1 Introduction

The spectacular performance of the two asymmetric $B$-factories allowed us to reach an important milestone in our understanding of CP-violation phenomena. For the first time it was established that the observed CP-violation in the $B$ and $K$ systems was indeed accountable by the single, CP-odd, Kobayashi-Maskawa phase in the CKM matrix\[12\]. In particular, the time dependent CP-asymmetry in the gold-plated $B^0 \to \psi K_s$ can be accounted for by the Standard Model (SM) CKM-paradigm to an accuracy of around 15\%\[34\]. It has then become clear that the effects of a beyond the standard model (BSM) phase can only be a perturbation. Nevertheless, in the
past few years as more data were accumulated and also as the accuracy in some theoretical calculations was improved it has become increasingly apparent that several of the experimental results are difficult to reconcile within the SM with three generations [SM3]. It is clearly important to follow these indications and to try to identify the possible origin of these discrepancies especially since they may provide experimental signals for the LHC which is set to start quite soon. While at this stage many extensions of the SM could be responsible, it seems that a very simple explanation is provided by the addition of a fourth family of quarks. In fact it is shown that the data suggests that the charge 2/3 quark of this family needs to have a mass in the range of (400 - 600) GeV. New physics scenarios with warped extra dimension also provide a very interesting and viable explanation; indeed some of the effects were predicted in these models. We will briefly discuss these as well.

2 B-CP anomalies

Below we briefly summarize the experimental observations involving $B$, $B_s$-$CP$ asymmetries that are indicative of possible difficulties for the CKM picture of $CP$-violation.

1. The predicted value of $\sin 2\beta$ in the SM seems to be about 2-3 $\sigma$ larger than the directly measured values. Using only $\epsilon_K$ and $\Delta M_s/\Delta M_d$ from experiment along with the necessary hadronic matrix elements, namely kaon “$B$-parameter” $B_K$ and using $SU(3)$ breaking ratio $\xi_s \equiv f_{K_s}/\sqrt{B_{K_s}}$, from the lattice, alongwith $V_{cb}$ yields a prediction, $\sin 2\beta_{\text{prediction}} = 0.87 \pm 0.09$ in the SM; see Fig. 1. If along with that $V_{ub}$ is also included as an input then one gets a somewhat smaller central value but with also appreciably reduced error: $\sin 2\beta_{\text{full fit}} = 0.75 \pm 0.04$; see Fig. 2.

![Figure 1: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.](image)

2. The celebrated measurement, via the “gold-plated” mode $B \to \psi K_s$, gives $\sin 2\beta_{\psi K} = 0.672 \pm 0.024$ which is smaller than either of the above predictions by $\approx 1.7$ to $2.1$ $\sigma$.

3. As is well known penguin-dominated modes, such as $B \to (\phi, \eta', \pi^0, \omega, K_sK_s, ...)K_s$ also allow an experimental determination of $\sin 2\beta$ in the SM. This method is less clean
as it has some hadronic uncertainty, which was naively estimated to be at the level of 5% \cite{11}. Unfortunately, this uncertainty cannot be reliably determined in a model-independent manner. However, several different estimates \cite{13} find that amongst these modes, $(\phi, \eta', K_s K_s)$ $K_s$ are rather clean up to an error of only a few percent. In passing, we note another intriguing feature of many such penguin-dominated modes is that the central value of sin $2\beta$ that they give seems to be below the two SM predicted values given above in \#1 and in fact, in many cases, even below the value measured via $B \to \psi K_S$ (given in \#2).

To further exhibit this more clearly we show a direct comparison between the fitted value of sin $2\beta$ and the one obtained by direct measurements via $\psi K_s$ and via the penguin dominated modes; see Fig. 3. A crucial test of the CKM paradigm of CP violation is that the single CP-odd phase in the $3 \times 3$ mixing matrix must be able to explain simultaneously the CP violation in $K$-decays as well as in $B, B_s$ decays. This means that directly measured values of sin $2\beta$ whether they are obtained from $\psi K_s$ or from clean penguin modes such as $\eta' K_s$ or $\phi K_s$ must agree with the fitted value of sin$2\beta$. We see that whether we use $V_{ub}$ or not the fitted value is not only high compared to the $\psi K_s$ one but in fact is higher even more compared to the penguin modes. It is also striking that the central value of the sin $2\beta$ from almost all ten or so penguin modes is lower than the fitted value. The only exception to this is the mode $B_d \to \phi \pi^0 K_s$ but here the negative error is huge, O(50%), so its meaningless to pay attention to the central value right now.

We also want to emphasize that, strictly speaking, a comparison of sin $2\beta$ from $\psi K_s$ with the one from penguin-modes need not reveal New Physics (NP) beyond CKM if NP is confined to $B_d$ mixing only and does not affect $b \to s$ penguin transitions or $b \to c \bar{c} s$ tree decay. Therefore, direct comparison with the fitted value of sin $2\beta$ obtained by using $\epsilon_K$ is essential.

4. Another apparent difficulty for the SM is understanding the rather large difference in the direct CP asymmetries $\Delta A_{CP} \equiv A_{CP}(B^- \to K^- \pi^0) - A_{CP}(B^0 \to K^- \pi^+) = (14.4 \pm 2.9)\%$ \cite{3}. Naively this difference is supposed to be zero, since the two decaying B’s are related.
by switching of the spectator u and d quark, but it is not by almost five σ. Using QCD factorization\[\text{11}\] in conjunction with any of the four scenarios for \(1/m_b\) corrections that have been proposed\[\text{15}\], we were able to estimate \(\Delta A_{CP} = (2.2 \pm 2.4)\%\)[\text{16}\] which is several σ’s away from the experimental observations. It is important to understand that by varying over those four scenarios one is actually spanning the space of a large class of final state interactions; therefore the discrepancy with experiment is serious\[\text{17}\]. Note also that this result for the \(\Delta A_{CP}\) is quite consistent with results obtained when a completely different approach is used to estimate final state rescattering effects giving rise to the non-leading corrections\[\text{18}\]. However, given our limited understanding of hadronic decays still makes it difficult to draw compelling conclusions from this difficulty for the SM (with three generations).

5. Finally, recently the possibility of the need for a largish non-standard \(CP\) phase has been raised\[\text{19,20}\] in the study of \(B_s \rightarrow \psi \phi\) at Fermilab by CDF\[\text{21}\] and D0\[\text{22}\] experiments. Since the presence of a beyond the SM \(CP\) odd phase in \(b \rightarrow s\) transitions as (for example) already emphasized in\[\text{5}\], such non-standard effects in \(B_s\) decays are quite unavoidable.
Table 1: Scale of New Physics, accompanied by a CP-odd phase, relevant to different scenarios to account for CP anomalies in the data; taken from Ref. 16.

| Scenario      | Operator | $\Lambda$ (TeV) | $\varphi$ ($^\circ$) |
|---------------|----------|-----------------|----------------------|
| $B_d$ mixing  | $O_{1}^{(d)}$ | $\begin{cases} 1.1 \div 2.1 & \text{no } V_{ub} \\ 1.4 \div 2.3 & \text{with } V_{ub} \end{cases}$ | $\begin{cases} 15 \div 92 & \text{no } V_{ub} \\ 6 \div 60 & \text{with } V_{ub} \end{cases}$ |
| $B_d = B_s$ mixing | $O_{1}^{(d)} \ & O_{1}^{(s)}$ | $\begin{cases} 1.0 \div 1.4 & \text{no } V_{ub} \\ 1.1 \div 2.0 & \text{with } V_{ub} \end{cases}$ | $\begin{cases} 25 \div 73 & \text{no } V_{ub} \\ 9 \div 60 & \text{with } V_{ub} \end{cases}$ |
| $K$ mixing    | $O_{1(K)}^{(K)}$ | $< 1.9$ | $130 \div 320$ |
| $O_{4(K)}$    | $< 24$ | $\text{0}$ |
| $A_{b\rightarrow s}$ | $O_{3}^{b\rightarrow s}$ | $.25 \div .43$ | $0 \div 70$ |
|              | $O_{3}^{s\rightarrow s}$ | $.09 \div .2$ | $0 \div 30$ |

Given that this effect (i.e., a non-vanishing CP-asymmetry in $B_s \rightarrow \psi\phi$) is theoretically very clean, it has special importance. Unfortunately, at present it is quite limited by statistics and stands at around $\approx 2.2 \sigma$. Fortunately the Tevatron is running very well and accumulating luminosity. If analysis with increased luminosity lead to an enhancement of the significance of this asymmetry, that could be very important. Thus running the Tevatron to resolve this issue deserves a very high priority.

3 Theoretical interpretations of the anomalies

In the following we discuss a few theoretical scenarios that could be the underlying cause for the observed anomalies. However, we first very briefly consider a model independent point of view and then some specific models that appear to be relevant.

3.1 Brief Summary of the model independent analysis

One of the important issue is how these B-CP anomalies will impact search for New Physics at the LHC. For this purpose it is vitally important to understand the scale of NP. With this in mind we write down dimension-6 operators under the general assumptions of NP in $\Delta Flavor = 2$ effective Hamiltonian for $K$, $B_d$ or $B_s$ mixing or for the case of $\Delta Flavor = 1$ Hamiltonian relevant for $b \rightarrow s$ penguin transitions. Table 1 summarises results of such a model independent analysis. We see that the scale of NP is only a few hundred GeV if it originates from $b \rightarrow s$, $\Delta Flavor = 1$ penguin Hamiltonian. It rises to about a few TeV if it originates from $B_d$ and/or $B_s$ mixing. From the perspective of LHC the scenario that is the most pessimistic, with NP scale in the range of a few tens of TeVs, is when all of the NP resides only in the dimension-6 LR-operator relevant for the $K - \bar{K}$ mixing. But in this case the indications for a non-vanishing CP-asymmetry in the CDF and D0 data for $B_s \rightarrow \psi\phi$ or for the large value of $\Delta A_{CP}[K\pi]$ or for the smallish value of $\sin 2\beta$ from penguin modes becomes difficult to reconcile.

3.2 Warped Flavordynamics & duality

Perhaps the most interesting and even compelling BSM scenario is that of warped extra dimensional models as they offer a simultaneous resolution to EW-Planck hierarchy as well as flavor puzzle. While explicit flavor models are still evolving, potentially this class of models does have extra CP-violating phase(s) that can have important repercussions for flavor physics.
Indeed in the simplest scenario (with the assumption of “anarchic” Yukawas i.e. in the 5D theory the entries in the Yukawa matrices are roughly of similar order) it was predicted\textsuperscript{28} that there should be smallish (i.e. $O(20\%)$) deviations from the SM in $B_d$ decays to penguin-dominated final states such as $\phi K_s, \eta' K_s$ etc as well as the possibility of large CP-odd phase in $B_s$ mixing which then of course has manifestations in e.g. $B_s \rightarrow \psi \phi$; forward-backward asymmetry in $X_s^{+} l^{-}$ etc\textsuperscript{27,28}. However, in this original study, for simplicity it was assumed that $B_d$ mixing was essentially described by the SM. More recently there have been two extensive studies of the possibility of warped models being the origin of the several hints in $B, B_s$ decays mentioned above\textsuperscript{29,30,31}.

A common feature of these warped models is that they also imply the existence of various Kaluza-Klein states, excited counterparts of the gluon, weak gauge bosons and of the graviton with masses heavier than about 3 TeV\textsuperscript{32}. Note also that unless the masses of these particles are less than about 3 TeV their direction detection at LHC will be very difficult\textsuperscript{33,34,35,36,37,38,39,40,41}.

An extremely interesting subtelty about these 5-dimensional warped models is that they are supposed to be dual to some 4-dimensional models with strong dynamics\textsuperscript{42,43,44,45}. This motivates us to search for effective 4-dimensional models that seem to provide a good description of the data.

### 3.3 Two Higgs doublet model for the top quark

Another interesting BSM scenario that was studied in the context of such hints of new physics in $B_d, B_s$ physics is that of a two higgs doublet model. Such class of models are of course a very simple extension of the SM and in fact in SUSY they find a natural place as there the 2HDM’s become a necessity. However, a specific such model, the two higgs doublet model for the top-quark (T2HDM)\textsuperscript{46} is also of interest for a variety of reasons. It naturally accommodates $m_t >> m_b$ by postulating that the second Higgs doublet has a much larger VEV ($v_2$) compared to the VEV ($v_1$) of the “first” doublet that couples with all the fermions other than the top quark. This of course means that this model does not preserve “natural flavor conservation”\textsuperscript{17} so, indeed it has tree-level flavor changing-Higgs couplings. However, these are restricted to the charge $+2/3$ sector only. Thus the severe $K - \bar{K}, B_d - \bar{B}_d, B_s - \bar{B}_s$ constraints are respected but the model predicts enhanced $D^0 - \bar{D}^0$ mixing\textsuperscript{48} and enhanced flavor changing decays of the type $Z \rightarrow b \bar{s}, t \rightarrow c Z$ etc\textsuperscript{49}. Furthermore, the model has additional CP violating phases that can have many interesting effects in flavor physics\textsuperscript{51,52,53,54,55,56}.

Specifically, the relevance of this model for some of the aforementioned anomalies in $B$ decays, was examined in \textsuperscript{5}.

### 3.4 Possible relevance of a “4th generation” of quarks

Interestingly SM with a fourth generation [SM4] provides a rather simple explanation for many of the observed deviations in $B, B_s$ decays from the predictions of Standard Model’s CKM-paradigm, the SM3 (Standard Model with 3 generations). Indeed the data is suggestive for the need of a $t'$ in the range (400 - 600) GeV\textsuperscript{55}.

For completeness, let us note that SM4 is a simple extension of SM3 with additional up-type ($t'$) and down-type ($b'$) quarks. It retains all the features of the SM. The $t'$ quark, like $u, c, t$ quarks, contributes in the $b \rightarrow s$ transition at the loop level\textsuperscript{52}. The addition of fourth generation means that the quark mixing matrix will become a 4 x 4 matrix and the parametrization of this unitary matrix requires six real parameters and three phases. The two extra phases imply the possibility of extra sources of CP violation\textsuperscript{53}. In order to constrain these extra parameters we use experimental inputs from processes such as, $B_d - \bar{B}_d$ and $B_s - \bar{B}_s$ mixing, $BR(B \rightarrow X_s \gamma)$,
The decay modes by using information from known parameters. In this way we have reduced the number of unknown parameters respectively whereas the relevant expressions for the \( V_{CKM} \) elements for \( 4 \times 4 \) functions. For concreteness, we use the parametrization suggested by Botella and Chau in 63 to include indirect CP violation in \( K_L \to \pi \pi \) described by \( |\epsilon_k|, Z \to b\bar{b} \) etc. Table 2 summarizes complete list of inputs that we have used to constrain the SM4 parameter space. Using these input parameters we have obtained the constraints on various parameters of the 4×4 mixing matrix. In Table 3 we present the one sigma allowed ranges of \( |V_{t's}V_{tb}| \) and \( \phi' \) (the phase of \( V_{t's} \)), which follow from our analysis.

The SM3 expressions for \( \epsilon_k \) and \( Z \to b\bar{b} \) decay width have been taken from 60 and 61 respectively whereas the relevant expressions for \( \Delta M_d \) and \( \Delta M_s \), along with the other observables can be found in 62. The corresponding expressions in SM4 i.e., the additional contributions arising due to \( t' \) quark can be obtained by replacing the mass of \( t\)-quark by \( m_{t'} \) in the respective Inami-Lim functions. For concreteness, we use the parametrization suggested by Botella and Chau in 63 for \( 4 \times 4 \) CKM matrix \( [V_{CKM4}] \). In \( \Delta M_d \) and \( \Delta M_s \), apart from the other factors, we have the CKM elements \( V_{tq}V_{tb}^* \) and \( \Delta M_s \) respectively, contains the term \( V_{ts}V_{tb}^* \) (with \( q=d \) or \( s \)),

\[
\begin{align*}
V_{tq}V_{tb}^* &= -(V_{uq}V_{ub}^* + V_{cq}V_{cb}^* + V_{t'q}V_{t'b}^*) \\
V_{ts}V_{tb}^* &= -(V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{t's}V_{t'b}^*),
\end{align*}
\]

which is replaced by using the unitarity relation, \( \lambda_q + \lambda_c + \lambda_{t'} = 0 \) where \( \lambda_q = V_{qb}V_{q'b}^* \). using the \( 4 \times 4 \) CKM matrix unitarity relations. The phase of \( V_{td} \) and \( V_{ts} \) will also be obtained by using this unitarity relation. In this way we have reduced the number of unknown parameters by using information from known parameters.

With a sequential fourth generation, the effective Hamiltonian describing, as an example, the decay modes \( B^- \to \pi^0 K^- \) and \( B^0 \to \pi^+ K^- \) becomes

\[
\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}}[\lambda_u(C_1^uO_1 + C_2^uO_2 + \sum_{i=3}^{10} C_i^uO_i)]
\]
Table 3: Allowed ranges for the parameters, \( \lambda'_{\tau} \times 10^{-2} \) and phase \( \phi'_s \) (in degree) for different masses \( m_{\tau'} \) (GeV), that has been obtained from the fitting with the inputs in Table 2 taken from [8].

| \( m_{\tau'} \) | 400    | 500    | 600    | 700    |
|----------------|--------|--------|--------|--------|
| \( \lambda'_{\tau} \) | (0.08 - 1.4) | (0.06 - 0.9) | (0.05 - 0.7) | (0.04 - 0.55) |
| \( \phi'_s \) | -80 → 80 | -80 → 80 | -80 → 80 | -80 → 80 |

Figure 4: The left panel shows the allowed range for \( S_{\psi\phi} \) in the \((S_{\psi\phi} - \phi'^s_s)\) plane for \( m_{\tau'} = 400 \) (red), 500 (green), 600 (magenta) and 700 (blue) GeV respectively. Black and red horizontal lines in the figure indicate 1-\( \sigma \) and 2-\( \sigma \) experimental ranges for \( S_{\psi\phi} \) respectively. The right panel shows the correlation between \( S_{bK_s} \) and \( S_{\psi\phi} \) for \( m_{\tau'} = 400 \) (red), 500 (green), 600 (magenta) and 700 (blue) GeV respectively. The horizontal lines represent the experimental 1-\( \sigma \) range for \( S_{bK_s} \), whereas the vertical lines (Black 1-\( \sigma \) and red 2-\( \sigma \)) represent that for \( S_{\psi\phi} \), taken from [8].

\[ +\lambda_c \sum_{i=3}^{10} C''_i O_i - \lambda_{\tau'} \sum_{i=3}^{10} \Delta C''_i O_i \]

where \( C''_i \)'s are the Wilson coefficients, \( \Delta C''_i \)'s are the effective (t subtracted) \( t' \) contributions and \( O_i \) are the current-current operators. Using the above effective Hamiltonian, for the \( b \rightarrow s \) transition and following [5] we use the S4 scenario of QCD factorization approach [15] for the evaluation of hadronic matrix elements and the amplitudes for the decay modes \( B \rightarrow \pi K \) and \( B \rightarrow \phi K_s \) for \( m_{\tau'} = 400 \) , 500, 600, 700 GeV respectively.

Using the ranges of \( \lambda'_{\tau} \equiv |V'_{ts}V'_{tb}| \) and \( \phi'_s \), the phase of \( V'_{ts} \) as obtained from the fit for different \( m_{\tau'} \) (Table 3), the allowed regions in the \( \Delta A_{CP} - \lambda'_{\tau} \) plane for different values of \( m_{\tau'} \) were studied. With the 4th family there is some enhancement and \( \Delta A_{CP} \) up to about 8\% may be feasible which is still somewhat small compared to the observed value (14.4 \( \pm \) 2.9)\%. Again, as we mentioned before this could be due to the inadequacy of the QCD factorization model we are using.

In Fig[4] we have shown the allowed regions in the \( S_{\psi\phi} - \phi'^s_s \) plane for different values of \( m_{\tau'} \) and also the correlation between \( CP \) asymmetries in \( B \rightarrow \psi\phi \) and \( B \rightarrow \phi K_s \). We follow the notation \( S_{\psi\phi} = \sin(\phi'^s_s - 2\beta_s) = \sin 2\beta'^{eff}_s \), where \( \phi'^s_s \) is the phase coming from mixing and \( \beta_s = arg(-\frac{V_{ts}^*V_{ts}}{V_{tb}^*V_{tb}}) = 1.1^o \pm 0.3^o \), is the phase of \( b \rightarrow c\bar{c}s \) decay amplitude [64]. The range for new \( B_s \) mixing phase \( \phi'^s_s \) is given (at 68\% CL) by \( \phi'^s_s \in (-18 \pm 7)^0 \) or, \( \phi'^s_s \in (-70 \pm 7)^0 \). The corresponding 2-\( \sigma \) and 1-\( \sigma \) ranges for \( S_{\psi\phi} \) is given by [-0.90, -0.17] and [-0.78, -0.40] respectively. The large error on \( S_{bK_s} \) and \( S_{\psi\phi} \) does not allow at present to draw strong conclusions on \( m_{\tau'} \), nevertheless the present experimental bounds seem to mildly disfavor \( m_{\tau'} > 600 \) GeV.

A very appealing feature of the 4th family hypothesis is that it quite readily explains the pattern of the observed anomalies. First of all the heavy \( m_{\tau'} \) generates a very important new source of electroweak penguin (EWP) contribution since, as is well known, these amplitudes are able to avoid the decoupling theorem and grow as \( m_{\tau'}^2 \) [60, 52]. This helps to explain two of the anomalies in \( b \rightarrow s \) transitions. The enhanced EWP contribution helps in explaining
the difference in CP-asymmetries, $\Delta A_{CP}$ as it is really the $K^\pm \pi^0$ that is enhanced because of the color allowed coupling of the $Z$ to the $\pi^0$. A second important consequence of $t'$ is that $b \to s$ penguin has a new CP-odd phase carried by $V_{t's}V^*_{ts}$. This is responsible for the fact that $\sin 2\beta$ measured in $B \to \psi K_s$ differs with that measured in penguin-dominated modes such as $B \to (q, \eta', K_s K_s) K_s$.

Note also that $\Delta B = 2$ box graph gets important new contributions from the $t'$ since these amplitudes as mentioned before are proportional to $m^2_t$. Furthermore, they are accompanied by new CP-odd phase which is not present in SM3. This phase is responsible for the fact that the $\sin 2\beta$ measured in $B \to \psi K_s$ seems to be bigger than the value(s) “predicted” in SM3$^{[7]}$ given in item # 1 on page 1.

Finally, we note briefly in passing how SM4 gives a rather simple explanation for the size of the new CP-phase effects in $B_d$ versus $B_s$ mesons. In $B_d$ oscillations resulting in $B \to \psi K_s$, top quark plays the dominant role and we see that the measured value of $\sin 2\beta$ deviates by $\approx 15\%$ from predictions of SM3. It is then the usual hierarchical structure of the mixing matrix (now in SM4) that guarantees that $\sin 2\beta \approx \text{fitted one}$, the one measured via $\psi K_s$ seems to be bigger than the value(s) “predicted” in SM3$^{[7]}$ given in item # 1 on page 1.

Improved prospects for baryogenesis

In SM3 a well known difficulty for baryogenesis is that the process is driven by product of square of mass differences of the 3 up-type quarks and the 3 down-type quarks:

$$Q_B \approx A_{UT-SM3}[(m_c^2 - m_u^2)(m_t^2 - m_u^2)(m_t^2 - m_d^2)(m_s^2 - m_u^2)(m_s^2 - m_d^2)/(m_W^2)]$$

where $A_{UT-SM3}$ is twice the (invariant) area of the unitarity triangle for the 3-generation SM$^{[69]}$. As is well known, $A_{UT-SM3}$ s multiplied by an extremely small number making it very difficult for baryogenesis to occur. However, in SM4 since each set of 3-generations (of three linearly independent ones) will have its own associated CP-odd phase$^{[2]}$. In the corresponding quantity with new CP-odd phase(s), therefore, masses of the first family no longer need to enter leading to a huge enhancement by the ratio,

$$(m_c^2/m_t^2)(m_t^4/m_t^4)(m_s^2/m_u^2)(m_s^4/m_u^4) \approx 10^{16}$$

So, at least from this point of view the chances of baryogenesis in SM4 are significantly improved$^{[70,71]}$ though its claimed that other difficulties may still need to be confronted$^{[72]}$.

Repurcussions for SBF

We now briefly summarize some of the definitive signatures of the 4th family scenario in flavor observables$^{[58]}$ at the flavor facilities of today or tomorrow, such as LHCb and Super-B Factory (SBF). The need for new CP phase(s) beyond the single KM phase$^{[2]}$ of course must continue to persist. This means that the three values of $\sin 2\beta$, the fitted one, the one measured via $\psi K_s$ and the one measured via penguin dominated modes (e.g. $\phi K_s$, $\eta' K_s$ etc.) should continue to differ from each other as more accurate analysis become available. Furthermore, $B_s$ mixing should also continue to show the presence of a non-standard phase (e.g. in $B_s \to \psi \phi$) as higher statistics are accumulated. For sure SM4 will have many more interesting applications in flavor physics, for example, direct CP asymmetry in $K_L \to \pi^0 \nu \bar{\nu}$, forward-backward asymmetry in $B \to X_s l^+ l^-$ etc. which need to be explored$^{[58]}$. 
Repurcussions for the LHC

For the LHC, one definitive prediction of this analysis is a 4th family of quarks in the range of \(\approx 400\)-600 GeV and the detection of these heavier quarks and their leptonic counterparts deserves attention. EW precision constrains the mass-splitting between \(t'\) and \(b'\) to be small, around 50 GeV\(^6\). This constraint will clearly have important repercussions for their decays and therefore their signals at the LHC.

For 500 GeV quarks the cross-section for pair production by gluon fusion is estimated to be around 4pb\(^7\). The final states via their decays should have pair of opposite sign charged leptons with missing energy carried by neutrinos and a \(t \rightarrow b W\) pair. Since the \(t' - b'\) mass splitting is likely to be less than \(m_W\), the 2-body decays of the \(t'\) (assuming it is heavier) may not be kinematically allowed. This should have the indirect consequence of boosting BR for the 2-body mode, \(t' \rightarrow b W\).

For the \(b'\) we should expect prominent 2-body mode, \(b' \rightarrow t + W\). The partial width will be suppressed by \(V_{bt}'\) boosting its lifetime. Flavor changing \(b' \rightarrow b Z\) may also be enhanced and quite interesting.

The decays of \(t'\) and/or \(b'\) should lead to hgh \(P_t\) multilepton final states. Decays of the \(t'\) are likely to be dominated by \(t' \rightarrow b + W\), followed by decays of the W. Thus we should expect opposite sign dileptons from pairs of \(t'\). From the pair production of \(b'\) followed by their decays, we can get both opposite sign or same sign dileptons. The same sign ones arise (e.g.) when one lepton comes from \(W^-\) originating from the \(b'\) and the other from the \(W^+\) originating from the \(t\) on the opposite side. These high \(p_t\) same sign dileptons clearly provide very distinctive signatures. Furthermore, the opposite sign leptons tend to have similar energies, whereas same sign tend to be asymmetric in energy with their average energies differing by a factor of about two.

Another important consequence of the 4th generation scenario with such heavy quarks is that correspondingly the higgs may be heavier with \(m_H \gtrsim 300\text{GeV}\)\(^8\). This could make its detection via decays to ZZ, WW final states more prominent and perhaps easier than the light mass case.

Possiblity for a dark matter candidate

As far as the lepton sector is concerned, it is clear that the 4th family leptons have to be quite different from the previous three families in that the neutral leptons have to be rather massive, with masses \(> m_Z/2\). This may also be a clue that the underlying nature of the 4th family may be quite different from the previous three families\(^9\). KM\(^2\) mechanism taught us the crucial role of the three families in endowing CP violation in SM3. It is conceivable that 4th family plays an important role\(^10\)\(^12\) in yielding enough CP to generate baryogenesis which is difficult in SM3. Of course it also seems highly plausible that the heavy masses in the 4th family play a significant role in dynamical generation of electroweak symmetry breaking. In particular, the masses around 500 or 600 GeV that are being invoked in our study, point to a tantalizing possibility of dynamical electroweak symmetry breaking as the Pagels-Stokar relation in fact requires quarks of masses around 500 or 600 GeV for dynamical mass generation to take place\(^13\)\(^14\)\(^15\)\(^16\)\(^17\). For such heavy masses the values of Yukawa coupling will be large but not so large to break down perturbation theory. Clearly all this brief discussion is signaling is that there is a lot of physics involving the new family that needs to be explored and understood.

Does need some tuning

While from the point of view of dynamical EW symmetry breaking, baryogenesis and the possibility of a dark matter candidate, a pair of 4th generation-like heavy quarks may be quite
interesting, to put things in perspective we should also recall that some degree of cancellations or tuning will be needed to accommodate such a family. First of all the EWP constraints show that some of the contribution of the heavier quarks to the S and T-parameters may have to cancel against a heavier higgs. Moreover, the EWP constraints also require that for such heavy quarks, the mass difference between the $t'$ and the $b'$ cannot be more than around 50 GeV\cite{78}. This means their masses may be degenerate to about 10%. While such a tuning may be a cause for concern, it may be worth remembering that this degeneracy is a lot less than proton-neutron mass difference which we now understand results from isospin symmetry of the strong interactions.

**Cannot be a conventional 4th generation**

Since LEP experiments tell us that there cannot be another sequential, essentially massless neutrino, the underlying nature of this “4th generation” that we need for fixing B-CP anomalies must be quite different. In fact, from our point of view, all that is really needed is a heavy charge + 2/3 quark that participates in the EW interactions through the $4 \times 4$ mixing matrix\cite{80}. Thus the underlying nature of this 4th generation may be quite different from the previous three\cite{82}.

**4 Summary & Outlook**

Attention is drawn to several 2-3 $\sigma$ indications for new CP violating physics in B, Bs and possibly in K-mixings and decays. Heavier quarks of another (“4th”) family offer a simple explanation for these effects. These indications should be resolved with high priority. In particular, the hints in $B_s \rightarrow \psi \phi$ are very clean from a theoretical standpoint and since the fermilab Tevatron is also working very well and accumulating data at a high luminosity, it is highly desirable to let the Tevatron run for another few years so that we can get to the bottom of this anomaly as soon as possible.

If these signals for NP are confirmed they will obviously have a large impact on flavor and on collider physics. It is useful to note that the flavor structure of warped model is sufficiently intricate that signals such as those highlighted here could originate from this class of new physics. However, our current understanding of these models is such that the Kaluza-Klein particles are likely to have masses heavier than about 3 GeV making their direct verification at the LHC rather challenging. In that case, higher sensitivity experiments in the flavor sector, at high luminosity machines may be our only way to seek confirmation. In contrast, if a 4th family explanation is the underlying cause then the masses of the new particles need only be around 600 GeV making their detection at LHC also quite feasible.

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