Phenomenological tests of the Two-Higgs-Doublet Model with MFV and flavour-blind phases

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Abstract. In the context of a Two-Higgs-Doublet Model in which Minimal Flavour Violation (MFV) is imposed, one can allow the presence of flavour-blind CP-violating phases without obtaining electric dipole moments that overcome the experimental bounds. This choice permits to accommodate the hinted large phase in the $B_s$ mixing and, at the same time, to soften the observed anomaly in the relation between $\epsilon_K$ and $S_{\psi K_S}$.

1. Introduction
During the last decade the $B$ factories and the Tevatron experiments have collected a large amount of data that permits a deep analysis of precision measurements. The agreement of the experimental data of flavour-changing processes with the Standard Model (SM) predictions is verified within 20%; a similar agreement is found with the CP-violating processes, but recently a few anomalies have been detected in this sector: (i) the CP-violation in the $B_s$ system signaled by the CP-asymmetry $S_{\psi\phi}$ in $B_s \to \psi\phi$ observed by CDF and D0 that appears to be roughly by a factor of 20 larger than the SM and MFV predictions [1, 2]; (ii) the value of $\sin 2\beta$ resulting from the UT fits tends to be significantly larger than the measured value of $S_{\psi K_S}$ [3]; (iii) the value of $\epsilon_K$ predicted in the SM by using $S_{\psi K_S}$ as the measure of the observed CP-violation is about $2\sigma$ lower than the data [3, 4]; (iv) recently D0 reported a measurement of the like-sign dimuon charge asymmetry in semileptonic $b$ decay that is $3.2\sigma$ from the SM prediction [5]. These anomalies, if confirmed, suggest that a room for New Physics could be present in CP-violating processes, even if other CP-violating observables, such as electric dipole moments (EDMs), put tight constraints on it.

One of the most elegant and effective ways to protect the flavour in the New Physics models is the MFV hypothesis [6, 7]; it forces the flavour sector of the model to respect the same flavour symmetry and symmetry breaking as the SM, i.e. to be governed only by the same Yukawa couplings. However, while in the SM the Yukawa couplings are the only sources of both flavour breaking and CP violation, this is not necessary true in New Physics models even assuming MFV: the flavour can be broken only by Yukawa couplings, but other sources of CP violation are allowed [8]. This possibility is particularly interesting in light of the experimental results described above, in which the flavour structure of the SM seems to be confirmed, but new CP-violating mechanisms could contribute.

We have analyzed a simple extension of the SM in which two Higgs doublets are present; we have imposed MFV but allowed the presence of flavour-blind CP-violating phases in the fermion-
scalar interactions; we will call this model 2HDM

\[ 2 \text{HDM} \]

[9]. First of all we have checked that the strict experimental flavour-changing neutral current (FCNCs) constraints can be naturally fulfilled, and that the bounds on CP-violation that come from EDMs are not overcome [10]. Then we have shown that a large phase in the \( B_s \) mixing can be easily accommodated and this, without extra free parameters, improves significantly in a correlated manner the issues about \( \epsilon_K \) and \( S_{\psi K_S} \).

2. The 2HDM

2.1. General structure of 2HDMs

The Higgs Lagrangian of a generic model with two-Higgs doublets, \( H_1 \) and \( H_2 \), with hypercharges \( Y = 1/2 \) and \( Y = -1/2 \) respectively, can be written as

\[
\mathcal{L} = \sum_{i=1,2} D_\mu H_i D^\mu H_i^\dagger + \mathcal{L}_Y - V(H_1, H_2),
\]

where \( D_\mu H_i = \partial_\mu H_i - ig' Y \bar{B}_\mu H_i - ig T_a \bar{W}_\mu^a H_i \), with \( T_a = \tau_a/2 \).

The potential \( V(H_1, H_2) \) is such that the \( H_i \) gets vacuum expectation value \( \langle H_i^0 \rangle = v_i \) with \( v = \sqrt{v_1^2 + v_2^2} \approx 246 \text{ GeV} \) fixed by the mass of the \( W \) boson; moreover, we only consider the case in which it does not contain new sources of CP violation. The Higgs spectrum contains three Goldstone bosons \( G^\pm \) and \( G^0 \), two charged Higgs \( H^\pm \), and three neutral Higgses \( h^0, H^0 \) (CP-even), and \( A^0 \) (CP-odd).

The most general renormalizable and gauge-invariant interaction of the two Higgs doublets with the SM quarks is

\[
-\mathcal{L}_Y = \bar{Q}_L X_1 D_R H_1 + \bar{Q}_L X_2 U_R H_2^c + \bar{Q}_L X_3 U_R H_2 + \text{h.c.},
\]

where \( H_i^c = -i \tau_2 H_i^* \) and the \( X_i \) are \( 3 \times 3 \) matrices with a generic flavour structure. By performing a global rotation of angle \( \beta = \arctan(v_2/v_1) \) of the Higgs fields \( (H_1, H_2) \) to the so-called Higgs basis \((\Phi_v, \Phi_H)\), the mass terms and the interaction terms are separated:

\[
-\mathcal{L}_Y = \bar{Q}_L \left( \frac{\sqrt{2}}{v} M_u \Phi_v + Z_u \Phi_H \right) D_R + \bar{Q}_L \left( \frac{\sqrt{2}}{v} M_d \Phi_v^c + Z_d \Phi_H^c \right) U_R + \text{h.c.};
\]

the quark mass matrices \( M_{u,d} \) and the couplings \( Z_{u,d} \) are linear combinations of the \( X_i \), weighted by the Higgs vacuum expectation values:

\[
M_{u,d} = \frac{v}{\sqrt{2}} (\cos \beta X_{u,d1} + \sin \beta X_{u,d2}) \quad \text{and} \quad Z_{u,d} = \cos \beta X_{u,d2} - \sin \beta X_{u,d1}.
\]

In this way it is clear that \( M_{u,d} \) and \( Z_{u,d} \) cannot be diagonalized simultaneously for generic \( X_i \), but still widely used method to obtain the aim is the Natural Flavour Conservation hypothesis [11], that states that renormalizable couplings contributing at the tree-level to FCNC processes are simply absent by assumption. Hence, in order to forbid these terms, one should impose some additional symmetry; however, it has been shown in [9] that this structure is not stable under quantum corrections, and sizable FCNCs operators are generated at higher energies unless a very severe fine tuning is performed.

2.2. Minimal Flavour Violation

In order to suppress the FCNCs, some additional hypotheses on the model are needed. The oldest but still widely used method to obtain the aim is the Natural Flavour Conservation hypothesis [11], that states that renormalizable couplings contributing at the tree-level to FCNC processes are simply absent by assumption. Hence, in order to forbid these terms, one should impose some additional symmetry; however, it has been shown in [9] that this structure is not stable under quantum corrections, and sizable FCNCs operators are generated at higher energies unless a very severe fine tuning is performed.
It seems instead that a protection of the flavour symmetry and of its breaking is necessary in many New Physics models. In this frame the popular hypothesis of MFV turns out to be effective in suppressing FCNCs and stable under renormalization. Formally, MFV consists in the assumption that the $SU(3)$ quark flavour symmetry is broken only by two independent terms, $Y_d$ and $Y_u$, transforming as

$$Y_u \sim (3, \bar{3}, 1)_{SU(3)^3}, \quad Y_d \sim (3, 1, \bar{3})_{SU(3)^3};$$  \hspace{1cm} (5)$$

in the 2HDM it implies for the $X_i$ the structure [7]

$$X_{d1} = Y_d$$  \hspace{1cm} (6a)$$
$$X_{d2} = P_{d2}(Y_uY_u^\dagger, Y_dY_d^\dagger) \times Y_d = \epsilon_0 Y_d + \epsilon_1 Y_d Y_d^\dagger Y_d + \epsilon_2 Y_d Y_d^\dagger Y_d + \ldots$$  \hspace{1cm} (6b)$$
$$X_{u1} = P_{u1}(Y_uY_u^\dagger, Y_dY_d^\dagger) \times Y_u = \epsilon'_0 Y_u + \epsilon'_1 Y_u Y_u^\dagger Y_u + \epsilon'_2 Y_u Y_u^\dagger Y_u + \ldots$$  \hspace{1cm} (6c)$$
$$X_{u2} = Y_u$$  \hspace{1cm} (6d)$$

that is renormalization group invariant. Differently from the Natural Flavour Conservation case, now FCNCs are absent only at the lowest order in $Y_i Y_i^\dagger$ since the $X_i$ are aligned [12]; they are present when one considers higher orders instead.

In order to investigate these FCNCs, one can perform an expansion in powers of suppressed off-diagonal CKM elements, so that the effective non-diagonal $Z_d$ between the down-type quarks and the neutral Higgses assumes the form [7]

$$Z_d = W^d \lambda_d \quad \text{with} \quad W^d_{ij} = \bar{\alpha} \delta_{ij} + \left(\alpha_0 V^\dagger \lambda_u^2 V + \alpha_1 V^\dagger \lambda_u^2 V + \alpha_2 \lambda_v^2 V\right)_{ij},$$  \hspace{1cm} (7)$$

where $\lambda_u,d \propto 1/v \text{diag}(m_u,d,m_c,s,m_t,b)$, $\Delta = \text{diag}(0,0,1)$, and the $\bar{\alpha}$, $\alpha_i$ are parameters naturally of $O(1)$; this structure already shows a large suppression due to the presence of two off-diagonal CKM elements and the down-type Yukawas. The case of $Z_u$ is less interesting since other suppression are present, and the FCNCs are negligible.

One can check that no fine tuning is required in this case by performing a comparison with experimental FCNCs observables: constraints on the free parameters are obtained by imposing that the new physics contributions must be compatible with the experimental data within errors. We have found the bounds [9]:

$$|\alpha_0| \tan \beta \frac{v}{M_H} < 18$$  \hspace{1cm} from $\epsilon_K$; \hspace{1cm} (8a)$$
$$\sqrt{(|a_0^a + a_0^\bar{a}|(a_0 + a_2)) \tan \beta \frac{v}{M_H}} = 10$$  \hspace{1cm} from $\Delta M_s$; \hspace{1cm} (8b)$$
$$\sqrt{|a_0 + a_1| \tan \beta \frac{v}{M_H}} < 8.5$$  \hspace{1cm} from $\text{Br}(B_s \to \mu^+ \mu^-)$; \hspace{1cm} (8c)$$

that, as can be noted, are well compatible and perfectly natural.

2.3. Flavour-blind phases
The mechanisms of flavour and CP violation do not necessary need to be related: in MFV the Yukawa matrices are the only sources of flavour breaking, but other sources of CP violation could be present, provided that they are flavour-blind [8]. However, so far it has been assumed the effective MFV parameters $a_i$ to be real, in order to fulfill the strong bounds on flavour-conserving CPV phases implied by the electric dipole moments. Allowing the FCNC parameters $a_i$ to be complex, we investigate the possibility of generic CP-violating flavour-blind phases in the Higgs sector [9]; we will show that this choice implies several interesting phenomenological results for the $\Delta F = 2$ transitions, and that at the same time the electric dipole moments, although much enhanced over the SM values, are still compatible with the experimental bounds.
3. $\Delta F = 2$ amplitudes

Considering the $\Delta F = 2$ FCNC transitions mediated by the neutral Higgs bosons, the leading MFV effective Hamiltonians are:

$$H_{d,s}^{[\Delta S]=2} \propto -\frac{a_0^2}{M_H^2} \frac{m_s m_d}{v} \left(\frac{m_t}{V_{td}}\right)^2 V_{ts}^* V_{td} \left(\bar{s}_R d_L (s_L d_R) + \text{h.c.}\right), \quad (9a)$$

$$H_{d,s}^{[\Delta B]=2} \propto -\frac{(a_0^* + a_1)(a_0 + a_2)}{M_H^2} \frac{m_s m_d}{v} \left(\frac{m_t}{V_{ts}}\right)^2 V_{td}^* V_{td(d,s)} \left[\bar{b}_R (d,s)_L (s_L (d,s)_R) + \text{h.c.}\right], \quad (9b)$$

that show two key properties:

- the impact in $K^0$, $B_d$ and $B_s$ mixing amplitudes scales with $m_s m_d$, $m_b m_d$ and $m_b m_s$ respectively, opening the possibility of sizable non-standard contributions to the $B_s$ system without serious constraints from $K^0$ and $B_d$ mixing;
- while the possible flavour-blind phases do not contribute to the $\Delta S = 2$ effective Hamiltonian, they could have an impact in the $\Delta B = 2$ case, offering the possibility to solve the anomaly in the $B_s$ mixing phase.

These Hamiltonians have a direct impact on some crucial observables of the neutral mesons systems, namely the mass differences and the asymmetries in the decays; in fact, in this analysis we consider

$$\Delta M_K = \frac{1}{m_K} \text{Re} \left[\langle K^0 | H^{[\Delta S]=2} | \bar{K}^0 \rangle \right], \quad (10)$$

$$\epsilon_K \simeq e^{i \frac{\pi}{4}} \frac{1}{\sqrt{2} m_K \Delta M_K} \text{Im} \left[\langle K^0 | H^{[\Delta S]=2} | \bar{K}^0 \rangle \right], \quad (11)$$

$$\Delta M_{d,s} = \frac{1}{m_{B_{d,s}}} \text{Re} \left[\langle B_{d,s}^0 | H^{[\Delta B]=2} | \bar{B}_{d,s}^0 \rangle \right], \quad (12)$$

$$S_{\psi_{K_S}} = \text{Im} \left(\text{arg} \langle B_{d,s}^0 | H^{[\Delta B]=2} | B_{d,s}^0 \rangle \right), \quad (13)$$

$$S_{\psi_{\phi}} = \text{Im} \left(\text{arg} \langle B_{s}^0 | H^{[\Delta B]=2} | B_{s}^0 \rangle \right). \quad (14)$$

Using the presence of the new free phase $\text{arg} [(a_0^* + a_1)(a_0 + a_2)]$ in $H_s^{[\Delta B]=2}$, the hinted large value of $S_{\psi_{\phi}}$ can be easily obtained. Moreover, MFV implies that the new phases in the $B_d$ and the $B_s$ systems are related by the ratio $m_d/m_s$, and hence a large phase in the $B_s$ system determines an unambiguous small shift in the relation between $S_{\psi_{K_S}}$ and the CKM phase $\beta$; as it can be seen in Fig. 1 (Left), it goes in the right direction to improve the existing tension between the experimental value of $S_{\psi_{K_S}}$ and its SM prediction.

Due to the $m_s m_d$ factor in $H^{[\Delta S]=2}$, the new physics contribution to $\epsilon_K$ is tiny and does not improve alone the agreement between data and prediction for $\epsilon_K$. However, given the modified relation between $S_{\psi_{K_S}}$ and the CKM phase $\beta$, the true value of $\beta$ extracted in this scenario increases with respect to SM fits. As a result of this modified value of $\beta$, also the predicted value for $\epsilon_K$ increases with respect to the SM case, resulting in a better agreement with data, as shown in Fig. 1 (Right).

4. Electric dipole moments

4.1. $2HDM_{\text{MFV}}$ predictions

The EDM of a particle is defined by one of its electromagnetic form factors [13]. In particular, for a spin-$\frac{1}{2}$ particle $f$, the form-factor decomposition of the matrix element of the electromagnetic
current $J_\mu$ is
\[ \langle f(p') | J_\mu(0) | f(p) \rangle = \bar{u}(p') \Gamma_\mu(p' - p) u(p) \] (15)

where
\[ \Gamma_\mu(q) = F_1(q^2) \gamma_\mu + F_2(q^2) i \sigma_{\mu\nu} \frac{q^\nu}{2m} + F_A(q^2) \left( \gamma_\mu \gamma_5 q^2 - 2m \gamma_5 q_\mu \right) + F_3(q^2) \sigma_{\mu\nu} \frac{q^\nu}{2m} . \] (16)

Since the electric dipole interaction of a particle with the electromagnetic field violates both $P$ and $T$ symmetry, one identifies the electric dipole moment of $f$ with
\[ d_f \equiv \frac{-F_3(0)}{2m} ; \] (17)
this corresponds to the effective electric dipole interaction
\[ \mathcal{L}_{\text{eff}} = -\frac{i}{2} d_f \bar{\psi} \sigma_{\mu\nu} \gamma_5 \psi F^{\mu\nu} , \] (18)

that indeed reduces to $\mathcal{L}_{\text{eff}} = d_f \bar{\sigma} \cdot \vec{E}$ in the nonrelativistic limit. In an analogous way one can define the chromoelectric dipole moment. Moreover, beyond the one-loop single-particle level, there are other CP-violating operators that can have significant effects on the EDMs, like, for example, the dimension-6 Weinberg operators or the CP-odd four-fermion interactions.

The effective Lagrangian describing the fermions (C)EDMs that is relevant for our analysis reads
\[ -\mathcal{L}_{\text{eff}} = \sum_f \frac{i}{2} \bar{f} F_{\mu\nu} \sigma^{\mu\nu} \gamma_5 f + \sum_f \frac{i}{2} \bar{f} g_5 \bar{f} G_{\mu\nu} \sigma^{\mu\nu} \gamma_5 f + \sum_{f,f'} C_{ff'} (\bar{f} f) (\bar{f'} i \gamma_5 f') , \] (19)

where $d_{f(C)}$ stands for the quarks and leptons (C)EDMs, while $C_{ff'}$ is the coefficient of the CP-odd four fermion interactions.

Among the various atomic and hadronic EDMs, the Thallium, neutron and Mercury ones represent the most sensitive probes of CP violating effects; their EDMs can be calculated from
the elementary particles EDMs using non-perturbative techniques [14]. The thallium EDM \(d_{Tl}\) can be estimated as
\[
d_{Tl} \simeq -585 \cdot d_e - e \ (43 \text{GeV}) \ C_S, \tag{20}
\]
where
\[
C_S \simeq C_{de} \frac{29 \text{ MeV}}{m_d} + C_{se} \frac{\kappa \times 220 \text{ MeV}}{m_s} + C_{be} \frac{66 \text{ MeV}(1 - 0.25 \kappa)}{m_b}, \tag{21}
\]
with \(\kappa \simeq 0.5 \pm 0.25\); the neutron and mercury EDMs can be estimated from QCD sum rules, which leads to
\[
d_n = (1 \pm 0.5) \left[ 1.4(d_d - 0.25d_u) + 1.1e (d_d^c + 0.5d_u^c) \right] \tag{22}
\]
and
\[
d_{Hg} \simeq 7 \times 10^{-3} e (d_u^c - d_d^c) + 10^{-2} d_e + e \ (3.5 \times 10^{-3} \text{ GeV}) \ C_S - \\
- e \left( 1.4 \times 10^{-5} \text{GeV}^2 \right) \left[ 0.5 \frac{C_{dd}}{m_d} + 3.3 \kappa \frac{C_{sd}}{m_s} + (1 - 0.25 \kappa) \frac{C_{ld}}{m_b} \right] \tag{23}
\]
(in which the \(d_f^{(c)}\) are evaluated at 1 GeV).

The values of \(C_{ff'}\) and \(d_f^{(c)}\) have been obtained in the context of Supersymmetry in [15, 16], and they have been extended to the case of the 2HDM\(_{\text{MFV}}\) in [10]; here we present the results for the case in which CP is not violated in the scalar potential.

- For \(C_{ff'}\) one has
\[
C_{ff'} = \frac{m_f m_{f'}}{v^2} \frac{\text{Im} \omega_{ff'}}{M_A^2} \rho_{\beta}^2, \tag{24}
\]
with
\[
\omega_{ff'} \simeq W_{ff'}^{d*} W_{ff'}^{d}. \tag{25}
\]

The explicit expressions for the \(\omega_{ff'}\) relevant for our analysis are
\[
\text{Im} \omega_{ed} = \text{Im} \omega_{cs} = \text{Im} \sigma_d, \tag{26}
\]
\[
\text{Im} \omega_{eb} = \text{Im} \xi, \tag{27}
\]
\[
\text{Im} \omega_{dd} = \text{Im} \omega_{ds} = 0, \tag{28}
\]
\[
\text{Im} \omega_{db} = \text{Im} (\sigma_d^\ast \xi), \tag{29}
\]
where we have defined
\[
\xi = \sigma + (a_0 + a_1 + a_2) \lambda_t^2, \quad \sigma_q = \sigma + |V_{tq}|^2 \lambda_t^2 a_0. \tag{30}
\]

- Concerning the fermions (C)EDMs, for the down quark they are induced already at the one-loop level by means of the exchange of the charged-Higgs boson and top quark. However, these effects are CKM suppressed by the factor \(|V_{td}|^2 \approx 10^{-4}\), and even the most extreme choice of the parameters leads to predictions for \(d_d\) and \(d_{Hg}\) well under control [10]; hence, we can neglect these contributions in this analysis.

Instead, the two-loop Barr–Zee contributions [17] to the fermionic (C)EDMs dominate over one loop-effects since they overcome the strong CKM suppression; in the 2HDM\(_{\text{MFV}}\) they read
\[
\frac{d_f}{e} = - \sum_{q=t,b} \frac{N_c \alpha_f m_f^2}{8\pi^2 s_W^2 M_W^2 M_A^2} \frac{\alpha_m}{M_W^2} \bar{q}_q \bar{q}_q (\tan \beta)^{0.2} \left[ f(\tau_q) \text{Im} \omega_{qf} + g(\tau_q) \text{Im} \omega_{qf} \right], \tag{31}
\]
\[
\frac{d_f^c}{e} = - \sum_{q=t,b} \frac{\alpha_s \alpha_m m_f^2}{16\pi^2 s_W^2 M_W^2 M_A^2} \bar{q}_q \bar{q}_q (\tan \beta)^{0.2} \left[ f(\tau_q) \text{Im} \omega_{qf} + g(\tau_q) \text{Im} \omega_{qf} \right], \tag{32}
\]
where $q_\ell$ is the electric charge of the fermion $\ell$, $\tau_q = m_\ell^2/M_A^2$ and $f(\tau)$, $g(\tau)$ are the two-loop Barr–Zee functions

$$f(\tau) = \frac{\tau}{2} \int_0^1 \frac{1 - 2x(1-x)}{\tau - x(1-x)} \log \left[ \frac{x(1-x)}{\tau} \right],$$

(33)

$$g(\tau) = \frac{\tau}{2} \int_0^1 \frac{1}{\tau - x(1-x)} \log \left[ \frac{x(1-x)}{\tau} \right],$$

(34)

and the relevant $\omega_f$, are only

$$\text{Im} \omega_{dt} = 0,$$

(35)

$$\text{Im} \omega_{dt} = \text{Im} \sigma^*_d,$$

(36)

since, as we have already noted, the MFV structure suppresses the contributions of the $u$ quark with a factor $(\tan \beta)^{-2}$.

A comparison of the $2\text{HDM}_{\text{MFV}}$ predictions for the Thallium, neutron and Mercury EDMs with their present experimental upper bounds is shown in Tab. 1. They have been obtained with the reference values $m_A = 500$ GeV and $\tan \beta = 10$; it can be seen that for natural values of $|\bar{a}|$, $|a_i| = \mathcal{O}(1)$ they are compatible with the experimental limits.

| Observable | Experimental bounds | $2\text{HDM}_{\text{MFV}}$ predictions |
|------------|---------------------|--------------------------------------|
| $|d_{Tl}|$ [e cm] | $< 9.0 \times 10^{-25}$ | $3 \times 10^{-25} \text{Im} \xi + 5 \times 10^{-25} \text{Im} \sigma_d$ |
| $|d_{n}|$ [e cm] | $< 2.9 \times 10^{-26}$ | $10^{-27} \text{Im} (\sigma^*_d \xi)$ |
| $|d_{Hg}|$ [e cm] | $< 3.1 \times 10^{-29}$ | $4 \times 10^{-29} \text{Im} (\sigma^*_d \xi) + 5 \times 10^{-29} \text{Im} \sigma_d + 2 \times 10^{-29} \text{Im} \xi$ |

Table 1. Predictions of the $2\text{HDM}_{\text{MFV}}$ for some experimentally interesting EDMs.

4.2. Correlation between EDMs and CP violation in the $B_s$ mixing

In the previous section we have shown that, in the context of the $2\text{HDM}_{\text{MFV}}$, one can accommodate a larger $B_s$ mixing phase obtaining at the same time some other interesting effects. However, it is necessary to check if this new phase can cause disagreements with other CP violating observables, such as the EDMs.

The correlation plot between the considered EDMs and the observable $S_{\psi K_s}$ is shown in Fig. 2. As it can be seen, the current constraints on the EDMs still allow values of $|S_{\psi K_s}|$ larger than 0.5, compatible with the highest values of the $B_s$ mixing phase reported by the Tevatron experiments.

5. Conclusions

It is well known that the choice of introducing only one Higgs doublet in the Standard Model is just the most economical, but not the only possible one; there is a variety of New Physics models that contain more Higgs doublets, bringing interesting phenomenological features such as new sources of CP violation, dark matter candidates, axion phenomenology. In order to protect $2\text{HDMs}$ from FCNCs the application of MFV is natural and effective, and still allows the introduction of new flavour-blind CP-violating phases whose presence is interesting in order to address the recent experimental anomalies detected in this sector. In the $2\text{HDM}_{\text{MFV}}$ in fact, once a larger phase in the $B_s$ mixing is introduced, the tensions in the relation between $\epsilon_K$, the CKM angle $\beta$ and the asymmetry $S_{\psi K_s}$ are automatically softened, and the agreement of the predictions of flavour-violating processes (FCNCs) and flavour-conserving observables (EDMs) with experimental data is not spoiled.
Figure 2. Correlation between EDMs of the Thallium (red dots), neutron (black dots), and Mercury (green dots), versus $S_{\psi\phi}$ [10]. It is obtained by means of the following scan: $\tilde{a} |a_0|, |a_1|, |a_2| < 2$, $0 < (\phi_{\psi_0}, \phi_{\psi_1}, \phi_{\psi_2}) < 2\pi$, $\tan \beta < 60$, $M_{H^\pm} < 1.5$ TeV.

Experimental data to test the $2\text{HDM}_{\text{MFV}}$ will probably be available in the next few years: first of all, the predicted values for the EDMs are strongly enhanced with respect to the SM, and sizable non standard values for $S_{\psi\phi}$ imply lower bounds for the aforementioned EDMs within the reach of the expected future experimental resolutions; moreover, the MFV structure of the model determines several unambiguous correlations between observables that are going to be studied by future experiments, such as the decays $B^0_{d,s} \rightarrow \mu^+\mu^-$.

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