\frac{1}{6} \left( \int_{-1}^{-1/2} - \int_{1/2}^{1} + \int_{1}^{3/2} \right) \frac{d^2 \Gamma}{ds d \cos \theta} d \cos \theta$$

$$\frac{b \sqrt{s}}{128 \pi^3 m_B^2 \left( m_D^2 - m_B^2 + s \right)} T_0 ,$$

$$A_1 = -\left( \int_{-1}^{-1/2} - \int_{1/2}^{1} \right) \frac{d^2 \Gamma}{ds d \cos \theta} d \cos \theta$$

$$\frac{b \sqrt{s}}{128 \pi^3 m_B^2 \left( m_D^2 - m_B^2 + s \right)} T_1 ,$$

$$A_2 = 2 \left( \int_{-1}^{-1/2} - \int_{1/2}^{1} \right) \frac{d^2 \Gamma}{ds d \cos \theta} d \cos \theta$$

$$\frac{b \sqrt{s}}{128 \pi^3 m_B^2 \left( m_D^2 - m_B^2 + s \right)} T_2 .$$

It is important to notice that these asymmetries are defined in the Gottfried-Jackson frame (in which the two leptons fly away from each other back-to-back) and not in the laboratory frame. It is also easy to notice that the forward-backward asymmetry $A_{FB}$ (again in the Gottfried-Jackson frame) is related to the asymmetry $A_1$ as follows,

$$A_{FB} \equiv \left( \int_{-1}^{0} - \int_{0}^{1} \right) \frac{d^2 \Gamma}{ds d \cos \theta} d \cos \theta = -A_1 .$$

Let us now analyse the three asymmetries keeping an eye on signatures of any new physics.

### B. The model-independent signatures of new physics

In case of the SM, only $F_A$ and $F_V$ contribute to the angular distribution. Therefore, all the interference terms in the expression for $T_1$ in Eq. (10b) are identically equal to zero, making $T_1$ to vanish in the SM. Moreover, if we consider the leptons to be massless, the combination $\left( T_0 + T_2 \right)$ also vanishes in the SM. Therefore, in the SM we have the following predictions,

$$T_1 = 0, \quad \text{(SM prediction)}$$

$$T_0 + T_2 = 0. \quad \text{(SM prediction with } m_e = 0)$$

Since, $A_n \propto T_n$ (for $n = 0, 1, 2$) with the same constant of proportionality as would be clear from Eq. (12), we get the following predictions for the asymmetries from the SM,

$$A_1 = -A_{FB} = 0, \quad \text{(SM prediction)}$$

$$A_0 + A_2 = 0. \quad \text{(SM prediction with } m_e = 0)$$

So the SM predicts that the forward-backward asymmetry in the decay modes under our consideration be identically equal to zero. Moreover, for the SM, the $T_2$ term is given by

$$T_2 = -8b^2 \left( |F_A|^2 + |F_{V}^*|^2 \right) ,$$
and considering massless leptons the \( T_0 \) term is given by (in the SM),
\[
T_0 = 8b^2 \left| F_A^+ \right|^2 + \left| F_V^+ \right|^2.
\]
In presence of sizeable new physics contribution we find that
\[
T_0 > 8b^2 \left( \left| F_A^+ \right|^2 + \left| F_V^+ \right|^2 \right), \quad T_2 > -8b^2 \left( \left| F_A^+ \right|^2 + \left| F_V^+ \right|^2 \right).
\]
\[\implies T_0 + T_2 > 0. \tag{16}\]
Also in the presence of new physics
\[
T_1 \neq 0. \tag{17}\]
Translating these into the observables \( A_0, A_1 \) and \( A_2 \) we find the following signatures of new physics (NP),
\[
A_1 = -A_{FB} \neq 0, \quad \text{(NP signature)} \tag{18a}
A_0 + A_2 \neq 0, \quad \text{(NP signature with} \ m_\ell = 0) \tag{18b}
\]
It is important to note that these signatures are truly independent of any specific model for new physics. Moreover, if \( \text{(18a)} \) gets satisfied it automatically ensures that \( \text{(18b)} \) is also true, but not vice versa. This is because of the fact that the \( T_1 \) term has interference terms in it, see Eqs. \((10b)\) and \((11b)\). We would like to emphasize that Eq. \((18a)\) is true irrespective of the mass of the lepton. Moreover, at the \( B \) meson mass scale both electron and muon are effectively massless, and hence effectively \( A_0 + A_2 \neq 0 \) is a signature of new physics.

Since in the SM, \( T_1 = 0 \), the angular distribution in the SM is completely symmetric under \( \cos \theta \leftrightarrow -\cos \theta \). Any asymmetry in the angular distribution under \( \cos \theta \leftrightarrow -\cos \theta \) exchange is, therefore, a distinct signature of new physics.

**C. Experimental signatures of new physics**

Here we provide expressions for the asymmetries \( A_0, A_1 \) and \( A_2 \), in terms of the easily observable distribution of events in the Dalitz plots for \( B \to D_{\ell^+}^{*} \ell^- \). The Dalitz plot can be obtained in any frame of reference, such as laboratory frame. We note that the quantity \( d^2\Gamma/(ds \, d\cos \theta) \) denotes the distribution of events inside the Dalitz plot. The Fig. 2 shows the variation of \( \cos \theta \) inside the Dalitz plot region allowed for \( B \to D_{\ell^+}^{*} \ell^- \) decays. As shown in Fig. 2 we can divide the Dalitz plot into four regions as defined below,

- **Region I**: \( 1 \geq \cos \theta \geq 0.5 \),
- **Region II**: \( 0.5 > \cos \theta \geq 0 \),
- **Region III**: \( 0 > \cos \theta \geq -0.5 \),
- **Region IV**: \( -0.5 > \cos \theta \geq -1 \).

The asymmetries \( A_0, A_1 \) and \( A_2 \) can now be redefined as follows,
\[
A_0 = -(N_I - 7N_{II} - 7N_{III} + N_{IV})/6, \tag{19a}
A_1 = N_I + N_{II} - (N_{III} + N_{IV}), \tag{19b}
A_2 = 2(N_I - N_{II} - N_{III} + N_{IV}). \tag{19c}
\]
where \( N_i \) denotes the number of events inside the Dalitz plot region \( i \). Since, the Dalitz plot for \( B \to D_{\ell^+}^{*} \ell^- \) can be constructed in any frame of reference, including the laboratory frame, it is easy to measure the asymmetries as defined in Eq. \((19)\). The model-independent signatures of new physics in terms of these three asymmetries are given in Eq. \((18b)\).

We can also define another asymmetry which will probe the symmetry of distribution of events in the Dalitz plot under \( \cos \theta \leftrightarrow -\cos \theta \) exchange. For this we need to divide the Dalitz plot into even number of segments, each segment centered about some fixed value of \( \cos \theta \), say \( c_{\theta m} \) and with width \( \Delta \theta \). The new asymmetry, called the binned asymmetry and denoted by \( A_{\text{bin}} \) can be defined as follows,
\[
A_{\text{bin}} = \sum_{c_{\theta m}} N(c_{\theta m}) - N(-c_{\theta m})/N(c_{\theta m}) + N(-c_{\theta m}), \tag{20}
\]

where \( N(c_{\theta m}) \) denotes the number of events in the segment in which \( \cos \theta = c_{\theta m} \pm \Delta \theta \). This binned asymmetry can be useful in probing the symmetry of distribution of events in the Dalitz plot under \( \cos \theta \leftrightarrow -\cos \theta \) exchange. If experimentally \( A_{\text{bin}} \neq 0 \), it would imply the presence of some NP. This asymmetry would be more useful with large number of events in the Dalitz plot.

**D. Discussions regarding the effect of \( B^0-\bar{B}^0 \) and \( B'^0-\bar{B}'^0 \) mixing**

It is essential to note that we get the same signatures of new physics as given in Eq. \((18)\) whether we consider \( B^0 \to D^0 \ell^+ \ell^- \) or \( B'^0 \to D'^0 \ell^+ \ell^- \), thus implying that the \( D^0-\bar{D}^0 \) mixing has no effect on our analysis. Similarly, it is also true...
that considering $B^0 \to \bar{D}^0 \ell^+\ell^-$ or $\bar{B}^0 \to D^0 \ell^+\ell^-$ also leads to the same signatures of new physics as given in Eq. (18). Thus $B^0-\bar{B}^0$ mixing also plays no role in our analysis. It must be noted that for each distinct decay mode under consideration, the concerned quark currents are also distinct. However, for the different $B \to D\ell^+\ell^-$ decays (with their distinct quark currents), we always get the same set of signatures for new physics as given in Eq. (18). Thus for a quick search for signature of new physics in the $B \to D\ell^+\ell^-$ modes we can take any neutral $B$ meson as parent particle and consider any neutral $D$ meson in the daughter particles. Furthermore, it must also be emphasized that even the events for $B^+ \to D^+ \ell^+\ell^-$ and $B^- \to D^- \ell^+\ell^-$ decays can be added as the charges of the $B$ and $D$ mesons do not affect the signatures of new physics as given in Eq. (18). If we combine all these decay modes, the data set will become larger and it will be possible to get an early measurement of the signature of new physics. However, a mode specific analysis would yield the extent to which new physics affects each specific decay mode.

IV. CONCLUSIONS

Thus we have provided a fully model independent analysis of the rare $B \to D\ell^+\ell^-$ decays. We have provided the full model-independent expression for the angular distribution along with expressions for three asymmetries which are sensitive to the three distinguishable parts of the angular distribution. We show that the three asymmetries are very sensitive to the presence of any new physics. We have also provided the distinct signatures of new physics in terms of these three experimentally observable asymmetries. Furthermore all the decay modes can be analysed combinedly in the search for new physics, as $B^0-\bar{B}^0$ and $D^0-\bar{D}^0$ mixings do not affect the concerned signatures of new physics as enunciated in this paper. These features make this particular decay mode a very interesting mode to look for in the various ongoing and upcoming $B$ physics experiments, such as LHCb and Belle II.

ACKNOWLEDGMENTS

The work of CSK was supported in part by the NRF grant funded by the Korea government of the MEST (No. 2016R1D1A1A02936965), DS would like to thank Prof Rahul Sinha for some helpful discussions regarding the decay mode at an earlier stage of this work, and The Institute of Mathematical Sciences, Chennai, India, where a part of this work was done, for hospitality.

[1] R. Aaij et al. [LHCb Collaboration], “Angular analysis of the $B^0 \to K^0\mu^+\mu^-$ decay using 3 fb$^{-1}$ of integrated luminosity,” JHEP 1602, 104 (2016) doi:10.1007/JHEP02(2016)104 [arXiv:1512.04442 [hep-ex]].
[2] A. Karan, R. Mandal, A. K. Nayak, R. Sinha and T. E. Browder, “Signal of right-handed currents using $K^+\ell^+\ell^-$ observables at the kinematic endpoint,” arXiv:1603.04355 [hep-ph].
[3] R. Mandal and R. Sinha, “Implications from $B \to K^+\ell^+\ell^-$ observables using 3 fb$^{-1}$ of LHCb data,” arXiv:1506.04535 [hep-ph].
[4] R. Mandal, R. Sinha and D. Das, “Testing New Physics Effects in $B \to K^+\ell^+\ell^-$,” Phys. Rev. D 90, no. 9, 096006 (2014) doi:10.1103/PhysRevD.90.096006 [arXiv:1409.3088 [hep-ph]].
[5] W. Altmannshofer and D. M. Straub, “New physics in $b \to s$ transitions after LHC run 1,” Eur. Phys. J. C 75, no. 8, 382 (2015) doi:10.1140/epjc/s10052-015-3602-7 [arXiv:1411.3161 [hep-ph]].
[6] M. Ciuchini, M. Fedele, E. Franco, S. Mishima, A. Paul, L. Silvestrini and M. Valli, “$B \to K^+\ell^+\ell^-$ decays at large recoil in the Standard Model: a theoretical reappraisal,” JHEP 1606, 116 (2016) doi:10.1007/JHEP06(2016)116 [arXiv:1512.07157 [hep-ph]].
[7] S. Jäger and J. Martin Camalich, “Reassessing the discovery potential of the $B \to K^+\ell^+\ell^-$ decays in the large-recoil region: SM challenges and BSM opportunities,” Phys. Rev. D 93, no. 1, 014028 (2016) doi:10.1103/PhysRevD.93.014028 [arXiv:1412.3183 [hep-ph]].
[8] S. Descotes-Genon, L. Hofer, J. Matías and J. Virto, “Global analysis of $b \to s\ell\ell$ anomalies,” JHEP 1606, 092 (2016) doi:10.1007/JHEP06(2016)092 [arXiv:1510.04239 [hep-ph]].
[9] S. Sahoo and R. Mohanta, “Study of the rare semileptonic decays $B_d \to K^+\ell^+\ell^-$ in scalar leptoquark model,” Phys. Rev. D 93, no. 3, 034018 (2016) doi:10.1103/PhysRevD.93.034018 [arXiv:1507.02070 [hep-ph]].
[10] K. A. Olive et al. [Particle Data Group Collaboration], Chin. Phys. C 38, 090001 (2014).
[11] D. H. Evans, B. Grinstein and D. R. Nolte, “Operator product expansion for exclusive decays: $B \to D_s^*e^+e^-$ and $B^\ast \to D_s^*e^+e^-$,” Phys. Rev. Lett. 83, 4947 (1999) doi:10.1103/PhysRevLett.83.4947 [hep-ph/9904434].
[12] D. H. Evans, B. Grinstein and D. R. Nolte, “Determining $V_{ub}$ from $B^\ast \to D_s^*e^+e^-$ and $B^\ast \to D_s^*e^+e^-$,” Phys. Rev. D 60, 057301 (1999) doi:10.1103/PhysRevD.60.057301 [hep-ph/9903480].
[13] R. F. Lebed, “Radiative weak annihilation decays,” Phys. Rev. D 61, 033004 (2000) doi:10.1103/PhysRevD.61.033004 [hep-ph/9908414].
[14] D. H. Evans, B. Grinstein and D. R. Nolte, “Short distance analysis of $\bar{B} \to D_s^*e^+e^-\bar{B} \to D^*e^+e^-$,” Nucl. Phys. B 577, 240 (2000) doi:10.1016/S0550-3213(00)00159-0 [hep-ph/9906528].
[15] C. S. Kim, R. H. Li and Y. Li, “Study of $\bar{B} \to D_s^*\mu^+\mu^-$ Decay in Perturbative QCD Approach,” JHEP 1110, 152 (2011) doi:10.1007/JHEP10(2011)152 [arXiv:1106.2711 [hep-ph]].