

Novel model-independent approach to search for new physics in five-body semileptonic decays

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(Received 12 October 2024; revised 3 August 2025; accepted 22 September 2025; published 15 October 2025)

Substantial contribution of the tensor current in semileptonic decays is regarded as a clear signal for new physics. In this work, we propose a model-independent approach to unambiguously test contribution of the tensor current in semileptonic five-body decays $\bar{D}_{(s)}/\bar{B}_{(s)} \rightarrow V\ell\bar{\nu}_\ell (\ell = e, \mu, \tau)$ with $V \rightarrow \pi^0\pi^+\pi^-$, where V denotes vector particles. We derive three parameters associated with the angular asymmetry, which are always equal to one in the Standard Model regardless the data of form factor but will deviate if contribution of the tensor current does not vanish. The outcomes have potential applications in precisely testing the Standard Model and searching for new physics. Relevant measurements can be performed using data collected by BESIII, Belle II, and LHCb.

DOI: 10.1103/kh77-td2c

The primary focus in particle physics today is the search for new physics and the semileptonic decays provide a clean environment, where the hadronic and leptonic currents can be effectively disentangled. The relevant hadronic form factors of heavy flavor mesons transitioning to final-state hadron are measured to test the Standard Model (SM) by comparing the measured results with predictions by theoretical models, such as lattice QCD [1–3] and various QCD-based models [4–8]. Some theoretical studies test the lepton flavor universality (LFU) in semileptonic decays of heavy mesons [9–14], particularly the ratios $R(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell)}|_{\ell \in \{e, \mu\}}$. Extensive experimental studies of three- and four-body semileptonic decays of heavy flavor mesons have also been conducted [15–19]. However, the discrepancies in form factors obtained from various models introduce significant uncertainty in the calculations and the fact that τ can only be identified via their pure leptonic decays leads to measurements lacking the necessary precision, making these searches for new physics not quantitatively sound.

In the SM, assuming neutrinos to be left-handed, semileptonic decays are described by the $V - A$ current, where

other types of current vanishes. In this work, we will propose a model-independent approach to unambiguously test contribution of the tensor current in semileptonic five-body decays $\bar{D}_{(s)}/\bar{B}_{(s)} \rightarrow V\ell\bar{\nu}_\ell (\ell = e, \mu, \tau)$ with $V \rightarrow \pi^0\pi^+\pi^-$, where V denotes vector particles. Five-body decays offer the advantage of introducing additional degrees of freedom compared to three- and four-body decays [20–23]. We initially present the angular distribution using $\bar{D} \rightarrow V\ell\bar{\nu}_\ell$ as an example for the derivation. The methodology remains identical for the $\bar{D}_s$, $\bar{B}$, $\bar{B}_s$, and $\bar{B}_c$ mesons. Subsequently, we introduce three parameters $\Theta_{1,2,3}$ associated with the asymmetry of angular distributions by incorporating various types of currents, other than the $V - A$ current. In particular, $\Theta_{1,2,3}$ remain constant at 1 in the SM, regardless of the shapes of form factors and without dependence on any specific new physics model. A diagrammatic representation of how our approach probes new physics in contrast to tests of LFU in semileptonic decays of heavy mesons is shown in Fig. 1. Finally, a summary will be presented.

There are 8 degrees of freedom in a $\bar{D} \rightarrow V\ell\bar{\nu}_\ell$, $V \rightarrow \pi^0\pi^+\pi^-$ decay. We adopt the kinematics shown in Fig. 2 [20]. The 4-momenta of ℓ , $\bar{\nu}_\ell$, π^0 , π^+ , and π^- are denoted as q_ℓ , q_ν , p_1 , p_2 , and p_3 , and their masses are denoted as m_ℓ , m_ν , m_1 , m_2 , and m_3 , respectively. For convenience, we define $Q \equiv q_\ell + q_\nu + p_1 + p_2 + p_3$, $Y \equiv q_\ell + q_\nu$, $K \equiv p_1 + p_2 + p_3$, and $Z \equiv p_2 + p_3$ and denote the masses of $\bar{D}$ and V as m_A and m_V , respectively. The angular distribution will be expressed using the three masses squared of the $\ell\bar{\nu}_\ell/\pi^0\pi^+\pi^-/\pi^+\pi^-$ systems, $Y^2/K^2/Z^2$, and five angles illustrated in Fig. 2.

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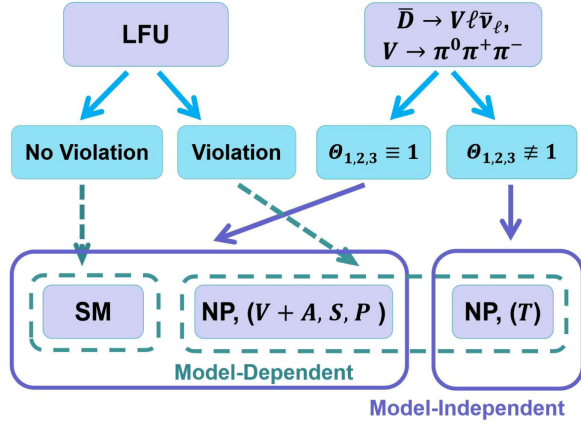


FIG. 1. Diagrammatic representation of how our approach probes new physics in contrast to tests of LFU in semileptonic decays of heavy mesons.

To derive the decay rate, one can start with the most general effective Hamiltonian describing the $\bar{c} \rightarrow \bar{d}\ell\bar{\nu}_\ell$ decays, assuming neutrinos are left-handed and containing all possible parity-conserving four-fermion dimension-6 operators [11,12,24–27],

$$\begin{aligned} \mathcal{H}_{\text{EFF}} = & \frac{G_F}{\sqrt{2}} V_{cq} [(1 + g_V) \bar{c} \gamma_\mu d \bar{u}(q_\ell) \gamma^\mu (1 - \gamma_5) v(q_\nu) \\ & + (-1 + g_A) \bar{c} \gamma_\mu \gamma_5 d \bar{u}(q_\ell) \gamma^\mu (1 - \gamma_5) v(q_\nu) \\ & + g_S \bar{c} d \bar{u}(q_\ell) (1 - \gamma_5) v(q_\nu) \\ & + g_P \bar{c} \gamma_5 d \bar{u}(q_\ell) (1 - \gamma_5) v(q_\nu) \\ & + g_T \bar{c} \sigma_{\mu\nu} (1 - \gamma_5) d \bar{u}(q_\ell) \sigma^{\mu\nu} (1 - \gamma_5) v(q_\nu)], \quad (1) \end{aligned}$$

where G_F is the Fermi constant and V_{cq} denotes the Cabibbo-Kobayashi-Maskawa matrix element. The coefficients g_V, g_A, g_S, g_P , and g_T represent the modification from the vector, axial-vector, scalar, pseudoscalar, and tensor currents to the SM, respectively. It is important to note that $g_{V,A,S,P,T}$ are zero in the SM. With the kinematics shown in Fig. 2, the differential decay rate of $\bar{D} \rightarrow V \ell \bar{\nu}_\ell, V \rightarrow \pi^0 \pi^+ \pi^-$ in the angular distribution is derived to be

$$\begin{aligned} \Gamma_5 = & \frac{1}{2^{17} \pi^9 m_A^2} \int \frac{|\vec{q}_1| |\vec{q}_4| |\vec{Z}| |\vec{K}|}{\sqrt{K^2} \sqrt{Y^2} \sqrt{Z^2}} \\ & \times \sum_{\lambda_l} |\mathcal{A}_p^{\lambda_l}|^2 d\Omega_1 d\Omega_3 d\cos\theta_2 dK^2 dY^2 dZ^2. \quad (2) \end{aligned}$$

Here, $d\Omega_{1,3} = d\cos\theta_{1,3} d\phi_{1,3}$ represent the differential solid angles, and $\mathcal{A}_p^{\lambda_l}$ is the decay amplitude with lepton polarization $\lambda_l = \pm$, which is expressed in terms of the form factors and angles related to the angular distribution,

$$\begin{aligned} \mathcal{A}_p^+ = & -\frac{g}{\sqrt{2}} |\vec{Z}| |\vec{q}_4| \sqrt{K^2} \sin\theta_3 \frac{G_F}{\sqrt{2}} V_{cd} \\ & \times (F_1 \alpha_1 + F_2 \alpha_2 + F_3 \alpha_3 + F_4 \alpha_4), \\ \mathcal{A}_p^- = & -\frac{g}{\sqrt{2}} |\vec{Z}| |\vec{q}_4| \sqrt{K^2} \sin\theta_3 \frac{G_F}{\sqrt{2}} V_{cd} \\ & \times (F'_1 \beta_1 + F'_2 \beta_2 + F'_3 \beta_3), \quad (3) \end{aligned}$$

where $g = g(Z^2, \theta_3)$ is effective coupling constant of $V \rightarrow \pi^0 \pi^+ \pi^-$, which can always be expressed as a function of Z^2 and θ_3 [20,28]. The coefficients (α, β) relate to

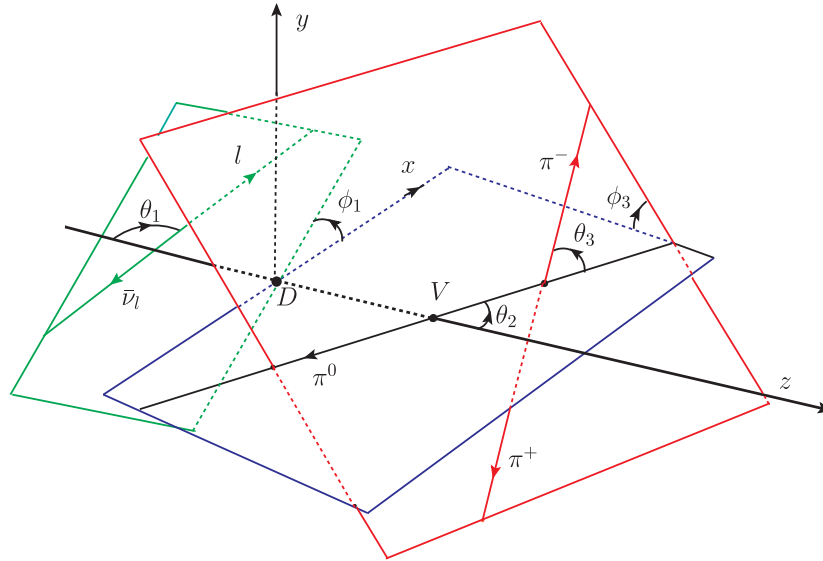


FIG. 2. Kinematics for $\bar{D} \rightarrow V \ell \bar{\nu}_\ell$ with $V \rightarrow \pi^0 \pi^+ \pi^-$ [20]. The angle between the 3-momentum of ℓ (π^0) and $\bar{D}$ in the $\ell \bar{\nu}_\ell$ (V) rest frame is denoted as θ_1 (θ_2), that of π^- and V in the $\pi^+ \pi^-$ rest frame is denoted as θ_3 , and the angle between the $\ell \bar{\nu}_\ell$ ($\pi^+ \pi^-$) system and the V (π^0) is denoted as ϕ_1 (ϕ_3).

angular variables, given by [20]

$$\begin{aligned}
\alpha_1 &= i \sin \theta_1 e^{-2i\phi_1} (\cos \phi_3 + i \cos \theta_2 \sin \phi_3), \\
&\quad + i \sin \theta_1 (\cos \phi_3 - i \cos \theta_2 \sin \phi_3), \\
\alpha_2 &= i \sin \theta_1 e^{-2i\phi_1} (\cos \phi_3 + i \cos \theta_2 \sin \phi_3) \\
&\quad - i \sin \theta_1 (\cos \phi_3 - i \cos \theta_2 \sin \phi_3), \\
\alpha_3 &= \cos \theta_1 e^{-i\phi_1} \sin \theta_2 \sin \phi_3, \\
\alpha_4 &= e^{-i\phi_1} \sin \theta_2 \sin \phi_3, \\
\beta_1 &= i(1 + \cos \theta_1) e^{-i\phi_1} (\cos \phi_3 + i \cos \theta_2 \sin \phi_3) \\
&\quad - i(1 - \cos \theta_1) (\cos \phi_3 - i \cos \theta_2 \sin \phi_3), \\
\beta_2 &= i(1 + \cos \theta_1) e^{i\phi_1} (\cos \phi_3 + i \cos \theta_2 \sin \phi_3) \\
&\quad + i(1 - \cos \theta_1) (\cos \phi_3 - i \cos \theta_2 \sin \phi_3), \\
\beta_3 &= \sin \theta_1 \sin \theta_2 \sin \phi_3,
\end{aligned} \tag{4}$$

and $F^{(\prime)}$ s are the expressions corresponding to the form factors, written as

$$\begin{aligned}
F_1 &= -\frac{m_l}{\sqrt{Y^2}} f_1 - \delta_1, \quad F_2 = -\frac{m_l}{\sqrt{Y^2}} f_2 - \delta_2, \\
F_3 &= \frac{m_l}{\sqrt{Y^2}} f_3 + \delta_3, \quad F_4 = \frac{m_l}{\sqrt{Y^2}} f_4, \quad F'_1 = f_1 + \frac{m_l}{\sqrt{Y^2}} \delta_1, \\
F'_2 &= f_2 + \frac{m_l}{\sqrt{Y^2}} \delta_2, \quad F'_3 = f_3 + \frac{m_l}{\sqrt{Y^2}} \delta_3.
\end{aligned} \tag{5}$$

In the above, we have separated the contribution from the tensor current into $\delta_{1,2,3}$ and the contribution from other types of currents into $f_{1,2,3}$. They are expressed in terms of form factors,

$$\begin{aligned}
f_1 &= -2\sqrt{2}\beta_l \frac{m_A}{m_A + m_V} |\vec{K}| (g_V + 1) V_0, \\
f_2 &= \sqrt{2}\beta_l (m_A + m_V) (1 - g_A) A_1, \\
f_3 &= 2\sqrt{2}\beta_l (1 - g_A) A_{12}, \\
f_4 &= 4\sqrt{2}\beta_l m_A |\vec{K}| A_0 \left[(1 - g_A) + \frac{Y^2}{m_l(m_c + m_d)} g_P \right], \\
\delta_1 &= -8\sqrt{2}\beta_l m_A |\vec{K}| g_T T_1, \\
\delta_2 &= -4\sqrt{2}\beta_l (m_A^2 - m_V^2) g_T T_2, \\
\delta_3 &= 8\sqrt{2}\beta_l \sqrt{Y^2} g_T T_{23},
\end{aligned} \tag{6}$$

with

$$\begin{aligned}
\beta_\ell &= \sqrt{1 - \frac{m_\ell^2}{Y^2}}, \\
A_{12} &= \frac{m_A + m_V}{2m_V \sqrt{Y^2}} (m_A^2 - m_V^2 - Y^2) A_1 - \frac{32}{\sqrt{Y^2}} \frac{m_A^3 m_V}{m_A + m_V} |\vec{K}|^2 A_2, \\
T_{23} &= \frac{1}{2m_V} \left[(-m_A^2 + 3m_V^2 - Y^2) T_2 + 4 \frac{m_A^2}{m_A^2 - m_V^2} |\vec{K}|^2 T_3 \right],
\end{aligned} \tag{7}$$

where $T_{1,2,3}$ denote the tensor form factors and $(V_0, A_{0,1,2})$ are the other types of form factors of the $\bar{D} \rightarrow V$ transition [12,27]. Note that the contribution from the scalar current is zero, and as a result, $f_{1,2,3,4}$ do not include the g_S term, which is associated with the scalar current.

There are seven nonzero asymmetries present in five-body decays. In the absence of the tensor current, contributions arise from only four form factors. One can always find three constant degrees of freedom. However, in the presence of the tensor current, the introduction of three additional tensor form factors results in these degrees of freedom not remaining constant. This offers an approach to identify new physics contributions by utilizing asymmetries in angular distributions, independent on numerical values and shapes of the form factors.

The seven nonzero asymmetries, which can be experimentally measured, are given as

$$\begin{aligned}
\Upsilon_1 &= \int_{S_1} d\phi_3 \int_{S_1} d\phi_1 \int_{D_1} d\cos \theta_2 \int_{D_1} d\cos \theta_1 d\Phi_5 \\
&\quad \propto \frac{16\pi^2}{9} (8F_1^2 + 8F_2^2 + 2F_3^2 + 3F_4^2 \\
&\quad + 16F_1'^2 + 16F_2'^2 + 2F_3'^2), \\
\Upsilon_2 &= \int_{S_3} d\phi_3 \int_{S_2} d\phi_1 \int_{D_1} d\cos \theta_2 \int_{D_1} d\cos \theta_1 d\Phi_5 \\
&\quad \propto 8\pi^2 (-F_1' F_3' + F_2 F_4), \\
\Upsilon_3 &= \int_{S_3} d\phi_3 \int_{S_3} d\phi_1 \int_{D_2} d\cos \theta_2 \int_{D_1} d\cos \theta_1 d\Phi_5 \\
&\quad \propto \frac{128}{3} (F_1^2 - F_2^2 + F_1'^2 - F_2'^2), \\
\Upsilon_4 &= \int_{S_1} d\phi_3 \int_{S_4} d\phi_1 \int_{D_2} d\cos \theta_2 \int_{D_1} d\cos \theta_1 d\Phi_5 \\
&\quad \propto -\frac{16\pi^2}{3} (F_1' F_3' + F_2 F_4), \\
\Upsilon_5 &= \int_{S_2} d\phi_3 \int_{S_1} d\phi_1 \int_{D_1} d\cos \theta_2 \int_{D_1} d\cos \theta_1 d\Phi_5 \\
&\quad \propto \frac{16\pi^2}{3} (8F_1' F_2' + F_3 F_4), \\
\Upsilon_6 &= \int_{S_3} d\phi_3 \int_{S_2} d\phi_1 \int_{D_1} d\cos \theta_2 \int_{D_2} d\cos \theta_1 d\Phi_5 \\
&\quad \propto \frac{32\pi}{3} (F_2 F_3 - F_2' F_3'), \\
\Upsilon_7 &= \int_{S_1} d\phi_3 \int_{S_4} d\phi_1 \int_{D_2} d\cos \theta_2 \int_{D_2} d\cos \theta_1 d\Phi_5 \\
&\quad \propto -\frac{64\pi}{9} (F_2 F_3 + F_2' F_3'),
\end{aligned} \tag{8}$$

where $\int_{D_{1(2)}} \equiv \int_{-1}^0 \pm \int_0^1$, $\int_{S_{1(2)}} \equiv \int_0^\pi \pm \int_\pi^{2\pi}$, $\int_{S_{3(4)}} \equiv \int_0^{\pi/2} - \int_{\pi/2}^\pi \pm \int_\pi^{3\pi/2} \mp \int_{3\pi/2}^{2\pi}$, and $d\Phi_5 \equiv \frac{d\Gamma_5}{d\Omega_1 d\phi_3 d\cos \theta_2 dY^2}$. The expression of $\int_{D_{1(2)}}$ is analogous to the regular

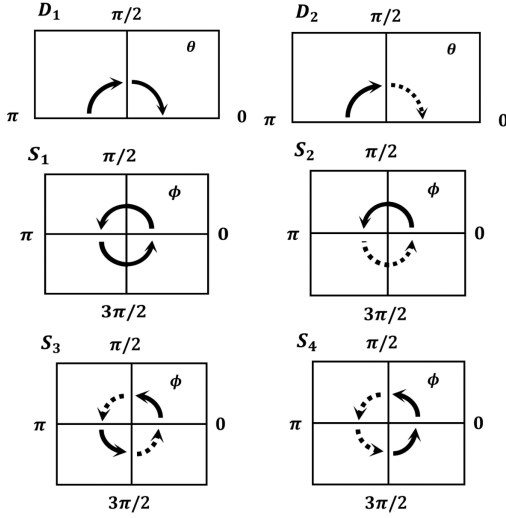


FIG. 3. Integration ranges and directions of angles. The solid lines indicate positive sign and dashed lines negative sign.

forward-backward asymmetry, and similar integration techniques have previously been used to extract angular coefficients in four-body decays [29,30]. A diagram for the integration ranges and directions of angles is depicted in Fig. 3.

In the most general case, these seven asymmetries are independent. This independence arises from the seven

independent form-factor-related parameters $f_{1,2,3,4}$ and $\delta_{1,2,3}$. Consequently, we introduce three parameters that are derived from the combination of $\Upsilon_{1,2,3,4,5,6,7}$ to distinguish the contribution from the tensor current,

$$\begin{aligned}\Theta_1 &= \frac{2Y^2 - m_l^2}{3Y^2 + m_l^2} \frac{\Upsilon_6}{\Upsilon_7}, \\ \Theta_2 &= \frac{\Delta}{\Upsilon_3} \left[\left(1 + \frac{m_l^2}{Y^2}\right)^2 \frac{2\Upsilon_2 + 3\Upsilon_4}{18\pi^3 \Upsilon_6} - \frac{\Upsilon_6}{2\pi(2\Upsilon_2 + 3\Upsilon_4)} \right], \\ \Theta_3 &= \frac{1}{\Upsilon_1} \left\{ \frac{3\Upsilon_4 + 2\Upsilon_2}{\Delta} \left[\frac{4\pi m_l^2 + 2Y^2}{3} \frac{\Upsilon_6}{m_l^2 + Y^2} \right. \right. \\ &\quad \left. \left. + \frac{4}{9\pi} \frac{m_l^2 + Y^2}{m_l^2} \frac{(2\Upsilon_2 - 3\Upsilon_4)^2}{\Upsilon_6} \right] \right. \\ &\quad \left. + \Delta \left(\frac{\pi m_l^2 + 2Y^2}{6} \frac{\Upsilon_6}{m_l^2 + Y^2} \frac{2\Upsilon_2 + 3\Upsilon_4}{\Upsilon_6} \right. \right. \\ &\quad \left. \left. + \frac{1}{54\pi} \frac{m_l^2 + Y^2}{Y^2} \frac{m_l^2 + 2Y^2}{Y^2} \frac{2\Upsilon_2 + 3\Upsilon_4}{\Upsilon_6} \right) \right\}, \quad (9)\end{aligned}$$

where

$$\Delta = \begin{cases} 3\Upsilon_5 + \sqrt{-32\Upsilon_2^2 + 72\Upsilon_4^2 + 9\Upsilon_5^2} & \text{if } Y^2 V_0 A_1 + 4m_A m_V \frac{m_l^2}{Y^2} A_0 A_{12} < 0. \\ 3\Upsilon_5 - \sqrt{-32\Upsilon_2^2 + 72\Upsilon_4^2 + 9\Upsilon_5^2} & \text{if } Y^2 V_0 A_1 + 4m_A m_V \frac{m_l^2}{Y^2} A_0 A_{12} > 0. \end{cases}$$

The fact that the tensor current vanishes ($\delta_{1,2,3} = 0$) in the SM results in that $\Theta_{1,2,3}$ are always equal to 1 for any Y^2 , but with effects from new physics which encompasses the nonzero elements of the tensor current, they may significantly deviate from one for certain Y^2 . The $\Theta_{1,2,3}$ as a function of Y^2 are exhibited in Fig. 4. For clarity, we derive the first-order approximation of $\Theta_{1,2,3}$ assuming that $\delta_{1,2,3}$ are small quantities,

$$\begin{aligned}\Theta_1 &\approx 1 + \frac{2t}{1+t^2} \left(\frac{\delta_2}{f_2} + \frac{\delta_3}{f_3} \right), \\ \Theta_2 &\approx 1 + \frac{t(1-t^2)}{1+t^2} \left(\frac{\delta_1}{f_1} \frac{2f_1^2}{f_1^2 - f_2^2} + \frac{\delta_2}{f_2} \frac{8f_1 f_2 + f_3 f_4}{8f_1 f_2 - t^2 f_3 f_4} + \frac{\delta_3}{f_3} \varsigma \right), \\ \Theta_3 &\approx 1 + \frac{t(1-t^2)}{(2+t^2)(8f_1^2 + 8f_2^2 + f_3^2) + 3t^2 f_3} \\ &\quad \times \left[\frac{\delta_1}{f_1} 16f_1^2 + \frac{\delta_2}{f_2} \varpi_1 + \frac{\delta_3}{f_3} \varpi_2 \right], \quad (10)\end{aligned}$$

with

$$\begin{aligned}t &= \frac{m_l}{\sqrt{Y^2}}, \\ \varsigma &= \frac{8f_1^3 f_2 + 8f_1 f_2^3 + f_2^2 f_3 f_4 - f_1^2 f_3 f_4 (1+2t^2)}{(f_1^2 - f_2^2)(8f_1 f_2 - t^2 f_3 f_4)}, \\ \varpi_1 &= -\frac{24f_1 f_2 f_4^2 - (8f_1 f_2 + 2f_3 f_4)(8f_1^2 + 8f_2^2 - f_3^2)}{8f_1 f_2 - t^2 f_3 f_4} \\ &\quad + \frac{8f_1^2 - 8f_2^2 - f_3^2 - 3f_4^2}{1+t^2}, \\ \varpi_2 &= \frac{24f_1 f_2 f_4^2 - (8f_1 f_2 + 2f_3 f_4)(8f_1^2 + 8f_2^2 - f_3^2)}{8f_1 f_2 - t^2 f_3 f_4} \\ &\quad + \frac{8f_1^2 - 8f_2^2 - f_3^2 - 3f_4^2}{1+t^2} + 16f_1^2. \quad (11)\end{aligned}$$

In the above, it is evident that $\Theta_{1,2,3} \equiv 1$ when $\delta_{1,2,3} = 0$.

In summary, the angular distributions of five-body semileptonic decays have three additional degrees of freedom compared to three- and four-body semileptonic decays, resulting in unique angular asymmetries. Based on these asymmetries, we have introduced three parameters

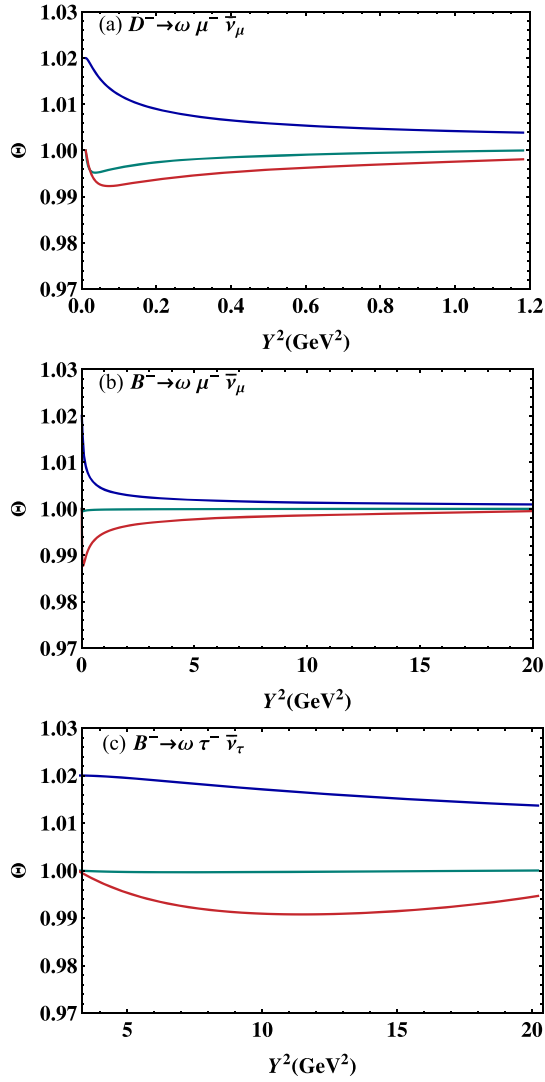


FIG. 4. Distributions of Θ_1 , Θ_2 , and Θ_3 as a function of Y^2 for (a) $D^- \rightarrow \omega \mu^- \bar{\nu}_\mu$, (b) $B^- \rightarrow \omega \mu^- \bar{\nu}_\mu$, and (c) $B^- \rightarrow \omega \tau^- \bar{\nu}_\tau$ with $\omega \rightarrow \pi^0 \pi^+ \pi^-$. The dark blue, teal, and dark red lines represent Θ_1 , Θ_2 , and Θ_3 , respectively. The numerical values of the form factors related to the SM are taken from Refs. [31,32]. To simplify the discussion of new physics contributions, we fix $\delta_1/f_1 = \delta_2/f_2 = \delta_3/f_3 = 0.01$.

$\Theta_{1,2,3}$, which are always equal to one in the SM for any Y^2 . These parameters are sensitive for the search of new physics, without dependence on the data of form factors and any particular new physics model. According to Eqs. (6), (7), and (10), $\Theta_{1,2,3}$ may deviate from 1 when

tensor current is present, and the magnitude of deviation increases with larger $t = \frac{m_l}{\sqrt{Y^2}}$. As a result, experimentally studying five-body semileptonic decays involving heavier leptons, such as $\bar{B}_{(s,c)} \rightarrow V \tau \bar{\nu}_\tau / V \mu \bar{\nu}_\mu$ and $\bar{D}_{(s)} \rightarrow V \mu \bar{\nu}_\mu$, could yield larger significance. Furthermore, many $V \rightarrow \pi^0 \pi^+ \pi^-$ candidates via strong decay can be used, for example, $D^- \rightarrow \omega \mu \bar{\nu}_\mu$, $D_s^- \rightarrow \phi \mu \bar{\nu}_\mu$, $B^- \rightarrow \omega \mu \bar{\nu}_\mu (\tau \bar{\nu}_\tau)$, and so on.

In general, five-body decays provide much richer information through their angular distributions. This feature significantly enhances the ability to separate SM contributions from new physics effects. For instance, in $\bar{D} \rightarrow \pi \ell \bar{\nu}_\ell$, the limited angular information makes it difficult to disentangle SM effects from potential new physics. In $\bar{D} \rightarrow \rho \ell \bar{\nu}_\ell$ ($\rho \rightarrow \pi \pi$), there are three angle-dependent parameters (out of a total of 5) [33], while in $\bar{D} \rightarrow \omega \ell \bar{\nu}_\ell$ ($\omega \rightarrow \pi^0 \pi^+ \pi^-$), the number of angle-dependent parameters increases to five (out of a total of 8). The larger number of angular degrees of freedom in the latter case provides a clear advantage. A similar situation also arises for B mesons. In addition, by first determining the presence or absence of a tensor current in the hadron sector, we can isolate its contribution. This allows us to attribute any anomalies in the angular distribution unambiguously to right-handed or tensor currents in the lepton sector, providing a clear path to investigate neutrino-related new physics.

In this work, we have proposed a novel and model-independent approach to search for new physics, and the three parameters $\Theta_{1,2,3}$ introduced can be measured with the datasets collected by BESIII [34], Belle II, and LHCb.

Acknowledgments. Y. Y. was supported in part by National Natural Science Foundation of China (NSFC) under Contracts No. 11905023, No. 12047564, and No. 12147102; the Natural Science Foundation of Chongqing (CQCSTC) under Contract No. cstc2020jcyj-msxmX0555; and the Science and Technology Research Program of Chongqing Municipal Education Commission (STRPCMEC) under Contracts No. KJQN202200605 and No. KJQN202200621. H. Z. and B. C. K. were supported in part by the Excellent Youth Foundation of Henan Scientific Committee under Contract No. 242300421044, NSFC under Contracts No. 11875054 and No. 12192263, and Joint Large-Scale Scientific Facility Fund of the NSFC and the Chinese Academy of Sciences under Contract No. U2032104.

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