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New Physics in $b \to s\bar{s}s$ Decay: Study of $B \to V_1V_2$ Modes

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Abstract

Various nonleptonic decay channels mediated by the quark-level subprocess $b \to s\bar{s}s$ show hints of deviation from the Standard Model expectations. We analyse the double-vector decay $B \to \phi K^*$ with different generic new physics structures and find the constraints on the parameter spaces of new physics. The allowed parameter spaces are compatible with, but further narrowed down from, those obtained from a similar analysis using pseudoscalar modes. We also discuss further predictions for this channel as well as for $B_s \to \phi\phi$, and show how even a partial measurement of the observables may discriminate between different models of new physics.

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I Introduction

It has been felt for a long time that the data from the nonleptonic decays of the B meson, mediated by the transition $b \to s\bar{s}s$, is not what one expects from the Standard Model (SM) with the Cabibbo-Kobayashi-Maskawa (CKM) paradigm for CP violation. On one hand this led to a vigorous exercise for the understanding of low-energy QCD dynamics, including different models for calculating the long-distance part of the amplitude, and on the other hand this made such nonleptonic modes an ideal testing ground for indirect signals of New Physics (NP) [1].

Let us make it clear here and now that no data, taken alone, is a clear indication for NP. Some of the discrepancies (like the value of $\sin(2\beta)$ extracted from $B \to \phi K_S$) are compatible with the SM predictions at less than 2σ, and some (like the abnormally large branching ratio of $B \to \eta' K$) may be explained by SM dynamics yet to be fully understood. However, all data, considered together, have a significant pull away from the SM predictions, and one may hope that this will emerge as an indirect signal of NP. This is more so since the $b \to s\bar{s}s$ transition involves quarks of the second and the third generations where the SM is less well-tested.

In an earlier publication [2], we have shown that from a model-independent analysis of $B \to P_1P_2$ (two pseudoscalars) and $B \to PV$ (one pseudoscalar and one vector) decays mediated by the $b \to s\bar{s}s$ transition, one can effectively constrain the parameter space of NP, characterised by the strength of the NP coupling and its weak phase.

In this paper we focus upon the relevant decays of type $B \to V_1V_2$, which, in this case, are $B \to \phi K^*$ (with all charge combinations) and $B_s \to \phi\phi$. These modes, in particular the former, have been discussed in the context of specific NP models [3] as well as in a model-independent way, including possible modifications of low-energy QCD dynamics [4, 5]. For $B \to \phi K^*$, data [6, 7] exists on branching ratios (BR), different CP asymmetries, and different polarisation fractions (see Table 1). The error bars are still large but hopefully a much better situation will arise in a few more years. For the B_s decay we have only some preliminary data [7] on its BR, but LHC-B should do a more thorough job.

The reason for such an analysis is twofold. First, one can construct more observables than $B \to P_1 P_2$ or $B \to PV$ cases, simply because the final state mesons can be in s, p or d-wave combinations. Since the wavefunctions have different parity, one can construct CP violating observables even if the strong phase difference between various amplitudes be zero. Second, there are a few SM conditions [8] whose violations are relatively simple to observe and which will indicate beyond any doubt the presence of NP.

Experimentally, the anomalous trend persists in $B \to V_1 V_2$ sector too. The fraction of final states in a longitudinally polarised combination is about 50%, whereas one expects this to be dominant over the transverse polarisation fractions, which are suppressed by the mass of the decaying quark. At the infinite mass limit, all decays should be longitudinally polarised.

We must emphasise here that the longitudinal polarisation anomaly may turn out entirely to be of SM origin. There are discussions in the literature where contributions, neglected so far, have been properly incorporated and their effects have been analysed. Needless to say, most of the insights have come *a posteriori*, after the experimental data is announced, but that is only to be expected while dealing with something like low-energy QCD. Kagan [9] has shown that the suppression of transverse polarisation is still there in QCD Factorisation, but a new strong penguin contribution can lower the longitudinal polarisation fraction in $B \to \phi K^*$. This, however, does not affect $B \to \rho K^*$, where there is no such polarisation anomaly. On the other hand, Beneke *et al.* [10] have shown that there is a significant EW penguin contribution in $B \to \rho K^*$, and possibly the same mechanism works for $B \to \phi K^*$ too. Cheng *et al.* [11] have shown that in perturbative QCD, the longitudinal polarisation can go down to 75% if one takes annihilation and nonfactorisable diagrams properly into account (without them it is about 92%). All in all, the explanation may lie within the SM, but there is ample motivation to look for new physics.

Here we perform a model-independent analysis of the channel $B \to \phi K^*$ and extend the analysis to the SU(3)-related channel $B_s \to \phi\phi$. (Such an analysis, with different set of operators, was also performed in [5], and our conclusions are in agreement.) This is the first analysis of *all* anomalous $b \to s\bar{s}s$ mediated decays in a model-independent way, alongwith predictions for $B_s \to \phi\phi$. Analyses within the framework of definite models (in particular different versions of SUSY) are available, so is a partial model-independent analysis. The problem with such partial analyses is that they give different allowed parameter space for the NP for different anomalies. Of course, this does not mean that we are evaluating the relevant amplitudes in a model-independent way!

In fact, this is the second part of the analysis. For the first part involving $B \to P_1 P_2$ and $B \to PV$ modes, we refer the reader to [2]. We stress that we had to redo the analysis again since the data changed in the last few months, in particular the $\sin(2\beta)$ anomaly. The results have been summarised in Section IV, but we do not repeat the formalism which obviously remains unchanged.

The data on BR, CP asymmetries, and polarisation fractions are taken as input. For the theoretical input, the major uncertainty occurs in the calculation of long-distance contributions. We circumvent the problem by a rather conservative approach. The NP effective Hamiltonian is characterised by a real positive coupling h, a NP weak phase ξ (between 0 and 2π), and a Lorentz structure for the $b \to s\bar{s}s$ current-current product. All short-distance corrections coming from the running to the NP scale to m_b are dumped in h, but just for simplicity, we assume the NP operator not to mix with the SM ones. The analysis not only gives the allowed region in the h-ξ plane, but also predicts the range of different observables. Similar predictions are obtained for the B_s decay channel.

II SM and NP amplitudes

The amplitude for $B(p) \to \phi(k_1, \varepsilon_1) + K^*(k_2, \varepsilon_2)$ can be written as [12, 13]

$$\mathcal{M} = a\varepsilon_1^*.\varepsilon_2^* + \frac{b}{m_B^2}(p.\varepsilon_1^*)(p.\varepsilon_2^*) + i\frac{c}{m_B^2}\varepsilon_{\mu\nu\alpha\beta}p^\mu q^\nu \varepsilon_1^{*\alpha}\varepsilon_2^{*\beta} \tag{1}$$

with $q = k_1 - k_2$, and the CP-conjugate amplitude (for $\bar{B}$) has the obvious form

$$\overline{\mathcal{M}} = \bar{a}\varepsilon_1^*.\varepsilon_2^* + \frac{\bar{b}}{m_B^2}(p.\varepsilon_1^*)(p.\varepsilon_2^*) - i\frac{\bar{c}}{m_B^2}\varepsilon_{\mu\nu\alpha\beta}p^\mu q^\nu \varepsilon_1^{*\alpha}\varepsilon_2^{*\beta}, \tag{2}$$

where a, b, and c are in general complex quantities, involving, apart from the short-distance effects, the weak and the strong phases.

In the linear polarisation basis, we write

$$\mathcal{M}(\overline{\mathcal{M}}) = A_0(\overline{A_0})\varepsilon_1^{*L}\varepsilon_2^{*L} - \frac{1}{\sqrt{2}}A_\parallel(\overline{A_\parallel})\vec{\varepsilon_1^{*T}}.\vec{\varepsilon_2^{*T}} - (+)\frac{i}{2}A_\perp(\overline{A_\perp})\left(\vec{\varepsilon_1^{*T}} \times \vec{\varepsilon_2^{*T}}\right).\hat{p} \tag{3}$$

where $\hat{p}$ is the unit vector along K^* in the rest frame of ϕ, and

$$\varepsilon_i^{*L} = \vec{\varepsilon_i^*}.\hat{p}, \quad \vec{\varepsilon_i^{*T}} = \vec{\varepsilon_i^*} - \varepsilon_i^{*L}\hat{p}. \tag{4}$$

The amplitudes of eq. (3) are related with those of eq. (1) by

$$A_\parallel = \sqrt{2}a, \quad A_0 = -ax - \frac{m_1 m_2}{m_B^2}b(x^2-1), \quad A_\perp = 2\sqrt{2}\frac{m_1 m_2}{m_B^2}c\sqrt{x^2-1}, \tag{5}$$

(and similarly for the barred variables) where

$$x = \frac{k_1.k_2}{m_1 m_2} = \frac{m_B^2 - m_\phi^2 - m_{K^*}^2}{2m_\phi m_K^*}. \tag{6}$$

In the SM, for the decay $B \to \phi K^*$, a and c are real and negative, and b is real and positive (assuming negligible strong phases), so that $A_0 > 0$ (the b-term is mass-suppressed), while $A_\parallel, A_\perp < 0$ [13]. Thus one expects $\phi_\perp \equiv arg(A_\perp/A_0) \approx \pi$, $\phi_\parallel \equiv arg(A_\parallel/A_0) \approx \pi$. However, these expectations may change due to the presence of final state interactions (FSI).

An alternative formulation is in terms of the so-called helicity basis, where the amplitudes are written in terms of H_0 and $H_\pm$, and

$$H_0 = A_0, \quad H_\pm = \frac{A_\parallel \pm A_\perp}{\sqrt{2}}. \tag{7}$$

The decay width is given by

$$\Gamma = \frac{|\mathbf{k}|}{8\pi m_B^2}\left(|H_0|^2 + |H_+|^2 + |H_-|^2\right) = \frac{|\mathbf{k}|}{8\pi m_B^2}\left(|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2\right) \tag{8}$$

where $\mathbf{k}$ is the magnitude of the three-momentum of either V_1 or V_2. For the experimental observables, the amplitudes are normalised in such a way that $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$, and similarly for the $\overline{A_\lambda}$s [8] [1].

To evaluate the transition amplitudes, we use the conventional factorisation (CF) model [14, 15], with the standardised matrix elements as shown below (with $q = k_1 - k_2$ and $p = k_1 + k_2$):

$$\langle V_2|V_\mu|\overline{B}^0\rangle = -\varepsilon_{\mu\nu\alpha\beta}\varepsilon^{*\nu}p^\alpha k_2^\beta \frac{2V}{m_B + m_{V_2}},$$

[1] This normalisation does not affect the definition of the experimental observables in eq. (14).

$$
\begin{aligned}
\langle V_2|A_\mu|\overline{B}^0\rangle &= i\left(\varepsilon^*_\mu - \frac{\varepsilon^*.q}{q^2}q_\mu\right)(m_B+m_{V_2})A_1 \\
&\quad -i\left((p+k_2)_\mu - \frac{m_B^2-m_{V_2}^2}{q^2}q_\mu\right)(\varepsilon^*.q)\frac{A_2}{m_B+m_{V_2}}, \\
\langle V_1|\bar{q}\gamma_\mu q|0\rangle &= f_{V_1}m_{V_1}\varepsilon^*_\mu, \\
\langle V_1|\bar{q}\sigma_{\mu\nu}q|0\rangle &= -if^T_{V_1}\left(\varepsilon^*_\mu k_{1\nu} - \varepsilon^*_\nu k_{1\mu}\right), \\
\langle V_2|\bar{q}\sigma_{\mu\nu}k_1^\nu(1+\gamma_5)b|\overline{B}^0\rangle &= 2iT_1\varepsilon_{\mu\nu\alpha\beta}\varepsilon_2^{*\nu}p^\alpha k_2^\beta \\
&\quad +T_2\left\{\varepsilon^*_{2\mu}(m_B^2-m_{V_2}^2) - (\varepsilon^*_2.p)\,(p+k_2)_\mu\right\} \\
&\quad +T_3\,(\varepsilon^*_2.p)\left\{k_{1\mu} - \frac{q^2}{m_B^2-m_{V_2}^2}\,(p+k_2)_\mu\right\}. \qquad (9)
\end{aligned}
$$

The form factors, calculated in the light-cone sum rule (LCSR) approach, are taken from [16]. Their values are given in Section III.

This gives, in the SM, the transition amplitude as

$$
\begin{aligned}
\mathcal{M}(B^-\to\phi K^{*-}) &= \mathcal{M}(\overline{B}^0\to\phi\overline{K^{*0}}) \\
&= i\frac{G_F}{\sqrt{2}}f_\phi m_\phi\{-(\epsilon_\phi.\epsilon_{K^*})(m_B+m_{K^*})A_1^{B\to K^*}(m_\phi^2) \\
&\quad +(\epsilon_\phi.p)(\epsilon_{K^*}.p)\frac{2A_2^{B\to K^*}(m_\phi^2)}{(m_B+m_{K^*})} - i\epsilon_{\mu\nu\alpha\beta}\epsilon_\phi^\mu\epsilon_{K^*}^\nu p^\alpha k_2^\beta\frac{2V^{B\to K^*}(m_\phi^2)}{(m_B+m_{K^*})}\} \\
&\times\ V_{tb}V_{ts}^*\{a_3+a_4+a_5-\frac{1}{2}(a_7+a_9+a_{10})\} \qquad (10)
\end{aligned}
$$

where the symbols have their usual meaning [15]. However, one may question the validity of the NF approach for this decay, and indeed calculations based on QCD factorisation [17] or perturbative QCD [11] indicate a discrepancy in the predicted BR by about a factor of 2 at the most (8.71×10^{-6} in QCD factorisation vis-à-vis $14.86^{+4.88}_{-3.36}\times10^{-6}$ in perturbative QCD for the decay $B^0\to\phi K^{*0}$). To account for this, we have allowed the SM amplitude to vary by 40% for a fixed $N_c=3$ (this is equivalent to a 96% variation in the BR). Also note that this mode, like $B\to\phi K$, is not N_c-stable, and the final result may have some quantitative variation for a different N_c [2]. Apart from this variation, all other effects that may change the predicted BR have been taken into account by varying the amplitude.

One may ask whether it would have been prudent to take QCD factorisation or perturbative QCD as the model for the SM dynamics and estimate NP effects. We would like to point out that they are models to calculate nonleptonic decay amplitudes, just as CF, and though there is theoretical justification for taking a particular model for a particular type of decay, there is no reason to believe that for the decays in question, one is definitely better than the others. So we stick to CF; however, it is necessary to take into account the differences among various models, at least in a rough way. This will provide for a larger uncertainty in the SM prediction. If we still need NP to explain the data, we may be hopeful about its presence. The question is how one does this. A good indicator is the predictions for the BRs. We may hope that, roughly, the differences in BRs are reflected in the amplitudes in different models. One may like to have some more error margin, since it is *better to be conservative than over-ambitious*. The same is true for experimental data; in fact, we will soon show that if the data is taken at 68% confidence limit (1σ), no possible NP can explain all the anomalies.

For the decay $B_s(p)\to\phi(k_1,\varepsilon_1)\phi(k_2,\varepsilon_2)$, the transition amplitude is

$$
\begin{aligned}
\mathcal{M}(B_s\to\phi\phi) &= i\frac{G_F}{\sqrt{2}}f_\phi m_\phi\{-2(\epsilon_1.\epsilon_2)(m_{B_s}+m_\phi)A_1^{B_s\to\phi}(m_\phi^2) \\
&\quad +(\epsilon_1.p)(\epsilon_2.p)\frac{4A_2^{B_s\to\phi}(m_\phi^2)}{(m_{B_s}+m_\phi)} - i\epsilon_{\mu\nu\alpha\beta}\epsilon_1^\mu\epsilon_2^\nu p^\alpha k_2^\beta\frac{2V^{B_s\to\phi}(m_\phi^2)}{(m_{B_s}+m_\phi)}\}
\end{aligned}
$$

[2] In the analysis, we stick to $N_c=3$ since the form factors are evaluated [16] for this value.

$$\times \quad V_{tb}V_{ts}^*\{a_3 + a_4 + a_5 - \frac{1}{2}(a_7 + a_9 + a_{10})\}. \tag{11}$$

This is analogous to eq. (10), with an extra factor of 2 for identical particles in the final state.

The amplitudes will have contributions from SM as well as from NP. Let us write

$$\begin{aligned} A_{\parallel} &= R_1 e^{i\theta_1}, A_0 = R_2 e^{i\theta_2}, A_{\perp} = R_3 e^{i\theta_3}, \\ \bar{A}_{\parallel} &= R_4 e^{i\theta_4}, \bar{A}_0 = R_5 e^{i\theta_5}, \bar{A}_{\perp} = R_6 e^{i\theta_6}, \end{aligned} \tag{12}$$

where R_is and θ_is include all SM and NP effects (couplings, weak and strong phases). The 18 variables proposed by [8] can be written as

$$\begin{aligned}
&\Lambda_{00} = \frac{1}{2}\left(R_2^2 + R_5^2\right), \quad \Lambda_{\parallel\parallel} = \frac{1}{2}\left(R_1^2 + R_4^2\right), \quad \Lambda_{\perp\perp} = \frac{1}{2}\left(R_3^2 + R_6^2\right), \\
&\text{Ł}_{\perp 0} = R_2 R_3 \sin(\theta_2 - \theta_3) - R_5 R_6 \sin(\theta_5 - \theta_6), \\
&\text{Ł}_{\perp\parallel} = R_1 R_3 \sin(\theta_1 - \theta_3) - R_4 R_6 \sin(\theta_4 - \theta_6), \\
&\text{Ł}_{\parallel 0} = R_1 R_2 \cos(\theta_1 - \theta_2) + R_4 R_5 \cos(\theta_4 - \theta_5), \\
&\Sigma_{00} = \frac{1}{2}\left(R_2^2 - R_5^2\right), \quad \Sigma_{\parallel\parallel} = \frac{1}{2}\left(R_1^2 - R_4^2\right), \quad \Sigma_{\perp\perp} = \frac{1}{2}\left(R_3^2 - R_6^2\right), \\
&\Sigma_{\perp 0} = R_2 R_3 \sin(\theta_2 - \theta_3) + R_5 R_6 \sin(\theta_5 - \theta_6), \\
&\Sigma_{\perp\parallel} = R_1 R_3 \sin(\theta_1 - \theta_3) + R_4 R_6 \sin(\theta_4 - \theta_6), \\
&\Sigma_{\parallel 0} = R_1 R_2 \cos(\theta_1 - \theta_2) - R_4 R_5 \cos(\theta_4 - \theta_5), \\
&\rho_{00} = R_2 R_5 \sin(2\beta + \theta_2 - \theta_5), \quad \rho_{\parallel\parallel} = R_1 R_4 \sin(2\beta + \theta_1 - \theta_4), \quad \rho_{\perp\perp} = -R_3 R_6 \sin(2\beta + \theta_3 - \theta_6), \\
&\rho_{\perp 0} = R_3 R_5 \cos(2\beta + \theta_3 - \theta_5) + R_2 R_6 \cos(2\beta + \theta_2 - \theta_6), \\
&\rho_{\perp\parallel} = R_3 R_4 \cos(2\beta + \theta_3 - \theta_4) + R_1 R_6 \cos(2\beta + \theta_1 - \theta_6), \\
&\rho_{\parallel 0} = R_1 R_5 \sin(2\beta + \theta_1 - \theta_5) + R_2 R_4 \sin(2\beta + \theta_2 - \theta_4).
\end{aligned} \tag{13}$$

Here $\beta = arg(V_{td}^*)$ is the SM weak phase coming in $B^0 - \overline{B}^0$ mixing. We assume no NP contribution in this mixing. For the B_s system, β_s is close to zero in the SM. However, NP of the type $b \to s\bar{s}s$ may contribute to $B_s - \overline{B_s}$ mixing. Even then, the contribution of NP in mixing, which is in effect a contamination to β_s, can hardly be worth considering. The reason is this. Only a lower bound on the SM amplitude exists. The NP amplitude with such a weak coupling as obtained from the decay fit to $B \to P_1 P_2$ or $B \to PV$ modes can never compete with the SM amplitude. We find $\sin(2\beta_s)$, the effective phase from the $B_s - \overline{B_s}$ box, to be never greater than 0.1. (Similarly, $b \to c\bar{c}s$ channels are hopeless to look for new physics.)

On the other hand, BaBar and Belle collaborations express their data in terms of eight independent variables over which a fit is performed. Apart from $f_L \equiv \Lambda_{00}$ and $f_{\perp} \equiv \Lambda_{\perp\perp}$, they are

$$\begin{aligned}
A_{CP}^0 &= \frac{f_L^B - f_L^{\bar{B}}}{f_L^B + f_L^{\bar{B}}} = \frac{R_2^2 - R_5^2}{R_2^2 + R_5^2}, \\
A_{CP}^{\perp} &= \frac{f_{\perp}^B - f_{\perp}^{\bar{B}}}{f_{\perp}^B + f_{\perp}^{\bar{B}}} = \frac{R_3^2 - R_6^2}{R_3^2 + R_6^2}, \\
\phi_{\parallel} &= \frac{1}{2}\left(arg(A_{\parallel}/A_0) + arg(\bar{A}_{\parallel}/\bar{A}_0)\right) = \frac{1}{2}\left(\theta_1 - \theta_2 + \theta_4 - \theta_5\right), \\
\phi_{\perp} &= \frac{1}{2}\left(arg(A_{\perp}/A_0) + arg(\bar{A}_{\perp}/\bar{A}_0)\right) = \frac{1}{2}\left(\theta_3 - \theta_2 + \theta_6 - \theta_5\right), \\
\Delta\phi_{\parallel} &= \frac{1}{2}\left(arg(A_{\parallel}/A_0) - arg(\bar{A}_{\parallel}/\bar{A}_0)\right) = \frac{1}{2}\left(\theta_1 - \theta_2 - \theta_4 + \theta_5\right), \\
\Delta\phi_{\perp} &= \frac{1}{2}\left(arg(A_{\perp}/A_0) - arg(\bar{A}_{\perp}/\bar{A}_0)\right) = \frac{1}{2}\left(\theta_3 - \theta_2 - \theta_6 - \theta_5\right),
\end{aligned} \tag{14}$$

where we have used a convention opposite to that used by BaBar, Belle and HFAG to define the first two and last two variables of eq. (14). These are the constraints that will go as inputs in our analysis. Note that the set $\{-\phi_\parallel, \pi-\phi_\perp, -\Delta\phi_\parallel, -\Delta\phi_\perp\}$ is identical as far as the angular analysis is concerned. If we entertain the possibility of NP, there is no reason to keep our analysis confined to the set with values nearest to the SM expectation.

As in [2], we discuss three different types of effective four-Fermi interactions coming from new physics:

$$\begin{aligned}
&\text{1. Scalar :} && \mathcal{L}_{new} = h_s e^{i\xi_s}\,(\bar{s}_\alpha(c_1+c_2\gamma_5)s_\alpha)\,(\bar{s}_\beta(c_3+c_4\gamma_5)b_\beta)\,,\\
&\text{2. Vector :} && \mathcal{L}_{new} = h_v e^{i\xi_v}\,(\bar{s}_\alpha\gamma^\mu(c_1+c_2\gamma_5)s_\alpha)\,(\bar{s}_\beta\gamma_\mu(c_3+c_4\gamma_5)b_\beta)\,,\\
&\text{3. Tensor :} && \mathcal{L}_{new} = h_t e^{i\xi_t}\,(\bar{s}_\alpha\sigma^{\mu\nu}(c_1+c_2\gamma_5)s_\alpha)\,(\bar{s}_\beta\sigma_{\mu\nu}(c_3+c_4\gamma_5)b_\beta)\,.
\end{aligned} \tag{15}$$

Here α and β are colour indices. The couplings $h_{s,v,t}$ are effective couplings (generically denoted as h_{NP}), of dimension $[M]^{-2}$, that one obtains by integrating out the new physics fields. They are assumed to be real and positive and the weak phase information is dumped in the quantities $\xi_{s,v,t}$ (again, generically denoted as ξ_{NP}), which can vary in the range 0-2π. Note that they are effective couplings at the *weak* scale, which one may obtain by incorporating all RG effects to the high-scale values of them. The couplings c_1-c_4 can take any values between -1 and 1; to keep the discussion simple, we will discuss only six limiting cases:

$$\begin{aligned}
(i)\ (S+P)\times(S+P)\ [(V+A)\times(V+A)] &\ :\ c_1=1,\ c_2=1,\ c_3=1,\ c_4=1;\\
(ii)\ (S+P)\times(S-P)\ [(V+A)\times(V-A)] &\ :\ c_1=1,\ c_2=1,\ c_3=1,\ c_4=-1;\\
(iii)\ (S-P)\times(S+P)\ [(V-A)\times(V+A)] &\ :\ c_1=1,\ c_2=-1,\ c_3=1,\ c_4=1;\\
(iv)\ (S-P)\times(S-P)\ [(V-A)\times(V-A)] &\ :\ c_1=1,\ c_2=-1,\ c_3=1,\ c_4=-1;\\
(v)\ (T+PT)\times(T+PT) &\ :\ c_1=1,\ c_2=1,\ c_3=1,\ c_4=1;\\
(vi)\ (T-PT)\times(T-PT) &\ :\ c_1=1,\ c_2=-1,\ c_3=1,\ c_4=-1;
\end{aligned} \tag{16}$$

This choice is preferred since the $1-(+)\gamma_5$ projects out the weak doublet (singlet) quark field. For the doublet fields, to maintain gauge invariance, one must have an SU(2) partner interaction, *e.g.*, $\bar{s}(1-\gamma_5)s$ must be accompanied by $\bar{c}(1-\gamma_5)c$. No such argument holds for the singlet fields. In the above equation, PT denotes a pseudotensor structure, characterised by $\sigma_{\mu\nu}\gamma_5$.

The tensor current was not considered in [2]. Neither this form nor its Fierz-reordered form can contribute to $B\to\phi K$. Now that with the latest data [7] one does not imperatively need NP for the $B\to\phi K$ sector, one may feel justified to include this structure as well. Note that only $\sigma^{\mu\nu}(1+(-)\gamma_5)\otimes\sigma_{\mu\nu}(1+(-)\gamma_5)$ structures are of any interest; the other two, after Fierz reordering, do not generate any scalar or pseudoscalar currents and hence can affect none of the $B\to P_1P_2$ or $B\to PV$ modes. In fact, the four-quark current $(T+(-)PT)\times(T-(+)PT)$ vanishes, which can be checked from the identity $\sigma^{\mu\nu}\gamma_5 = -(i/2)\epsilon^{\mu\nu\alpha\beta}\sigma_{\alpha\beta}$, with $\epsilon^{0123}=-1$ (though the factorised matrix element need not vanish).

We have chosen the interaction in a singlet-singlet form under $SU(3)_c$. The reason is simple: one can always make a Fierz transformation to the local operator to get the octet-octet structure. Note that the forms $(S+(-)P)\times(S+(-)P)$ generate tensor currents under Fierz reordering. Such currents were not important in [2] since at least one of the final state mesons was a pseudoscalar. Here it will be important since both the final state mesons are spin-1 objects, and as we will see, the tensor currents play a crucial role in bringing down the longitudinal polarisation fraction of $B\to\phi K^*$. Since no such tensor current is available for $(S+(-)P)\times(S-(+)P)$ type operators, or the vector-axial vector operators, there is no lowering of the longitudinal polarisation fraction.

We have kept the strong phase difference between the SM and the NP amplitudes a free parameter. The short-distance strong phase, coming from the imaginary parts of the respective Wilson coefficients, are calculable but small. The long-distance strong phase, coming mostly from final-state rescattering, is a priori not calculable, but since there are not too many final states of identical quark configuration, the strong phase is expected to be not too large. However, there should not be any correlation between the strong phase in $B\to\phi K^*$ and the strong phases in $B\to\phi K$ or $B\to\eta^{(\prime)}K^{(*)}$, the channels discussed in [2], but the strong phase of $B_s\to\phi\phi$ can be related to that of $B\to\phi K^*$ by SU(3) symmetry. We will assume the breaking of flavour SU(3) to be small and take equal strong phases in both these cases. The results are not at all sensitive to a precise equality.

The a, b, and c terms of the NP amplitudes (eq. (1)) for the decay processes $B \to \phi K^*$ and $B_s \to \phi\phi$ take the following form:

$B \to \phi K^*$ (the contributions are same for neutral and charged channels):
(i) Scalar-pseudoscalar channel

$$\begin{aligned}
a_{NP} &= i\left[-f_\phi m_\phi (c_1c_4 - c_2c_3)(m_B + m_{K^*})A_1 + 2f_\phi^T c_1c_4(m_B^2 - m_{K^*}^2)T_2\right]\frac{h_{NP}}{4N_c}e^{i\xi_{NP}},\\
\frac{b_{NP}}{m_B^2} &= i\left[f_\phi m_\phi (c_1c_4 - c_2c_3)\frac{2A_2}{m_B + m_{K^*}} - c_1c_4 f_\phi^T\left(4T_2 + 4T_3\frac{m_\phi^2}{m_B^2 - m_{K^*}^2}\right)\right]\frac{h_{NP}}{4N_c}e^{i\xi_{NP}},\\
\frac{c_{NP}}{m_B^2} &= i\left[-f_\phi m_\phi (c_2c_4 - c_1c_3)\frac{V}{m_B + m_{K^*}} + 2c_1c_3 f_\phi^T T_1\right]\frac{h_{NP}}{4N_c}e^{i\xi_{NP}}. \qquad (17)
\end{aligned}$$

Note the $1/N_c$ suppression; this channel can only contribute to the decay after reordering. Also, note that for $(S+(-)P)\times(S+(-)P)$ structures only the terms with tensor form factors survive, which is obvious since they do not generate any vector or axialvector currents.

(ii) Vector-axial vector channel

$$\begin{aligned}
a_{NP} &= f_\phi m_\phi\left[(c_1c_4 + c_2c_3) + 4N_c c_1c_4\right](m_B + m_{K^*})A_1\frac{h_{NP}}{4N_c}e^{i\xi_{NP}},\\
\frac{b_{NP}}{m_B^2} &= -f_\phi m_\phi\left[(c_1c_4 + c_2c_3) + 4N_c c_1c_4\right]\frac{2A_2}{(m_B + m_{K^*})}\frac{h_{NP}}{4N_c}e^{i\xi_{NP}},\\
\frac{c_{NP}}{m_B^2} &= -f_\phi m_\phi\left[(c_2c_4 + c_1c_3) + 4N_c c_1c_3\right]\frac{V}{(m_B + m_{K^*})}\frac{h_{NP}}{4N_c}e^{i\xi_{NP}}. \qquad (18)
\end{aligned}$$

(iii) Tensor-pseudotensor channel

$$\begin{aligned}
a_{NP} &= -i\left[2f_\phi^T c_1c_4(m_B^2 - m_{K^*}^2)T_2\right]\left(1 + \frac{1}{2N_c}\right)h_{NP}e^{i\xi_{NP}},\\
\frac{b_{NP}}{m_B^2} &= i\left[c_1c_4 f_\phi^T\left(4T_2 + 4T_3\frac{m_\phi^2}{m_B^2 - m_{K^*}^2}\right)\right]\left(1 + \frac{1}{2N_c}\right)h_{NP}e^{i\xi_{NP}},\\
\frac{c_{NP}}{m_B^2} &= -i\left[2c_1c_3 f_\phi^T T_1\right]\left(1 + \frac{1}{2N_c}\right)h_{NP}e^{i\xi_{NP}}. \qquad (19)
\end{aligned}$$

The expressions for $B_s \to \phi\phi$ are analogous, with the obvious replacements $B \to B_s$, $K^* \to \phi$, and an extra factor of 2; see, for comparison, eqs. (10) and (11). We do not tabulate them separately.

III Theoretical and Experimental Inputs

The experimental data, taken from [7], is shown in Table 1. The numbers are quoted for $B \to \phi K^*$ (neutral mode) while the corresponding numbers for charged B decay, wherever they exist, are given in parenthesis. The error margins are shown at 1σ confidence limit (CL), while for the analysis, we have taken a more conservative approach and kept the error margins at 2σ. We do not use the numbers that are derived from the primary measurements assuming the validity of the SM, mostly $\Lambda_{\|\|}$, $Ł_{\|0}$, and various Σs. Note that since we are interested only in the $b \to s\bar{s}s$ transition, no other decay modes (like $B \to \rho\rho$) have been taken into consideration.

While the BR($B \to \phi K^*$) is in the expected ballpark, BR($B_s \to \phi\phi$) is smaller than expected. The amplitude for the latter is twice that of the former (identical particles in the final state) times the SU(3) breaking effects, which gives an enhancement of the BR of the latter by roughly a factor of 5.5-6. But the number of events for $B_s \to \phi\phi$ is small; it is compatible with zero at 95% CL! For analysis, we take this particular data with a 3σ error bar on the higher side instead of the usual 2σ, just to be cautious over the preliminary nature of the data.

Observable	Value	Observable	Value
$\mathrm{Br}(B \to \phi K^*)$	$(9.5 \pm 0.9) \times 10^{-6}$	$\mathrm{Br}(B_s \to \phi\phi)$	$(14^{+8}_{-7})) \times 10^{-6}$
	$((9.7 \pm 1.5) \times 10^{-6})$		
Λ_{00}	0.48 ± 0.04	$f_\perp = \Lambda_{\perp\perp}$	0.26 ± 0.04
	(0.50 ± 0.07)		(0.19 ± 0.08)
$\phi_\parallel$	$2.36^{+0.18}_{-0.16}$	$\phi_\perp$	2.49 ± 0.18
	(2.10 ± 0.28)		(2.31 ± 0.31)
A^0_{CP}	-0.01 ± 0.08	$A^\perp_{CP}$	0.16 ± 0.15
$\Delta\phi_\parallel$	-0.03 ± 0.18	$\Delta\phi_\perp$	-0.03 ± 0.18

Table 1: Data on $B \to \phi K^*$ modes, from [7]. Our convention of defining CP asymmetries is opposite to that of HFAG, see text. We do not show, for obvious reasons, those observables which are not directly measured but estimated using the validity of the SM.

Apart from the BRs and CP asymmetries, we also use the following results from [7]:

- $\sin(2\beta)$ from charmonium modes: 0.685 ± 0.032;
- $\sin(2\beta)$ from $B \to K_S\phi$ transitions: 0.47 ± 0.19 (the results do not show any qualitative change if we use the combined $b \to s\bar{s}s$ result: 0.50 ± 0.06; however, the averaging is a bit naive [7] and should be used with caution);
- $43.8^\circ < \gamma < 73.5^\circ$ at 95% CL [18]; this is needed for a reevaluation of the constraints on the allowed parameter space (APS) of new physics as found in [2].

The CKM elements V_{ts} and V_{tb} are taken from [19], with only the unitarity constraint imposed.

The constituent quark masses, in GeV, are taken to be [15]

$$m_u = m_d = 0.2, \quad m_s = 0.5, \quad m_c = 1.5, \quad m_b = 4.88, \tag{20}$$

though the final result is totally insensitive to the precise values. The constituent quark masses are independent of the renormalisation scale. The Wilson coefficients, evaluated at the regularisation scale $\mu = m_b/2 \approx 2.5$ GeV, are also taken from [15]. The corresponding current quark masses, which appear in the Dirac equation for quarks while evaluating the hadronic matrix elements, are (in GeV)

$$m_u = 0.0042,\ m_d = 0.0076,\ m_s = 0.122,\ m_c = 1.5,\ m_b = 4.88 \tag{21}$$

at $\mu = 2.5$ GeV (see table I of the first paper of [15]). The light quark masses will obviously shift if we evaluate them at some other scale, say 1 GeV, and they also depend on how we evaluate them (*e.g.*, lattice QCD or QCD sum rules). The decay constant of ϕ, through vector and tensor currents, are defined as

$$\begin{aligned} \langle 0|\bar{s}\gamma_\mu s|\phi(p,\lambda)\rangle &= f_\phi m_\phi \epsilon^{(\lambda)}_\mu, \\ \langle 0|\bar{s}\sigma_{\mu\nu} s|\phi(p,\lambda)\rangle &= i f^T_\phi \left(\epsilon^{(\lambda)}_\mu p_\nu - \epsilon^{(\lambda)}_\nu p_\mu\right), \end{aligned} \tag{22}$$

and their numerical values (in GeV) are [16]

$$f_\phi = 0.231 \pm 0.004, \quad f^T_\phi = 0.200 \pm 0.010. \tag{23}$$

The form factors, evaluated in the light-cone sum rule (LCSR) approach, are [16]

$$\begin{aligned} B \to K^* : \quad & A_1 = 0.292, A_2 = 0.259, V = 0.411, T_1 = T_2 = 0.333, T_3 = 0.202, \\ B_s \to \phi : \quad & A_1 = 0.313, A_2 = 0.234, V = 0.434, T_1 = T_2 = 0.349, T_3 = 0.175. \end{aligned} \tag{24}$$

These form factors include the full twist-2 and twist-3 and the leading order twist-4 contributions. These numbers are for $q^2 = 0$. For nonzero q^2, they change by about 10%. We take the $q^2 = 0$ values for our numerical evaluation. They are evaluated for $N_c = 3$.

IV Results

Lorentz structure	h_{NP} ($\times 10^{-8}$)	ξ_{NP} ($^\circ$)
$(S-P)\times(S+P)$	$0.0-3.0$ $(0.5-3.0)$	$180-360$ $(185-340)$
$(S+P)\times(S+P)$	$0.0-4.5$	$0-180$
$(S-P)\times(S-P)$	$0.0-4.5$	$180-360$
$(S+P)\times(S-P)$	$0.0-3.0$	$0-180$
$(V-A)\times(V+A)$	$0.0-0.8$	$180-360$
$(V+A)\times(V+A)$	$0.0-2.1$ $(0.25-0.7)$	$0-180$ $(30-140)$
$(V-A)\times(V-A)$	$0.0-0.6$	$180-360$
$(V+A)\times(V-A)$	$0.0-2.2$ $(0.5-0.8)$	$0-180$ $(40-130)$

Table 2: Allowed parameter space from the analysis of $B \to P_1P_2$ and $B \to PV$ modes, mediated by $b \to s\bar{s}s$ transition (upgrade of [2] in view of the Summer 2005 data [7]). All error bars are taken to be at 2σ. With 1σ error bars, only three structures survive, as shown in parenthesis.

Before we embark on an analysis of $B \to V_1V_2$ modes, let us revisit the results of [2] in the light of Summer 2005 data. The main change is the prediction of $\sin(2\beta)$ from $B \to \phi K_S$: this is now less than 2σ away from the charmonium result. Thus, a nonzero NP amplitude based on this data alone is no longer necessary (and hence tensor currents are a possibility). Of course, the branching ratios of the $\eta^{(\prime)}K^{(*)}$ modes are still too large, but there is no way one can reconcile that with a pure NP amplitude; there must be some dynamics beyond the naive valence quark model [2]. (Lipkin [20] has suggested that this is due to interferences between $B \to K\eta_8$ and $B \to K\eta_1$ amplitudes, constructive for η' and destructive for η. Recently, an analysis based on the Soft Collinear Effective Theory (SCET) claims this to be supported in that framework [21]. However, SCET is yet to provide numerical data on all the modes taken in our analysis.) The allowed regions for different Lorentz structures is shown in Table 2. Note that h_{NP} can be vanishingly small. However, the upper limits, which are controlled by the BRs, remain unaltered. There does not seem to be any pressing need to introduce new physics from this data alone, but we will soon find that the longitudinal polarisation anomaly forces us to consider the NP option seriously.

In Table 2 we show the principal allowed parameter space (APS) for different Lorentz structures. For each structure, there is a subdominant parameter space with very small h_{NP}, but ξ_{NP} in the opposite half-plane (*i.e.*, $\xi_{NP} + \pi$ modulo 2π). For example, for the structure $(S+P)\times(S+P)$ there is an APS with very small $h_{NP} \sim 10^{-9}$ and $\pi < \xi_{NP} < 2\pi$. This was absent in [2], but now that $\sin(2\beta)$ from $B \to \phi K_S$ at 2σ may overshoot the charmonium value, there is a scope for opposite interference. This is a general trend for all structures. However, these regions do not survive the $B \to V_1V_2$ analysis. Also note that with 1σ error bars, three structures survive, in contrast to only one as found in [2]. Again, they disappear after the $B \to V_1V_2$ analysis.

Set No.	Lorentz structure	h_{NP} ($\times 10^{-8}$)	ξ_{NP} ($^\circ$)	δ_{NP} ($^\circ$)
I	$(S+P)\times(S+P)$	2.0 - 3.6	0 - 30 45 - 65 150 - 180	90 - 145 25 - 35 270 - 325
II	$(S-P)\times(S-P)$	2.8 - 3.5	271 - 278 338 - 360	216 - 223 307 - 320
III	$(T+PT)\times(T+PT)$	0.14 - 0.36	0 - 25 — do — 150 - 180 — do — 45 - 70	140 - 170 270 - 320 90 - 140 320 - 350 205 - 215
IV	$(T-PT)\times(T-PT)$	0.20 - 0.27	0 - 15 90 - 100 158 - 180	125 - 135 215 - 225 305 - 320

Table 3: Allowed parameter space for different Lorentz structures of new physics.

With the expressions for BRs and CP asymmetries at hand, we perform a scan on the new physics (NP) parameters h_{NP} and ξ_{NP}. The starting ranges for each Lorentz structure are shown in Table 2. We perform a full scan over the tensor structures. This time, however, we must introduce a nonzero strong phase difference between the SM and the NP amplitudes (for simplicity, we assume this difference to be the same for all angular momentum channels). The reason is that both $\phi_\|$ and $\phi_\perp$ differ from the SM expectation of π, even taking the uncertainties $\Delta\phi$ into account. It is easy to see that if the strong phase difference δ_{NP} is zero (modulo π), both $\phi_\|$ and $\phi_\perp$ retain their SM expectation values. If the strong phase is generated from rescattering, it should not be related in any way from the strong phases in $B \to P_1 P_2$ or $B \to PV$ channels; but from SU(3) flavour symmetry, we expect the same δ_{NP} (at least to the leading order) for both $B \to \phi K^*$ and $B_s \to \phi\phi$. In our analysis, we take them to be the same. This effectively reduces our parameter set to h_{NP}, ξ_{NP} and δ_{NP}.

Using the inputs discussed earlier, we find the APS for these three parameters for different Lorentz structures. The result is shown in Table 3. Note that only two scalar-pseudoscalar and two tensor-pseudotensor channels survive. This is due to the fact that only these channels, under Fierz reordering, generate a tensor current, which helps to bring down the longitudinal polarisation fraction Λ_{00}. This is in agreement with [5]. These results are obtained with 2σ error bars; nothing survives at 1σ CL.

In Tables 4 and 5, we show our main results: our expectations for the four allowed sets. The results are quite similar for $B \to \phi K^*$ and $B_s \to \phi\phi$, which is nothing but the manifestation of a rough SU(3) symmetry. In particular, we expect a similar suppression of Λ_{00} for $B_s \to \phi\phi$ too.

At this point, one may like to look at the SM predictions for these observables. In the conventional factorisation scheme, they are:
(i) $B \to \phi K^*$:

$$\begin{aligned}
&\Lambda_{00} = 0.893,\ \Lambda_{\perp\perp} = 0.051,\ \Lambda_{\|\|} = 0.056,\ \Lambda_{\|0} = 0.446,\\
&\rho_{00} = -0.035,\ \rho_{\perp\perp} = -0.612,\ \rho_{\|\|} = -0.038,\\
&\rho_{\perp 0} = 0.312,\ \rho_{\|0} = 0.306,\ \rho_{\perp\|} = 0.078.
\end{aligned} \tag{25}$$

(ii) $B_s \to \phi\phi$:

$$\begin{aligned}
&\Lambda_{00} = 0.948,\ \Lambda_{\perp\perp} = 0.009,\ \Lambda_{\|\|} = 0.044,\ \Lambda_{\|0} = 0.406,\\
&\rho_{\perp 0} = 0.184,\ \rho_{\perp\|} = 0.039.
\end{aligned} \tag{26}$$

All the other variables are zero. Again, this is in the conventional factorisation model; nonfactorisable and

Observable	Set I	Set II	Set III	Set IV
Λ_{00}	$0.40 \to 0.56$	$0.40 \to 0.56$	$0.40 \to 0.56$	$0.41 \to 0.56$
$\Lambda_{\perp\perp}$	$0.21 \to 0.29$	$0.18 \to 0.26$	$0.21 \to 0.29$	$0.18 \to 0.27$
$\Lambda_{\parallel\parallel}$	$0.23 \to 0.32$	$0.21 \to 0.40$	$0.23 \to 0.32$	$0.23 \to 0.41$
$\Lambda_{\perp 0}$	$-0.15 \to 0.25$	$-0.06 \to 0.16$	$-0.25 \to 0.25$	$-0.06 \to 0.18$
$\Lambda_{\parallel 0}$	$0.25 \to 0.71$	$0.46 \to 0.70$	$0.25 \to 0.70$	$0.46 \to 0.75$
$\Lambda_{\perp\parallel}$	0.0	$-0.30 \to 0.10$	0.0	$-0.29 \to 0.18$
Σ_{00}	$-0.07 \to 0.03$	$-0.04 \to -0.005$	$-0.07 \to 0.03$	$-0.04 \to 0.12$
$\Sigma_{\perp\perp}$	$-0.01 \to 0.03$	$0.01 \to 0.14$	$-0.01 \to 0.03$	$-0.03 \to 0.13$
$\Sigma_{\parallel\parallel}$	$-0.01 \to 0.04$	$-0.09 \to -0.006$	$-0.01 \to 0.04$	$-0.09 \to 0.18$
$\Sigma_{\perp 0}$	$0.22 \to 0.64$	$0.44 \to 0.60$	$0.24 \to 0.62$	$0.37 \to 0.60$
$\Sigma_{\parallel 0}$	$-0.21 \to 0.22$	$-0.37 \to -0.05$	$-0.20 \to 0.22$	$-0.38 \to 0.12$
$\Sigma_{\perp\parallel}$	0.0	$0.005 \to 0.25$	0.0	$0.005 \to 0.23$
ρ_{00}	$-0.25 \to 0.05$	$-0.25 \to 0.05$	$-0.3 \to 0.05$	$-0.26 \to 0.04$
$\rho_{\perp\perp}$	$-0.41 \to -0.18$	$-0.50 \to -0.25$	$-0.40 \to -0.18$	$-0.50 \to -0.25$
$\rho_{\parallel\parallel}$	$-0.27 \to 0.05$	$-0.21 \to -0.04$	$-0.35 \to 0.07$	$-0.35 \to 0.0$
$\rho_{\perp 0}$	$0.42 \to 0.70$	$0.47 \to 0.67$	$0.40 \to 0.70$	$0.46 \to 0.67$
$\rho_{\parallel 0}$	$-0.10 \to 0.42$	$0.16 \to 0.27$	$-0.10 \to 0.50$	$0.14 \to 0.42$
$\rho_{\perp\parallel}$	$0.18 \to 0.70$	$0.34 \to 0.60$	$0.20 \to 0.65$	$0.34 \to 0.58$

Table 4: Observables for $B \to \phi K^*$.

Observables	Set I	Set II	Set III	Set IV
Λ_{00}	$0.39 \to 0.66$	$0.40 \to 0.60$	$0.20 \to 0.65$	$0.38 \to 0.58$
$\Lambda_{\perp\perp}$	$0.14 \to 0.32$	$0.19 \to 0.29$	$0.15 \to 0.42$	$0.18 \to 0.31$
$\Lambda_{\parallel\parallel}$	$0.20 \to 0.33$	$0.21 \to 0.36$	$0.20 \to 0.38$	$0.22 \to 0.36$
$\Lambda_{\perp 0}$	$-0.70 \to 0.60$	$-0.06 \to 0.16$	$-0.70 \to 0.60$	$-0.09 \to 0.18$
$\Lambda_{\parallel 0}$	$0.10 \to 0.72$	$0.52 \to 0.70$	$0.10 \to 0.73$	$0.49 \to 0.74$
$\Lambda_{\perp\parallel}$	$-0.08 \to 0.07$	$-0.20 \to 0.04$	$-0.08 \to 0.07$	$-0.20 \to 0.06$
Σ_{00}	$-0.026 \to 0.015$	$-0.04 \to -0.002$	$-0.030 \to 0.013$	$-0.04 \to 0.008$
$\Sigma_{\perp\perp}$	$-0.025 \to 0.01$	$0.01 \to 0.09$	$-0.024 \to 0.01$	$-0.018 \to 0.09$
$\Sigma_{\parallel\parallel}$	$-0.015 \to 0.04$	$-0.06 \to -0.03$	$-0.013 \to 0.04$	$-0.06 \to 0.01$
$\Sigma_{\perp 0}$	$-0.24 \to 0.70$	$0.44 \to 0.66$	$-0.22 \to 0.70$	$0.36 \to 0.65$
$\Sigma_{\parallel 0}$	$-0.25 \to 0.25$	$-0.37 \to -0.04$	$-0.30 \to 0.25$	$-0.38 \to 0.12$
$\Sigma_{\perp\parallel}$	$-0.06 \to 0.08$	$0.004 \to 0.16$	$-0.07 \to 0.08$	$0.004 \to 0.15$
ρ_{00}	$-0.26 \to 0.25$	$-0.13 \to 0.15$	$-0.26 \to 0.22$	$-0.15 \to 0.18$
$\rho_{\perp\perp}$	$-0.05 \to 0.11$	$-0.15 \to 0.06$	$-0.04 \to 0.11$	$-0.15 \to 0.05$
$\rho_{\parallel\parallel}$	$-0.22 \to 0.30$	$0.06 \to 0.22$	$-0.20 \to 0.24$	$-0.14 \to 0.25$
$\rho_{\perp 0}$	$0.28 \to 0.62$	$0.40 \to 0.75$	$0.26 \to 0.74$	$0.37 \to 0.77$
$\rho_{\parallel 0}$	$-0.46 \to 0.25$	$-0.40 \to -0.22$	$-0.47 \to 0.30$	$-0.42 \to -0.14$
$\rho_{\perp\parallel}$	$-0.30 \to 0.50$	$0.30 \to 0.55$	$-0.30 \to 0.80$	$0.28 \to 0.60$
$A_{CP}^{\perp}$	$-0.15 \to 0.10$	$-0.22 \to -0.02$	$-0.20 \to 0.10$	$-0.23 \to -0.02$
A_{CP}^{0}	$-0.2 \to 0.1$	$0.03 \to 0.25$	$-0.20 \to 0.10$	$0.03 \to 0.25$
$\phi_{\perp}$	$-1.2 \to 0.8$	$-0.95 \to -0.82$	$-1.2 \to 0.8$	$-0.98 \to -0.65$
$\phi_{\parallel}$	$-1.1 \to 0.6$	$-0.97 \to -0.55$	$-1.2 \to 0.6$	$-0.96 \to -0.46$
$\delta\phi_{\perp}$	$-1.5 \to 1.5$	$-0.15 \to 0.35$	$-1.3 \to 1.3$	$-0.25 \to 0.40$
$\delta\phi_{\parallel}$	$-1.2 \to 0.5$	$0.08 \to 0.36$	$-1.2 \to 0.4$	$-0.18 \to 0.3$

Table 5: Observables for $B_s \to \phi\phi$.

annihilation contributions may reduce Λ_{00} of $B \to \phi K^*$ to about 0.75 [11]. More variables are zero for the latter case since we have two identical vector mesons and the $B_s - \overline{B_s}$ mixing phase is close to zero in the SM.

From tables 4 and 5, it appears that possible four structures can be divided into two sets: one with $(S+P)\times(S+P)$ and $(T+PT)\times(T+PT)$, and the other with $(S-P)\times(S-P)$ and $(T-PT)\times(T-PT)$. Precise measurement of all the observables should be able to discriminate between the two sets, but considering the respective numbers, this is a more than formidable job. (An almost impossible task is to discriminate between the pair of a given set. One way out is to look for anomalies in semileptonic decays and analyse the angular distribution of the emitted leptons.) On the other and, nonzero values of most of these observables will point to new physics. Note that the values of $\phi_\parallel$ and $\phi_\perp$ are modulo 2π, and the ambiguity of $\{\phi_\parallel, \phi_\perp, \Delta\phi_\parallel, \Delta\phi_\perp\} \leftrightarrow \{-\phi_\parallel, \pi - \phi_\perp, -\Delta\phi_\parallel, -\Delta\phi_\perp\}$ is still there.

This analysis makes some of the more favourite models of new physics less so. A prime example is R-parity violating supersymmetry, which generates only $(S + (-)P) \times (S - (+)P)$ type interactions, but not those that survive our analysis. The NP particles may be directly detected at the LHC if the corresponding dimensionless couplings of the full theory are perturbative. For example, if it is ~ 0.1, then we expect new particles to be about 200-400 GeV, perfectly in the range of LHC. This is true even for tensor currents if the tensor structure appears from an underlying radiative effect with loop suppressions coming into play.

We would still like to mention again that the analysis should not be taken as as irrefutable proof for and against certain types of new physics models. We have tried to constrain the parameter space for generic NP models, but unfortunately the SM uncertainty is still inordinately large. We have taken a middle-of-the-way approach and tried to take into account the variations in predictions of different models (for amplitude calculation) by incorporating some uncertainties in the SM prediction by hand. The uncertainties are so chosen as to cover the BR predictions of different models. Hopefully, the estimates on NP parameter space err on the conservative side. What one needs to make the arguments watertight is to have more control on the theoretical uncertainties. It is imperative that we have, as soon as possible, a particular theoretical model whose results can be relied upon upto a certain order. This model should have a sound theoretical justification and *should not concentrate on reproducing the experimental results alone* (in particular those that may contain hints of new physics). With this, and more data, can one hope to refine this analysis.

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