Novel Effects in B System: From SUSY to Intrinsic Charm

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We have entered the era of BaBar, Belle and Tevatron competition; with new hardware and unprecedented statistics reach, we must be prepared for discovering new phenomena. While these unfoldings could be coming from new physics, it could also come about as new tricks from old. We illustrate new physics with generic bsg dipole and its impact on sin2Φ_{ψK_S} and at a deeper level, the marriage of flavor symmetries and SUSY, which could impact on B_d, B_s and D^0 mixings and CP violation, and possibility of a light sb squark. As simple unfolding, we touch upon charmless B → baryonic pair decay, with or without an associated s' / γ. We close with the possible spectacular signal of B → J/ψDπ as a flabbergasting new trick from nonperturbative QCD: intrinsic charm of B.

1 New Physics Signals: Where Large?

Traditionally, new physics signals creep out initially as rather faint effects. In the B Factory era (including Tevatron Run II), we pray that new physics would emerge with a splash. We give below three scenarios for flavor violation in context of SUSY.

1.1 Generic bsg Dipole: sin2Φ_{ψK_S} ≠ sin2Φ_{J/ψK_S}

It is known that squark-gluino loops can generate sizable b_R → s_Rg transitions, which probes a possible new CP phase associated with b_R that is not probed by V_{CKM}. Parametrizing the dipole strength as c_{11} = |c_{11}|e^{i\sigma}, the coupling was employed to enhance the direct CP asymmetries (a_{CP}) in B^0 → K^+π^- mode, rumored to be sizable in late 1997. By interfering destructively with SM penguins to satisfy B^+ → φK^- \lesssim 5 \times 10^{-6} from CLEO, it was found that a_{CP}(K^+π^-) > 50% is possible. Subsequently, CLEO reported no evidence for a_{CP}(K^+π^-). This diminishes, but does not eliminate, the prospects for direct CP in φK mode, especially since Belle discovered that B^+ → φK^+ is considerably above the old CLEO bound. Besides a_{CP}, we are now more interested in mixing-dep. CP in φK mode. Taking as illustration that b → sg ≈ 2.5%, which is 10 times larger than SM but very hard to rule out, we find that Φ_{ψK_S} could be shifted by \sim 20^\circ, leading to e.g. sin2Φ_{ψK_S} ≈ 0.93 for sin2Φ_{J/ψK_S} ≈ 0.48 (the Belle value). \footnote{Novel Effects in B System: From SUSY to Intrinsic Charm}

1.2 Generic Abelian Flavor Symmetry with SUSY

New physics in flavor sector is likely since little is understood. The intriguing pattern of mass and mixing hierarchies in powers of λ \equiv |V_{ns}| suggest

\[
\frac{M_u}{m_t} \sim \begin{bmatrix} \lambda^7 & \lambda^5 & \lambda^3 \\ \lambda^4 & \lambda^2 & 1 \end{bmatrix}, \quad \frac{M_d}{m_b} \sim \begin{bmatrix} \lambda^4 & \lambda^3 & \lambda^3 \\ \lambda^5 & \lambda^3 & \lambda^3 \\ \lambda^6 & \lambda^6 & \lambda^6 \end{bmatrix},
\]

where the upper right is from U_L, D_L \sim V_{CKM} \equiv U_L^\dagger D_L which holds in suitable basis. Note that the lower left are diagonalized by U_R, D_R but unknown to us with SM dynamics only. Eq. (1) clearly suggest some possible underlying flavor (horizontal) symmetry. If this symmetry is Abelian, commuting horizontal charges imply M_{ij}M_{ji} \sim M_{ii}M_{jj} (i, j not summed), hence

\[
\begin{bmatrix} \frac{M_u}{m_t} \\ \frac{M_d}{m_b} \end{bmatrix} \sim \begin{bmatrix} \lambda^4 & \lambda^3 & \lambda^3 \\ \lambda^5 & \lambda^3 & \lambda^3 \\ \lambda^6 & \lambda^6 & \lambda^6 \end{bmatrix},
\]

is inferred. It is intriguing, then, that M_{32}^2/m_b, M_{31}^2/m_b are the most prominent off-diagonal elements, hence impact on B_d and B_s mixings naturally, iff right-handed down sector can be heard. However, the SM has no right-handed flavor dynamics. This is where SUSY enters to help: d_R couples to g.

Assuming that SUSY breaking itself does not introduce flavor violations, we find that (M_{32}^2)_{LR} = (M_{31}^2)_{RL} \sim \bar{m} M_{ij}^3, (M_{Q}^2)_{LL} \sim \bar{m}^2 V_{CKM}, but

\[
(M_{32}^2)_{RR} \sim \bar{m}^2 \begin{bmatrix} 1 & \lambda & \lambda \\ \lambda & 1 & 1 \\ \lambda & 1 & 1 \end{bmatrix}, (3)
\]

contribute significantly to B_d (or B_s) mixings.

Generic flavor symmetry and its breaking can impact on measurable via SUSY! We stress that the flavor and CP violation in Eq. (3) are on the same footing as V_{CKM}.

\[
d_{bR-R} \text{ Mixing: Low sin2Ф_{B_d} and D^0 Mixing?}
\]

The RR sector could contribute significantly to B_d mixing via \phi_{dRR} \sim \lambda since this is much larger than V_{d}\sim \lambda^3. A simple dimensional analysis suggests that \bar{m}, m_3 \sim M_W/λ^2 \sim \text{TeV} scale could generate squark-gluino box diagram contributions that are comparable to SM. We illustrate this observation in Fig. 1, where sin2Φ_{B_d} via J/ψ K \psi can range from 0.3 to 1 vs sin2φ_1 \approx 0.75–0.71 for φ_1 = 65°–85° in SM.

Of particular interest is the low sin2Φ_{B_s} \sim 0.3–0.4 possibility, stated already in May 2000 (before...
ICHEP2000), as compared with the present world average of 0.48±0.16, dominated by BaBar (0.34±0.20±0.05) and Belle (0.58±0.32±0.09) values reported at this conference. It is clear that CKM unitarity bound from \( \Delta m_{B_s}/\Delta m_{B_d} \) should be relaxed, and potential conflict on \( \phi_3/\gamma \) w.r.t. charmless rare B decays may be alleviated. What we mean is that, with \( \tilde{m} \), \( m_\tilde{g} \gtrsim \text{TeV} \) and \( (M_d^2)_{L.R.} \) suppressed by \( m_q/m_\tilde{u} \), there is little impact on penguins, hence charmless rare B decays may have better access to CKM phases (except for hadronic uncertainty). Thus, \( \phi_3/\gamma \gtrsim 90^\circ \) may well be the case, which is strengthened by \( \pi^+\pi^-/K^+\pi^- \sim 1/4 \) as reported by CLEO, Belle and now BaBar at this conference.

We eagerly await summer results on \( \sin 2\Phi_{B_s} \)!!

But we have been too naive so far: \( \Delta m_K \) and \( \epsilon_K \) constraints are much more stringent. It is impossible to sustain \( \delta_{dLL,RR}^\nu \sim \lambda \) even with \( \tilde{m} \), \( m_\tilde{g} \gtrsim \text{TeV} \). Traditionally one employs quark-squark alignment (QSA) to impose “texture zeros” on quark mass matrices, i.e. \( M_d^{12,21} = 0 \) hence \( D_{L,R}^1 = 0 \) or highly suppressed.

In the 

So doing, however, one notices that \( D_{L}^{12} \simeq 0 \) implies \( U_{L}^{12} \sim |V_{cd}| = \lambda \), which is a general consequence of QSA. Thus, \( \hat{u}_L^c \tilde{c}_L \) mixing \( \delta_{dLL}^{\nu} \sim \lambda \) is sizable, which can generate \( D^0-\bar{D}^0 \) mixing, right in the ballpark of recent tantalizing hints from the CLEO and FOCUS experiments, \( x_D \sim 0.01 \). Note that the zeros in Fig. 2 reflect cancellation when different terms have common phase, and shows that \( x_D \) can be considerably below 0.01. In any case it is exciting that \( D^0 \) mixing at such levels can be further studied at Belle and BaBar.

There is an interesting subtlety for our choice of \( M_d^{31} \neq 0 \) if one wishes to retain \( M_d^{23,32} \): \( M_d^{12,21} \) would once again be generated. Thus, if we choose to keep \( (M_d^2)_{RR}/\tilde{m}^2 \sim \lambda \) then \( M_d^{23} = M_d^{32} = 0 \) need to be imposed on top of \( M_d^{12} = M_d^{13} = 0 \) and the s flavor is decoupled from \( d, b \), hence there will be no new physics effects in \( B_s \) mixing and \( b \to s\gamma \) decays! We seem to find that the stringent \( \Delta m_{K} \) and \( \epsilon_K \) constraints imply 4 texture zeros in \( M_d \). We now turn briefly to the case of decoupling \( d \) flavor with QSA. For a more generic discussion of SUSY flavor impact on \( \sin 2\Phi_{B_d} \), \( B \to \pi\pi \) and \( \rho\gamma \), see the poster talk of C.K. Chan.

I will be brief since this subject is covered by the poster talk of A. Arbrib. The previous \( d-b \) mixing case satisfy \( \Delta m_K, \epsilon_K \) by construction (via alignment), but still have interesting, measurable effects in \( B_d \) and \( D^0 \) mixings, even if SUSY particles are at TeV scale. The reason is the large \( d_{L,R}^L \tilde{b}_R \) and \( \tilde{u}_R^c \tilde{c}_L \) mixings (\( \sim \lambda \)) that arise from Abelian horizontal charges and low energy constraints. Unfortunately, the SUSY scale becomes so high, practically there can be no impact on penguins, hence \( \varepsilon'/\varepsilon \), \( b \to s\gamma \) and \( b \to \ell\nu \) are all unaffected. Though viable, the case is depressing in that squarks and gluino cannot be produced at Tevatron or even the LHC, while there is also no impact on \( B_s \) System!

Changing the mindset, however, one could have interesting phenomena in a rather similar context: \( s-b \) mixing (\( \sim \lambda \))! Decoupling \( d \) flavor now with QSA, one finds,

\[
(M_{d}^{2})_{RR} \sim \tilde{m}^2 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix},
\]

where one has 4 texture zeros analogous to \( d-b \) case, but \( s_R-b_L \) mixing is \( \sim 1 \)! The exciting new feature from the see-saw pattern of Eq. (4) is that, one down type squark, which we call the strange-beauty squark \( \tilde{s}_L \), could be driven light by the large \( s-b \) mixing! This is rather different from the scenarios of light stop or sbottom which are generated by large top Yukawa coupling (with or without large tan \( \beta \)), and represents a third mechanism for having one squark much lighter than the rest, in this case as arising from flavor violation in right-hand sector.

It is truly intriguing that, even for \( m_{\tilde{s}_L} \) and neutralino (dominantly bino) mass \( m_{\tilde{\chi}_1^0} \) as light as 100 GeV, penguins are still little affected, and \( b \to s\gamma \) is quite accommodating even with large \( s_R-b_L \) mixing! But the impact on \( B_s \) mixing and \( \sin 2\Phi_{B_d} \), whether \( \tilde{s}_L \) is light or not, is rather visible, as one can easily see by scaling up from \( B_d \) result for \( d-b \) mixing case. Thus, once again the \( \Delta m_{B_s}/\Delta m_{B_d} \) constraint should be loosened, this time due to \( \Delta m_{B_s} \) being affected. We note that \( D^0 \) mixing remains volatile and interesting because of alignment.
If the \( \bar{s}b_1 \) is in fact light and with \( \bar{\chi}^0_1 \) as LSP, there is a change in signature for collider search. Since \( \bar{s}b_1 \) has roughly equal mixture of \( s \) and \( b \) flavor, one should keep in mind that \( \bar{s}b_1 \to b\bar{\chi}^0_1, s\bar{\chi}^0_1 \) are both present, hence \( b \)-tagging is less efficient. Thus, the direct bound on \( \bar{s}b_1 \) should be weaker than the standard \( b \)-squark.

We find with interest that the signatures of \( \Delta m_{B_s} \), \( \sin 2\Phi \) and \( \bar{\Lambda} \) in mind that \( \sim \) effective at spitting out energetic \( \tilde{\eta} \). A change in signature for collider search. Since \( \tilde{\eta} \) is in fact light and with many modes now with measured rates far less fruitful. We

\[ \tilde{\eta} \to \tilde{\eta} \to \tilde{\eta} \to \tilde{\eta} \]  

2 Rare Baryons: New Pathways?

Charmless rare mesonic modes started to emerge in 1997, with many modes now with measured rates > 10^{-5}. Charmless rare baryonic modes are far less fruitful. We have only the CLEO98 bounds of \( B \to A \), \( A \to \pi \), 0.26, 1.3, 0.7 \times 10^{-5} based on 5.8M \( BB \) 's. The corresponding theory is equally sparse: just a handful of models that were “stimulated” by the old ARGUS false observation of \( B \to \tilde{\eta} X \) in the late 1980’s.

**Where is the best place to search?**

Observation: Smallness of \( B \to \tilde{\eta} B \) likely rooted in the large energy release, aggravated by more complicated composition of baryons (\( q \bar{q} \bar{q} \) vs mesons (\( q \bar{q} \)). In particular, the 4-quark operators that mediate \( b \) decay quite naturally project a \( B \) meson onto a pair of \( q \bar{q} \) quarks in final state. Thus, to find larger charmless baryonic \( B \) decays, one needs 1) reduced energy release and 2) baryonic ingredients in final state.

From these insights, we suggest the natural starting points as: Inclusive \( B \to \eta' + X \) and \( \gamma + X \). Both cases start with large rates, the former \( \sim 6 \times 10^{-4} \) for \( p_{\eta'} > 2.0 \) GeV, while the latter \( \sim 2 \times 10^{-4} \) for \( p_{\gamma} \gtrsim 2.0 \) GeV. Both processes have \( \eta'/\gamma \) carry away large energy, hence reduced energy release is effective in the recoil \( X \) system!

From an inclusive picture of charmed baryon formation, we envision the anomaly mechanism \( 1 \) which is effective at spitting out energetic \( \eta' \) mesons (Fig. 3(a)), followed by \( g^* \to DD \) splitting of gluon into diquark pair. In this way, as can be seen from Fig. 3(b), we have baryonic pair ingredients in final state. We then allow a phase space argument for baryon pair formation (Fig. 4).

Since \( DD \) pairs already appear to left of \( m_g \sim 1.1 \) GeV (dots) in Fig. 4, while \( \Lambda N \) threshold opens up only at 2.05 GeV (left vertical line with arrow), we expect threshold enhancement for \( sgq \to B_s(\gamma) \) around \( m_{X_s} \sim 2.3 \) GeV, which corresponds to the experimental cut on \( K + n\pi \) partial reconstruction. The modes to search for are \( B \to \eta' \Lambda N \) and similar low lying \( \tilde{B}_B \) states, together with relatively fast \( \eta' \). Since reconstruction is easy and background is expected to be low (\( \Lambda N \) threshold at 3.22 GeV), the process may offer important probe into higher mass \( m_{X_s} \) spectrum (the envelope that drops beyond \( m_{X_s} \) beyond 2.5 GeV) that is important for confirming the anomaly mechanism itself.

Further encouragement is obtained by improving \( 13 \) the pole model approach \( 12 \) by making analogy (see Fig. 5) of \( B \to \eta' p \Lambda \) with the recently reported \( B \to D^* \rightarrow p \bar{p} \) mode by CLEO. Assuming factorization, using \( B \to D^* \) form factors and incorporating proton form factor (FF), the vector current part can account for \( \sim \) half the observed rate, with the other half presumably through axial-vector (e.g. \( a_1 \)) channel. Extending to \( B \to \eta' \Lambda p, \gamma \Lambda p \), even \( tN \Lambda N \), we caution that there is no analogy to proton FF, but this may actually imply a larger effect. We therefore suggest \( 12 \) that \( B \to \eta' \Lambda p, \gamma \Lambda p \sim 10^{-5} \Lambda p \) as plausible, and may be the first charmless baryon mode(s) to be observed. One has the extra bonus of self-analyzed spin in \( \Lambda \to p \nu \) decay, which may probe \( B \to \eta' \), \( \gamma \) dynamics via the CP odd and even \( \Delta_{\text{odd}, \text{even}} \), \( \kappa \Lambda \), \( \kappa \Lambda = s \Lambda \times p \Lambda \) and \( \kappa \Lambda = s \Lambda \times p \Lambda \) are both T-odd. New physics may be eventually uncovered by such triple products.

Of course, search for traditional \( B \to B_{s(\gamma)} \) 2-body modes should continue! Unlike \( K \pi > \pi \pi \), we find that \( B^0 \to \Sigma^+ p \rightarrow B^0 \to p \bar{p} \) as the two leading modes.
excess. There may be a hint of $B \to J/\psi D^*$, but there is no indication for $J/\psi D$. The plausibility is enhanced when we find that an IC at 1% level or higher, with distribution as indicated in Fig. 7, can account for the rate of few $\times 10^{-4}$. The search should be straightforward, and verification could be as early as this summer.

We note that the process of Fig. 6(f) may explain the soft spectrum of $\Upsilon(1S) \to J/\psi + X$, where $p_{J/\psi}$ peak at $\sim 1.5$ GeV. It would be amusing if smoking gun evidence for IC emerges at B Factories, rather than for lighter hadrons.

Acknowledgement. I have enjoyed collaborating with Abdes Arhrib, Chia-Hung Chang, Chun-Khiang Chua, Amarjit Soni, Shang-Yuu Tsai and Kwei-Chou Yang, as well as earlier collaborators.

References

5. P. Chang, in proceedings of ICHEP2000; A. Bozek, this proceedings.