Search for TeV Scale Physics in Heavy Flavour Decays

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Abstract. The subject of heavy flavour decays as probes for physics beyond the TeV scale is covered from the experimental perspective. Emphasis is placed on the more traditional Beyond the Standard Model topics that have potential for impact in the short term, with the physics explained. We do unabashedly promote our own phemonenology work.

PACS. 13.20.He Decays of bottom mesons – 12.60.-i Models beyond the standard model

As humans we aspire to reach up to the heavens, to reach beyond the veiling clouds of the v.e.v. scale. The conventional high energy approach, such as the LHC, is like Jack climbing the bean stalk up into the clouds, where impressions are that the Higgs boson is just floating in a lower cloud close by, but then maybe not. However, "Jack" may not have to actually climb the bean stalk: quantum physics allows him to stay on Earth, and let virtual "loops" do the work. It is in this way that flavour physics offers probes of the TeV scale, at reduced costs.

To illustrate the potential impact, let us entertain a hypothetical "What if?" question, by forwarding to the recent past. On July 31, 2000, the BaBar experiment announced at Osaka conference the low value of $\sin 2\beta \sim 0.12$. The Belle value for the equivalent $\sin 2\phi_1$ was slightly higher, but also consistent with zero. Within the same day, a theory paper appeared on the arXiv [**?**], entertaining the implications of the low $\sin 2\beta$ value. A year later, however, both BaBar and Belle claimed the observation of $\sin 2\beta/\phi_1 \sim 1$, which turn out to be consistent with SM expectations. But, *what if it stayed close to zero?* Well, you would have heard more about it: a definite large deviation from SM! Even beforehand, one expected from indirect data that in SM context, $\sin 2\beta/\phi_1$ had to be nonzero.

With $\beta/\phi_1 = -\arg V_{td}$ in SM, it is instructive to recall that B^0–$\bar{B}^0$ mixing was discovered by the ARGUS experiment 20 years ago, which was the first clear indication that m_t is heavy. This illustrates the power of flavour loops as probes into high scales. The non-decoupling of the top quark from the box diagram, $M_{12}^d \propto m_t^2 (V_{tb} V_{td}^*)^2$, illustrates the *Higgs affinity* of heavy SM quarks, i.e. $\lambda_t \sim 1$. At the same time, it is this *Higgs affinity that allows us to probe the CPV β/ϕ_1 phase at the B factories.*

With $b \to d$ transitions seemingly consistent with SM, i.e. no discrepancy in the CKM triangle

$$V_{ud}^* V_{ub} + V_{cd}^* V_{cb} + V_{td}^* V_{tb} = 0, \qquad (1)$$

what about $b \to s$ transitions? This will be our starting point and the main theme.

1 CPV in $b \to s$ with Boxes and Penguins

With $\tau \to \mu$ echoes, CPV in $b \leftrightarrow s$ transitions is the current frontier. We focus on four topics.

1.1 $\Delta\mathcal{S}$

The B factories were built to measure time-dependent CP violation (TCPV) in $B^0 \to J/\psi K_S$ mode. Besides reconstructing the final state which is a CP eigenstate, one needs to *tag* the other B meson flavour (B^0 or $\bar{B}^0$), and measure both the B decay vertices. The BaBar and Belle (illustrated schematically in Fig. **??** detectors are rather similar, differing basically only in the particle identification detector (PID) used for flavour tagging. Both the PEP-II and KEKB accelerators started in 1999. By 2001, KEKB/Belle outran PEP-II/BaBar in luminosity.

With TCPV in $B^0 \to J/\psi K_S$ measured by 2001, attention quickly turned to the $b \to s$ penguin modes, where a virtual gluon is emitted from the virtual top

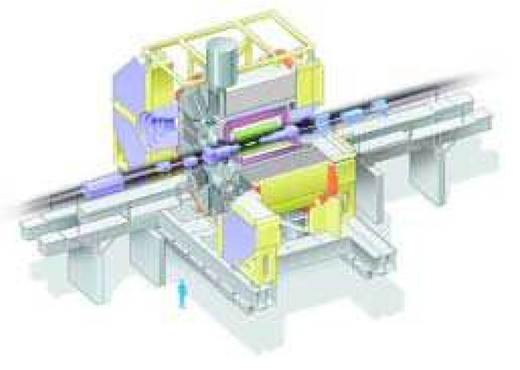

Fig. 1. Schematic picture of Belle detector.

quark in the vertex loop. Take $B^0 \to \phi K_S$ for example, where the virtual gluon pops out an $s\bar{s}$ pair. The $b \to s$ penguin loop amplitude is practically real within SM, just like the tree level $B^0 \to J/\psi K_S$. This is because $V_{us}^* V_{ub}$ is very suppressed. Thus, SM predicts

$$\mathcal{S}_{\phi K_S} \cong \sin 2\phi_1/\beta, \qquad (2)$$

where $\mathcal{S}_{\phi K_S}$ is the analogous measure in the $B^0 \to \phi K_S$ mode. New physics FCNC and CPV, such as SUSY in the loop, could break this equality, prompting the experiments to search vigorously.

Many might remember the big splash made by Belle in 2003, which found $\mathcal{S}_{\phi K_S}$ to be opposite in sign [?] to $\sin 2\phi_1/\beta$, deviating by more than 3σ. The situation softened by 2004 and is now far less dramatic, but it has persisted in a nagging way. Comparing to the average of $\mathcal{S}_{c\bar{c}s} = 0.68 \pm 0.03$ [?] over $b \to c\bar{c}s$ transitions, $\mathcal{S}_f$ is smaller in practically all $b \to s\bar{q}q$ modes measured so far, with the naive mean[1] of $\mathcal{S}_{s\bar{q}q} = 0.56 \pm 0.05$ [?]. The deviation is only 2.1σ, and has been slowly diminishing. We stress, however, that the persistence over several years and in multiple modes make this "$\Delta\mathcal{S}$ problem" a potential indication for New Physics from the B factories, and should be taken seriously.

The point is that theoretical studies, though troubled by hadronic effects, all give $\mathcal{S}_{s\bar{q}q}$ values above $\mathcal{S}_{c\bar{c}s}$. A model-independent approach suggested [?] that, with enough precision, a deviation as little as a couple of degrees would indicate New Physics. Alas, the data can at best double in the remaining B factory era. Lacking good vertices in the leading channels of $\eta' K_S$, ϕK_S and $K_S\pi^0$, the situation may not improve greatly with LHCb. Thus, this problem would need a Super B factory to clarify.

1.2 $\Delta\mathcal{A}_{K\pi}$

There is a second possible indication for BSM in $b \to s\bar{q}q$. It is less widely known, but experimentally firm.

Between BaBar and Belle, direct CPV (DCPV) in the B system was claimed in 2004 [?], just 3 years after the observation of TCPV in B. This attests to the prowess of the B factories, as it took 35 years for the same evolution in the K system. The CDF experiment recently joined the club, with results consistent with the B factories. The current world average [?] is $\mathcal{A}_{\rm CP}(K^+\pi^-) = -9.7 \pm 1.2$ %. This by itself does not suggest New Physics, but rather, it indicates the presence of a finite strong phase between the strong penguin (P) and tree (T) amplitudes, which most QCD based factorization approaches failed to predict.

Even in 2004, however, there was a hint of a puzzle. In contrast to the negative value for $B^0 \to K^+\pi^-$, DCPV in the charged $B^+ \to K^+\pi^0$ mode was found to be consistent with zero for both Belle and BaBar, which has steadily strengthened, to the current [?] $\mathcal{A}_{\rm CP}(K^+\pi^0) = +4.7 \pm 2.6$ %, with some significance for the positive sign. This will further strengthen with an updated value of $\mathcal{A}_{\rm CP}(K^+\pi^0) = +3.0 \pm 3.9 \pm 1.0$ % from BaBar [?]. The deviation between the charged and neutral modes,

$$\Delta\mathcal{A}_{K\pi} \equiv \mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} = 0.144 \pm 0.029, \qquad (3)$$

is now beyond 5σ.

Why is this a puzzle? For B^0 decay mode, one has

$$\mathcal{M}(B^0 \to K^+\pi^-) \propto T + P \equiv r\, e^{i\phi_3} + e^{i\delta}, \qquad (4)$$

where $r \equiv |T/P|$, $\phi_3 = \arg V_{ub}^*$, and δ is the strong phase difference between T and P. It is the interference between the two kinds of phases that gives DCPV, i.e. $\mathcal{A}_{\rm CP}(K^+\pi^-)$. Note that for TCPV, $\delta = \Delta m_B t$, the measurable oscillation phase. This is part of the beauty of TCPV. The $B^+ \to K^+\pi^0$ decay amplitude is similar to the $B^0 \to K^+\pi^-$ one, up to subleading corrections,

$$\sqrt{2}\mathcal{M}_{K^+\pi^0} - \mathcal{M}_{K^+\pi^-} \propto P_{\rm EW} + C, \qquad (5)$$

where $P_{\rm EW}$ is the electroweak penguin (replacing the virtual gluon in P by Z or γ) amplitude, and C is the colour-suppressed tree. In the limit that these subleading terms vanish, one expects $\Delta\mathcal{A}_{K\pi} \sim 0$, which is contrary to the experimental result of Eq. (??).

Could C be greatly enhanced? Indeed, fitting with data, one finds $|C/T| > 1$ is needed [?], in contrast to the very tiny value 10 years ago [?]. Furthermore, as the amplitude C has the same weak phase ϕ_3 as T, the enhancement has to contrive to cancel the effect of the strong phase difference δ between T and P that helped induce $\mathcal{A}_{\rm CP}(K^+\pi^-)$, amounting to a "double somersault". Next order perturbative QCD calculations do move C in the right direction, but insufficient to account for Eq. (??). The SCET approach completely fails in the DCPV sector.

The other option is to have a sizable contribution from the electroweak penguin. The interesting point is that *this calls for a New Physics CPV phase*, as it is

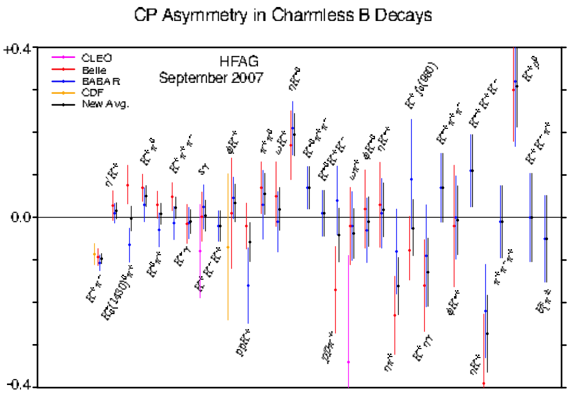

Fig. 2. HFAG plot for DCPV measurements. The difference between $\mathcal{A}_{K^+\pi^0}$ and $\mathcal{A}_{K^+\pi^-}$, including sign, could indicate New Physics.

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[1] We use the EPS2007 result, rather than the LP2007 update that includes the new $\mathcal{S}_{f_0(980)K_S}$ result from BaBar. Though the latter appears to be larger than $\mathcal{S}_{c\bar{c}s}$ and very precise, it needs confirmation from Belle.

known that P_{EW} and T have almost the same weak phase within SM [?]. So what NP can this be? Note that this is not so easy for SUSY, since SUSY effects tend to be of the "decoupling" kind, compared to the *nondecoupling* top effect in the Z penguin loop, which is very analogous to what happens in box diagrams. So, can there be more *nondecoupled* quarks beyond the top in the Z penguin loop? We will look further into this, after we discuss NP prospects in B_s mixing.

With the two hints for NP in $b \to s$ penguin modes, i.e. $\Delta\mathcal{S}$ (TCPV) and $\Delta\mathcal{A}_{K\pi}$ (DCPV), one might expect possible NP in B_s mixing. On the other hand, recent results for Δm_{B_s} and $\Delta\Gamma_{B_s}$ are SM-like. But the real test should be in the CPV measurables $\sin 2\Phi_{B_s}$ and $\cos 2\Phi_{B_s}$, as the NP hints all involve CPV.

1.3 B_s Mixing and $\sin 2\Phi_{B_s}$

The oscillation between B_s^0 and $\bar{B}_s^0$ mesons is too fast for B factories, hence brings us to the hadronic collider detectors, CDF and D0 at the Tevatron. After a slow start of the Run II, the experiments have recently reached 3 fb^{-1} integrated luminosity, and is growing steadily.

The special two-track trigger of CDF allowed it to leapfrog the earlier announcement made by D0 in Winter 2006, and by Summer 2006, based on 1 fb^{-1}, B_s mixing became a precision measurement [?],

$$\Delta m_{B_s} = 17.77 \pm 0.10 \pm 0.07 \ \mathrm{ps}^{-1}. \tag{6}$$

We remark that, if one takes the nominal value for f_{B_s} e.g. from lattice studies, *the result of Eq. (**??**) seems a bit on the small side.* Before the fact, the values from the CKMfitter and UTfit "global fit" groups tended to be larger than 20 ps^{-1}. However, given the hadronic uncertainty in $f_{B_s}^2 B_{B_s}$, this can hardly be taken as a hint for New Physics. One has to turn to CPV.

In SM, $M_{12}^s \propto m_t^2 (V_{tb}V_{ts}^*)^2$, and CPV in B_s mixing is controlled by the phase of V_{ts}. Since $V_{us}^* V_{ub}$ is very tiny, the triangle relation

$$V_{us}^* V_{ub} + V_{cs}^* V_{cb} + V_{ts}^* V_{tb} = 0, \tag{7}$$

collapses to the approximate line of $V_{ts}^* V_{tb} \simeq -V_{cb}$, which is practically real, or $\arg V_{ts} \sim -0.02$ rad. Only the LHCb experiment would have enough sensitivity to probe this. Thus, it is well known that $\sin 2\Phi_{B_s}$, the analogue of $\sin 2\phi_1/\beta$ for B_d, is an excellent window on BSM. In SUSY, this could be squark-gluino loop with $\tilde{s}$-$\tilde{b}$ mixing.

Let us first comment on the approach through width mixing, i.e. $\Delta\Gamma_{B_s}$ and ϕ_{B_s} from $B_s^0 \to J/\psi\phi$. Here, the D0 experiment has made a concerted effort on dimuon charge asymmetry A_{SL}, the untagged single muon charge asymmetry A_{SL}^s, and the lifetime difference in untagged $B_s \to J/\psi\phi$ decay (hence does not involve oscillations). D0 holds the advantage in periodically flipping magnet polarity to reduce the systematic error on A_{SL}. Combining the three studies, they probe the CPV phase $\cos 2\Phi_{B_s}$ via

$$\Delta\Gamma_{B_s} = \Delta\Gamma_{\mathrm{CP}} \cos 2\Phi_{B_s}. \tag{8}$$

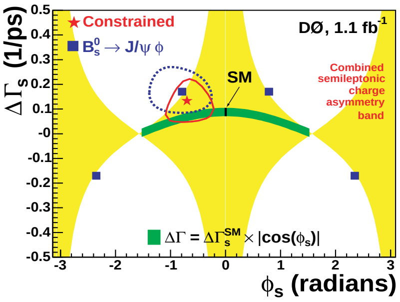

Fig. 3. Combined analysis of A_{SL}, A_{SL}^s and lifetime difference in $B_s \to J/\psi\phi$ by D0 [?].

We give the main result for our interest in Fig. **??**; this "first" $\cos 2\Phi_{B_s}$ value is slightly off, but consistent with, SM expectation, hence certainly allows for NP. Details can be found in Ref. [?]. For a phenomenological digest, see Ref. [?]. Overall, $\cos 2\Phi_{B_s}$ is a somewhat "blunt instrument".

We return to assessing the short term prospects for Φ_{B_s} measurement. $B_s \to J/\psi\phi$ decay is analogous to $B_d \to J/\psi K_s$, except it is a VV final state. Thus, besides measuring the decay vertices, one also needs to perform an angular analysis to separate the CP $+/-$ components. As J/ψ is reconstructed in say the dimuon final state, CDF and D0 should have comparable sensitivity. Assuming 8 fb^{-1} per experiment, the Tevatron could reach (?) the sensitivity of $0.2/\sqrt{2}$. However, the LHC would start running a year from now, in 2008. I will adopt a conservative estimate [?] for the first year running of LHC: 2.5 fb^{-1} for ATLAS and CMS, and 0.5 fb^{-1} for LHCb. Then the projection for ATLAS is $\sigma(\sin 2\Phi_{B_s}) \sim 0.16$, not better than the Tevatron, while for LHCb one has $\sigma(\sin 2\Phi_{B_s}) \sim 0.04$, which starts to probe the SM expectation of $\sigma(\sin 2\Phi_{B_s}) = -0.04$.

The forward design of LHCb detector (see Fig. **??**) is for B physics, allowing more space for devices such as RICH for PID. If SM again holds sway, it would clearly be the winner. We wish to stress, however, that *2009 looks rather interesting* — Tevatron could get really lucky: it could glimpse the value of $\sin 2\Phi_{B_s}$ only if it is large; but *if* $\sin 2\Phi_{B_s}$ *is large, it would definitely indicate New Physics.* Thus, the Tevatron could preempt LHCb and carry away the glory. Maybe the

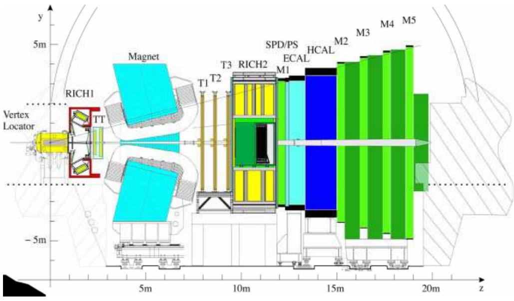

Fig. 4. The LHCb detector.

Table 1. Rough sensitivity to $\sin 2\Phi_{B_s}$ ca. 2009.

	CDF/DØ	ATLAS/CMS	LHCb
$\sigma(\sin 2\Phi_{B_s})$	0.2/expt	0.16/expt	0.04
$\int \mathcal{L}dt$	(8 fb^{-1})	(2.5 fb^{-1})	(0.5 fb^{-1})

Tevatron should even run beyond 2008? The question is then,

— **Can $|\sin 2\Phi_{B_s}| > 0.5$?** —

One can of course resort to squark-gluino box diagrams. Note, however, that squark-gluino loops, while possiblly generating $\Delta\mathcal{S}$, cannot really move $\Delta\mathcal{A}_{K\pi}$ because their effects are decoupled in $P_{\rm EW}$. If one cares about contact with both hints for NP in $b \to s$ transitions from the B factories, then one should pay attention to some common nature between $b \to s$ electroweak penguin and the B_s mixing box diagram. If there are new *nondecoupled* quarks in the loop, then both $\Delta\mathcal{A}_{K\pi}$ and $\Delta\mathcal{S}$ could be touched. Such nondecoupled quarks are traditionally called the 4th generation. The t' quark in the loop adds a term $V_{ts}^* V_{tb} \equiv r_{sb}\, e^{i\phi_{sb}}$ to Eq. (**??**), bringing in the additional NP CPV phase $\arg(V_{t's}^* V_{t'b}) \equiv \phi_{sb}$ with *Higgs affinity* $\lambda_{t'} > \lambda_t \simeq 1$.

It was shown [**?**] that the 4th generation could affect $\Delta\mathcal{A}_{K\pi}$ in the right way, and $\Delta\mathcal{S}$ [**?**] then moves in the right direction. This was done in the PQCD approach at NLO, which is state of the art. PQCD is the only QCD-based factorization approach that predicted both the strength and sign of $\mathcal{A}_{\rm CP}(B^0 \to K^+\pi^-)$, and at NLO, saw the improvement of $\Delta\mathcal{A}_{K\pi}$ by enhancement of C. It is nontrivial, then, that incorporating the nondecoupled 4th generation t' quark to account for $\Delta\mathcal{A}_{K\pi}$, brings $\Delta\mathcal{S}$ in the right direction.

The exciting implication is the impact on $\sin 2\Phi_{B_s}$. As the difference of $\Delta\mathcal{A}_{K\pi}$ in Eq. (**??**) is large, both the strength and phase of $V_{t's}^* V_{t'b}$ is sizable [**?**], with the phase near maximal. Interestingly, a near maximal phase for t' allows minimal impact on Δm_{B_s}, as it adds only in quadrature to the real contribution from top, but exerts the maximal impact on $\sin 2\Phi_{B_s}$. The predicted value is [**?**]

$$\sin 2\Phi_{B_s} = -0.5 \text{ to } -0.7, \quad \text{(4th generation)} \tag{9}$$

where even the sign is predicted. We note that the range can be demonstrated by using the (stringent) Δm_{B_s} vs (less stringent) $\mathcal{B}(B \to X_s \ell^+\ell^-)$ constraints alone, with $\Delta\mathcal{A}_{K\pi}$ selecting the minus sign in Eq. (**??**).

We stress that Eq. (**??**) can be probed even before LHCb gets first data, and should help motivate the Tevatron experiments. *It's not over until it's over.*

1.4 $\mathcal{A}_{\rm CP}(B^+ \to J/\psi K^+)$

Suppose there is New Physics in the $B^+ \to K^+\pi^0$ electroweak penguin. Rather than turning into a π^0, the Z^* from the effective bsZ^* vertex could turn into a J/ψ as well. One can then contemplate DCPV in $B^+ \to J/\psi K^+$ as a probe of NP.

$B^+ \to J/\psi K^+$ decay is of course dominated by the colour-suppressed $b \to c\bar{c}s$ amplitude, which is proportional to $V_{cs}^* V_{cb}$ and is practically real. At the loop level, the penguin amplitudes are proportional to $V_{ts}^* V_{tb}$. Because $V_{us}^* V_{ub}$ is very suppressed, from Eq. (**??**) one has $V_{ts}^* V_{tb} \cong -V_{cs}^* V_{cb}$. It is not only practically real, but has the same phase as the tree amplitude, hence it is commonly argued that DCPV is less than 10^{-3} in this mode. However, because of possible hadronic effects, there is no firm prediction that can stand scrutiny. We shall argue that, in the 4th generation scenario, DCPV in $B^+ \to J/\psi K^+$ decay could be at % level.

Experiment so far is consistent with zero, but has a somewhat checkered history. Belle has not updated from their 2003 study based on 32M $B\bar{B}$ pairs, although they now have almost 20× the data. BaBar's study flipped sign from the 2004 study based on 89M, to the 2005 study based on 124M, which seemed dubious at best. However, the sign was flipped back in PDG 2007, because it was found that the 2005 paper simply used the opposite convention to the (standard) one used for 2004. The opposite sign between Belle and BaBar suppresses the central value, but the error is at 2% level. This rules out, for example, the suggestion [**?**] of enhanced H^+ effect at 10% level.

One impediment to higher statistics B factory studies is the systematic error, where it seems difficult to break the 1% barrier. Recent progress has been made, however, by DØ. Using 1.6 fb^{-1}, DØ measures [**?**]

$$\mathcal{A}_{B^+\to J/\psi K^+} = 0.67 \pm 0.74 \pm 0.26\ \%, \quad \text{(DØ)} \tag{10}$$

where there is a large correction for the $K^\pm$ asymmetry of the detector due to matter effect. Of special note is the small (below 0.5% level!) systematic error. This is because one has a larger control sample than at B factories, e.g. in D^* tagged $D^0 \to K^-\pi^+$ decays. Thus, even scaling up to 8 fb^{-1}, one is still statistics limited, and one would have 2σ sensitivity with % level asymmetries. CDF should have similar sensitivity, and the situation can drastically improve with LHCb.

The Tevatron study was in fact inspired by a 4th generation study [**?**] following the lines of the previous sections. The 4th generation parameters are taken from the $\Delta\mathcal{A}_{K\pi}$ study. By analogy with what is observed in $B \to D\pi$ modes, as well as between different helicity components in $B \to J/\psi K^*$ decay, the dominant C amplitude for $B^+ \to J/\psi K^+$ would likely have a strong phase of order 30°. The $P_{\rm EW}$ amplitude is assumed to factorize and hence does not pick up a strong phase. Heuristically this is because the Z^* produces a small, colour singlet $c\bar{c}$ that projects into J/ψ. With a strong phase in C and a weak phase in $P_{\rm EW}$, one then finds $\mathcal{A}_{B^+\to J/\psi K^+} \simeq \pm 1\%$, with negative sign ruled out by Eq. (**??**). Of course, DCPV is directly proportional to the strong phase difference, which is not well predicted. However, if % level asymmetry is observed in the next few years, it would support the scenario of New Physics in $b \to s$ transitions, while stimulating theoretical efforts to compute the strong phase difference between C and $P_{\rm EW}$.

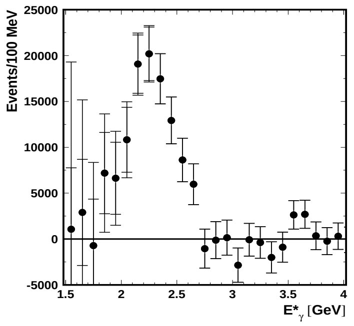

Fig. 5. The E_γ spectrum above 1.8 GeV in $\Upsilon(4S)$ frame for inclusive $b \to s\gamma$ (Belle [?] 152M $B\bar{B}$ pairs).

2 H^+ Probes

2.1 $b \to s\gamma$

The inclusive $b \to s\gamma$ decay, identified with $B \to X_s\gamma$ experimentally, where X_s are reconstructed as $K + n\pi$, is one of the most important probes of NP. There had been good agreement for the past few years between NLO theory and the experimental average of

$$\mathcal{B}_{B\to X_s\gamma} = (3.55 \pm 0.26) \times 10^{-4} \text{ (HFAG 06)}. \quad (11)$$

Recently, however, the NNLO theory prediction has shifted lower [?,?] to $\sim 3 \times 10^{-4}$, with errors comparable to experiment. Although the NNLO work is not yet complete, the ball appears to be in the experiments' court.

The photon energy cut, where the latest Belle study sets at $E_\gamma > 1.8$ GeV [?] (see Fig. ??) and done for 152M $B\bar{B}$ pairs, should be lowered further. But, to confront the theoretical advancement, a fresher approach is needed. For example, the $X_s \equiv K + n\pi$ "partial reconstruction" technique is over a decade old. A promising new development, as the B factories increase in data, is the full reconstruction of the tag side B meson. The signal side is then just an energetic photon, without specifying the X_s system. First attempts have recently been performed by BaBar, but since full reconstruction takes a 10^{-3} hit in efficiency, it seems that the NNLO theory development would demand a Super B factory upgrade to continue the supreme dialogue between theory vs. experiment in this mode.

This close dialogue allowed $b \to s\gamma$ to provide one of the most stringent bounds on NP models. It is sensitive to all types of possible NP in the loop, such as stop-charginos. However, $b \to s\gamma$ is best known for its stringent constraint on the MSSM (minimal SUSY SM) type of H^+. MSSM demands at least two Higgs doublets (2HDM), where one Higgs couples to right-handed down type quarks, the other to up type. The physical H^+ is a cousin of the ϕ_{W^+} Goldstone boson of the SM that gets eaten by the W^+. It is the ϕ_W that couples to masses, and at the root of the nondecoupling phenomenon of the heavy top quark in the loop. In $bs\gamma$ coupling, however, the top is effectively decoupled, by a subtlety of gauge invariance. This underlies the reason why QCD corrections make such large impact in this loop-induced decay. It also makes the process sensitive to NP such as H^+.

Replacing the W^+ by H^+ in the loop, in the MSSM type of 2HDM, the H^+ effect *always enhances* $b \to s\gamma$ *rate, regardless of* $\tan\beta$, as pointed out 20 years ago [?,?], where $\tan\beta$ is the ratio of v.e.v.s between the two doublets. Basically, the H^+ couples to $m_t \cot\beta$ at one end of the loop, and to $-m_b \tan\beta$ on the other end, so this contribution is independent of $\tan\beta$, and the sign is fixed to be always constructive with the SM amplitude. With NNLO result lower than experiment, one has the bound [?]

$$m_{H^+} > 295 \text{ GeV } (90\%\text{C.L.}), \quad (12)$$

if one takes the low range of NNLO result and compare with the higher range of Eq. (??). A nominal $\tan\beta = 2$ is taken. If one takes the central value of both results seriously, one could say [?] that an H^+ boson with mass around 695 GeV is needed to bring the NNLO rate up to Eq. (??). Again, this is because the H^+ effect in the MSSM type of 2HDM is always constructive [?] with ϕ_W effect in SM. We note that the behavior for the other 2HDM that is not the MSSM type, the H^+ effect is different [?].

The ongoing saga should be watched.

2.2 $B \to (D^{(*)})\tau\nu$

As a cousin of the ϕ_{W^+}, the H^+ boson has an amazing tree level effect that has only recently come to fore by the prowess of the B factories.

Like $\pi^+ \to \ell^+\nu_\ell$ decay, one has the formula for $B^+ \to \tau^+\nu_\tau$ decay,

$$\mathcal{B}_{B\to\tau\nu} = r_H \frac{G_F^2 m_B m_\tau^2}{8\pi}\left[1 - \frac{m_\tau^2}{m_B^2}\right]\tau_B f_B^2 |V_{ub}|^2, \quad (13)$$

where $r_H = 1$ for SM, but [?]

$$r_H = \left[1 - \frac{m_{B^+}^2}{m_{H^+}^2}\tan^2\beta\right]^2, \quad (14)$$

for 2HDM. Within SM, the pure gauge W^+ effect is helicity suppressed, hence the effect vanishes with the m_τ mass. For H^+, there is no helicity suppression, but one has the "Higgs affinity" factor, i.e. mass dependent couplings. With m_u negligible, the H^+ couples as $m_\tau m_b \tan^2\beta$. This leads to the r_H factor of Eq. (??), where the sign between the SM and H^+ contribution is always destructive [?].

$B^+ \to \tau^+\nu$ followed by τ^+ decay results in at least two neutrinos, which makes backgrounds very hard to suppress in the $B\bar{B}$ production environment. Thus, for a long time, the limit on $B^+ \to \tau^+\nu$ was rather poor. This had allowed for the possibility that H^+ effect could be the dominant one over SM, given that the SM expectation was only at 10^{-4} level. The change came with the enormous number of B mesons accumulated by the B factories, allowing the aforementioned full reconstruction method to become useful.

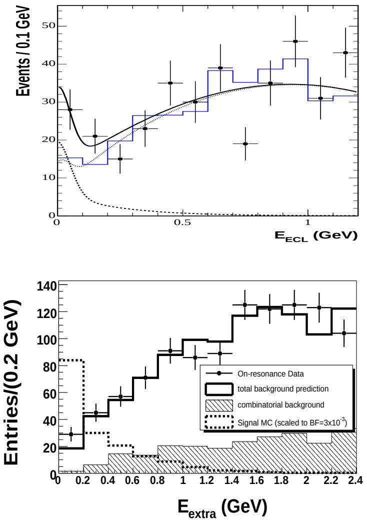

Fig. 6. Data showing evidence for $B \to \tau\nu$ (hadronic tag) search by Belle [**?**] and BaBar [**?**].

Fully reconstructing the tag side B meson in, e.g. $B^- \to D^0\pi^-$ decay, one has an efficiency of only 0.1%–0.3%. At this cost, however, one effectively has a "B beam". As shown in Fig. **??**, using full reconstruction in hadronic modes and with a data consisting of 449M $B\bar{B}$ pairs, Belle found $17.2^{+5.3}_{-4.7}$ events, where the τ decay was searched for in decays to $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$ and $\rho\nu$ modes. This constituted the first evidence (at 3.5σ) for $B^+ \to \tau^+\nu$, with [**?**]

$$\mathcal{B}_{B\to\tau\nu} = 1.79^{+0.56+0.46}_{-0.49-0.51} \times 10^{-4} \text{ (Belle 449M)}. \quad (15)$$

With 320M $B\bar{B}$s and $D\ell\nu$ reconstruction on tag side, however, BaBar saw no clear signal, giving $(0.88^{+0.68}_{-0.67} \pm 0.11) \times 10^{-4}$. Updating more recently to 383M, BaBar finds with $D\ell\nu$ tag the result $(0.9 \pm 0.6 \pm 0.1) \times 10^{-4}$, which is consistent with 320M result. However, with hadronic tag, BaBar now also reports some evidence, at $(1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2) \times 10^{-4}$ (Fig. **??**). The combined result for BaBar is [**?**],

$$\mathcal{B}_{B\to\tau\nu} = (1.2 \pm 0.4_{\rm stat} \pm 0.3_{\rm bkg} \pm 0.2_{\rm eff}) \times 10^{-4} \qquad \text{(BaBar 383M)}, \quad (16)$$

which has 2.6σ significance ("bkg" stands for background and "eff" stands for efficiency), and is more or less consistent with the Belle result.

Taking central values from lattice for f_B, and $|V_{ub}|$ from semileptonic decays, the nominal SM expectation is $(1.6 \pm 0.4) \times 10^{-4}$. Thus, Belle and BaBar have reached SM sensitivity, and Eqs. (**??**) and (**??**) now place a constraint on the $\tan\beta$-m_{H^+} plane through $r_H \simeq 1$. If one has a Super B factory, together with development of lattice QCD, this can become a superb probe of the H^+, complementary to direct H^+ searches at the LHC.

An analogous mode with larger branching ratio, $B \to D^{(*)}\tau\nu$, has recently emerged. Belle announced the observation of [**?**]

$$\mathcal{B}_{D^{*-}\tau\nu} = 2.02^{+0.40}_{-0.37} \pm 0.37\ \% \quad \text{(Belle 535M)}, \quad (17)$$

based on 60^{+12}_{-11} reconstructed signal events, which is a 5.2σ effect. Subsequently, based on 232M, BaBar announced the observation (over 6σ) of $D^{*0}\tau\nu$, and evidence (over 3σ) for $D^+\tau\nu$ [**?**]

$$\begin{aligned} \mathcal{B}_{D^*\tau\nu} &= 1.81 \pm 0.33 \pm 0.11 \pm 0.06\ \% \\ \mathcal{B}_{D\tau\nu} &= 0.90 \pm 0.26 \pm 0.11 \pm 0.06\ \% \qquad (18) \\ &\qquad \text{(BaBar 232M)}, \end{aligned}$$

where the last error is from normalization.

The SM branching ratios, at 1.4% for $B \to D^*\tau\nu$, are poorly estimated. Furthermore, though the H^+ could hardly affect the $B \to D^*\tau\nu$ rate, it could leave its mark on the D^* polarization. The $B \to D\tau\nu$ rate, like $B \to \tau\nu$ itself, is more directly sensitive to H^+ [**?**]. More theoretical work, as well as polarization information, would be needed for BSM (in particular, H^+ effect) interpretation. But it is rather curious that, almost 25 years after the first B meson was reconstructed, we have a newly measured mode with $\sim 2\%$ branching faction!

3 Electroweak Penguin: Z-loop, Z', DM

3.1 $\mathcal{A}_{\rm FB}(B \to K^*\ell\ell)$

The $B \to K^*\ell^+\ell^-$ process ($b \to s\ell^+\ell^-$ inclusively) arises from photonic penguin, Z penguin and box diagrams. The top quark exhibits nondecoupling in the latter diagrams, analogous to the box diagrams for M^0-$\bar{M}^0$ mixing. It turns out that the Z penguin dominates the $b \to s\ell^+\ell^-$ decay amplitude [**?**]. Interference between the vector (γ and Z) and axial vector (Z only) contributions to $\ell^+\ell^-$ production gives rise to an interesting forward-backward asymmetry [**?**]. This is akin to the familiar $\mathcal{A}_{\rm FB}$ in $e^+e^- \to f\bar{f}$, except the enhancement of bsZ penguin brings the Z much closer to the γ in B decay, and one probes potential New Physics in the loops.

Both inclusive $B \to X_s\ell^+\ell^-$ and exclusive $B \to K^{(*)}\ell^+\ell^-$ decays have now been measured [**?**], and interest has turned to $\mathcal{A}_{\rm FB}$ for $B \to K^*\ell^+\ell^-$,

$$\mathcal{A}_{\rm FB}(q^2) = -C_{10}\xi(q^2)\left[{\rm Re}(C_9)F_1 + \frac{1}{q^2}C_7F_2\right], \quad (19)$$

where C_i are Wilson coefficients, and formulas for $\xi(q^2)$ and the form factor related functions F_1 and F_2 can be found in Ref. [**?**]. The study by Belle with 386M $B\bar{B}$ pairs [**?**] is consistent with SM, and rules out the possibility of flipping the sign of C_9 or C_{10} separately from SM value, but having both C_9 or C_{10} flipped in sign is not ruled out. BaBar took the more conservative approach of giving $\mathcal{A}_{\rm FB}$ in just two q^2 bins, below and above $m^2_{J/\psi}$. With 229M, the higher q^2 bin is consistent [**?**] with SM and disfavors BSM scenarios. Interestingly, in the lower q^2 bin, while sign-flipped BSM's

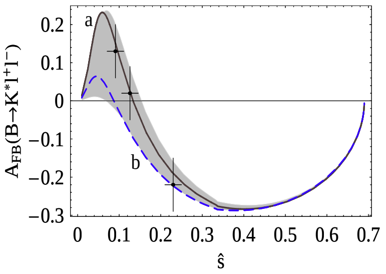

Fig. 7. Possible $\mathcal{A}_{\rm FB}$ in $B \to K^*\ell^+\ell^-$ allowed by complex Wilson coefficients, Eq. (**??**). The three data points are taken from 2 fb^{-1} LHCb Monte Carlo for illustration.

are less favored, the measurement is $\sim 2\sigma$ away from SM. Unfortunately, statistics are poor, which cannot be much improved without a Super B factory. But this is a domain where LHCb can do very well.

In the context of LHCb prospects, it was recently noticed [**?**] that, in Eq. (**??**), there is no reason *a priori* to keep the Wilson coefficients real when probing BSM physics! Note that Re(C_9) in Eq. (**??**) differs from C_9 within SM by just a small correction arising from long distance $c\bar{c}$ effects. But if one keeps an open mind (rather than, for example, taking the oftentimes tacitly assumed Minimal Flavour Conservation mindset), Eq. (**??**) should be replaced by

$$\mathrm{Re}\left(C_9^{\rm eff}C_{10}^*\right)\mathcal{F}_1 + \frac{1}{q^2}\mathrm{Re}\left(C_7^{\rm eff}C_{10}^*\right)\mathcal{F}_2, \qquad (20)$$

where $\mathcal{F}_i$ are form factor combinations. Eq. (**??**) can exhibit a richer interference pattern than Eq. (**??**).

We illustrate [**?**] in Fig. **??** the situation where New Physics enters through effective bsZ and $bs\gamma$ couplings. In this case, C_9 and C_{10} cannot differ by much at short distance, which gives rise to the "degenerate tail" for larger $\hat{s} \equiv q^2/m_B^2$. But allowing the Wilson coefficients to be only constrained by measured radiative and electroweak penguin rates, $\mathcal{A}_{\rm FB}$ could vary in the shaded region, basically for $q^2 < m_{J/\psi}^2$, and not just in the position of the zero. The fourth generation with parameters as determined from Δm_{B_s}, $\mathcal{B}(B \to X_s\ell^+\ell^-)$ and $\Delta\mathcal{A}_{K\pi}$ belongs to this class of BSM models, and is plotted as the dashed line. We take the MC study for 2 fb^{-1} data at LHCb (achievable in a couple years of running) and plot three sample data points to illustrate expected data quality.

It is clear that the LHCb has good discovery potential using $\mathcal{A}_{\rm FB}$ to probe complexity of short distance Wilson coefficients without measuring CPV. If there are New Physics that affects the $bs\ell\ell$ as a 4-quark operator, for example in Z' models with FCNC couplings, the allowed range for $\mathcal{A}_{\rm FB}$ is practically unlimited. If such large effects are uncovered, one would expect sizable CPV in $b \to s\gamma$ [**?**].

3.2 $B \to K^*\nu\nu$

The $B \to K^*\nu\nu$ (and $b \to s\nu\nu$) is attractive from the theory point of view that it can arise only from short distance physics, such as Z penguin and box diagram contributions [**?**]. The photonic penguin does not contribute. In turn, these processes allow us to probe, in principle, what happens in the loop. Interestingly, since the neutrinos go undetected, the process also allows us to probe light dark matter (DM), which is complementary to the DAMA/CDMS type of direct search. For instance, DM pairs could arise from exotic Higgs couplings to the $b \to s$ loop. BaBar has pioneered $B \to K^*\nu\nu$ search. More recently Belle has searched in many modes with a large dataset of 535M $B\bar{B}$ pairs [**?**], using the aforementioned method of fully reconstructing the other B. No signal is found, and the most stringent limit is 1.4×10^{-5} in $B^+ \to K^+\nu\nu$. While this is still a factor of 3 above SM expectation, it strengthens a bound on light DM production in $b \to s$ transitions [**?**].

To measure the theoretically clean $B \to K^*\nu\nu$ modes, one again requires a Super B factory, and there is no resort to LHCb.

We remark, in this context, that Belle has made a special data run on the $\varUpsilon(3S)$ to pursue DM search via $\varUpsilon(3S) \to \pi^+\pi^-\varUpsilon(1S)$ followed by $\varUpsilon(1S) \to$ *nothing*, with $\pi^+\pi^-$ and $\varUpsilon(3S)$ kinematics as tag. No signal is found, and only a limit is set [**?**].

4 RH Currents and Scalar Interactions

4.1 TCPV in $B \to X_0\gamma$

It is clear that the SM, with large QCD enhancement, dominates the $b \to s\gamma$ rate. The left-handedness of the weak interaction dictates that the γ emitted in $\bar{B}^0 \to \bar{K}^{*0}\gamma$ decay has left-handed helicity (defined somewhat loosely), with the emission of right-handed photons suppressed by $\sim m_s/m_b$. This reflects the need for a mass insertion for helicity flip, and the fact that a power of m_b is needed for the $b \to s\gamma$ vertex by gauge invariance (or current conservation). For $B^0 \to K^{*0}\gamma$ decay that involves $\bar{b} \to \bar{s}\gamma$, the opposite is true, and the emitted photon is dominantly of RH kind.

An interesting insight can then be made. Mixing-dependent CPV, i.e. TCPV, involves the interference of $\bar{B}^0 \to \bar{K}^{*0}\gamma$ direct decay with $\bar{B}^0 \overset{\rm mix}{\Longrightarrow} B^0 \to K^{*0}\gamma$ decay. The former process produces γ_L while the latter γ_R, which are orthogonal hence cannot interfere! The interference is suppressed by $m_s/m_b \sim$ few % within SM. However, if there are RH interactions that induce $b \to s\gamma$ transitions, then $\bar{B}^0 \to \bar{K}^{*0}\gamma$ would also have a γ_R component to interfere with the $\bar{B}^0 \Rightarrow B^0 \to K^{*0}\gamma$ amplitude. Thus, TCPV in $B^0 \to K^{*0}\gamma$ decay mode probes [**?**] RH interactions!

Alas, Nature plays a trick on us: $K^{*0}\gamma$ has to be in a *CP* eigenstate. This means that one needs $K^{*0} \to K_S^0\pi^0$, and the final state is $K_S^0\pi^0\gamma$. The K_S typically decays at the edge of the silicon detector, and one has poor vertex information. Fortunately, BaBar demonstrated [**?**] that "K_S vertexing", though degraded, was still possible.

The current status of TCPV in $B^0 \to K^{*0}\gamma$ decay, combining the 535M $B\bar{B}$ pair result from Belle [?], and the 232M result from BaBar [?], gives the average of $\mathcal{S}_{K_S\pi^0\gamma} = -0.28 \pm 0.26$, which is consistent with zero. A recent BaBar update with 431M gives [?] $\mathcal{S}_{K_S\pi^0\gamma} = -0.08 \pm 0.31 \pm 0.05$. Measurements have also been made in $K_s\pi^0\gamma$ mode without requiring $K_s\pi^0$ reconstruct to a K^*.

Again, a Super B factory is needed to probe further, but this is a very interesting direction to explore. Other ideas to probe RH currents in $b \to s\gamma$ are $\gamma \to e^+e^-$ conversion, Λ polarization in $\Lambda_b \to \Lambda\gamma$ decay, and angular F_L and A_T measurables in $B \to K^*\ell^+\ell^-$.

4.2 $B_s \to \mu\mu$

$B_s \to \mu^+\mu^-$ decay has been a favorite mode to probe Higgs sector effects in MSSM, because of possible large $\tan\beta$ enhancement.

The process proceeds in SM just like $b \to s\ell^+\ell^-$, except $\bar{s}$ is the spectator quark that annihilates the b quark. Since B_s is a pseudoscalar, the photonic penguin does not contribute, and one is sensitive to scalar operators. The SM expectation is only at the 3.5×10^{-9} level, because of helicity suppression. In MSSM, a t-W-H^+ loop can emit neutral Higgs bosons that turn into muon pairs, giving rise to an amplitude $\propto \tan^6\beta$ [?], which could greatly enhance the rate even with modest pseudoscalar mass m_A. Together with the ease for trigger and the enormous number of B mesons produced, this is the subject vigorously pursued at hadron facilities, where there is enormous range for search.

With Run-II data taking shape, the Tevatron experiments have improved the limits on this mode considerably. The recent 2 fb^{-1} limits from CDF and D0 are $< 5.8 \times 10^{-8}$ [?] and 9.3×10^{-8} [?] respectively, combining to give $\mathcal{B}(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-8}$. This is still an order of magnitude away from SM.

The expected reach for the Tevatron is 2×10^{-8}. Further improvement would have to come from LHCb. LHCb claims that, with just 0.05 fb^{-1}, it would overtake the Tevatron, attain 3σ evidence for SM signal with 2 fb^{-1}, and 5σ observation with 10 fb^{-1}. To follow our modest 0.5 fb^{-1} expectation for the first year of LHCb data taking, we expect LHCb to exclude branching ratio values down to SM expectation.

Clearly, much progress will come with the turning on of LHC, where direct search for Higgs particles and charginos would also be vigorously pursued.

5 D/K: Box and EWP Redux

We touch upon D and K mesons only very briefly.

5.1 D^0 Mixing

D^0-$\bar{D}^0$ mixing is the only neutral meson mixing yet to be observed. In 2007, it was claimed. This is quite some feat of experiment.

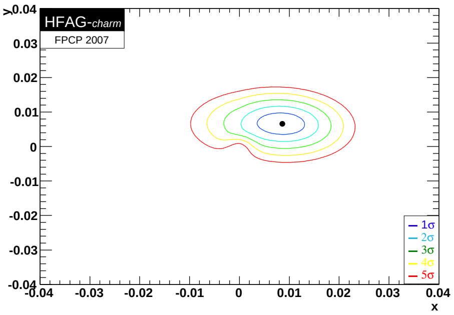

Fig. 8. HFAG plot of combined fit to D^0 mixing data, with Eq. (**??**) as best fit result, together with $\delta_D = 0.33^{+0.26}_{-0.29}$.

Box diagrams, much like K^0, B_d^0 and B_s^0 meson system, govern short distance contributions to D^0 mixing. Unfortunately, the d and s quark masses are small compared to m_b (which is also tiny compared to m_t), hence only b quark contributes in the box at short distance. But $V_{ub}V_{cb}^*$ is extremely small compared to the leading $V_{ud}V_{cd}^* \simeq -V_{us}V_{cs}^* \cong -0.22$ in the CKM triangle relation $V_{ud}V_{cd}^* + V_{us}V_{cs}^* + V_{ub}V_{cb}^*$. Thus, the short distance contribution to D^0 mixing is very small, making it susceptible to long distance contributions. It has been argued that the latter can generate a percent level *width difference*, $y_D = \Delta\Gamma_D/2\Gamma_D$. In turn, a $\Delta\Gamma_D$ at the percent level can generate [?], via dispersion, a comparable width mixing $x_D = \Delta m_D/\Gamma_D$. Unfortunately, so far this seems to be what is observed.

Belle has analyzed 540 fb^{-1} data in $D^0 \to K^+K^-$, $\pi^+\pi^-$ (CP eigenstates) to extract y_{CP}, and a Dalitz analysis of $D^0 \to K_S\pi^+\pi^-$ to extract x_D and y_D. Both Belle and BaBar have analyzed $D^0 \to K^\mp\pi^\pm$ (Cabibbo allowed vs suppressed), with 384 fb^{-1} and 400 fb^{-1} data respectively, to extract $x_D'^2$ and y_D', where x_D' and y_D' is a rotation from x_D and y_D by a strong phase δ_D between the Cabibbo allowed and suppressed $D^0 \to K^\mp\pi^\pm$ decays. The analyses are too complicated to report here. Suffice it to say that currently $(x_d,\ y_D) = (0,\ 0)$ is excluded at the 5σ level (see Fig. **??**), and D^0 mixing is now observed. The current best fit, assuming CP invariance, gives,

$$x_D = 0.87^{+0.30}_{-0.34}\,\%,\ y_D = 0.66^{+0.21}_{-0.20}\,\%, \qquad (21)$$

with $\delta_D = 0.33^{+0.26}_{-0.29}$. While y_D is more solid, a finite % level x_D is indicated. Although the observed strength could arise from long distance effects, one recalls the Δm_K enterprise 20-30 years ago: comparable BSM, at twice the observed x_D, is always allowed.

For the future, there are several things to watch. It is interesting that the Dalitz analysis of Belle [?] sees, for the first time, an indication for x_D. Second, by a tagged Dalitz analysis in $\psi(3770) \to D^0\bar{D}^0$, one can extract the phase δ_D, which would in turn feedback on x and y extraction. Here, CLEO-c and BES-II can contribute. These are the things to watch. Ultimately, one would need to measure CPV, expected to be tiny within SM (with or without long distance dominance), to find unequivocal evidence for BSM.

This is an area where a Super B factory can compete well with LHCb.

5.2 Rare K

This field saw its last hurrah in ε'/ε. Unfortunately, the interpretation of ε'/ε is almost completely clouded by long-distance effects.

With the cancellations of CKM and KOPIO, the kaon program in the US has withered, despite a long standing hint of 3 events for $K^+ \to \pi^+\nu\nu$ at BNL by E787/949. At CERN, one now has the P236 proposal to use the SPS, aiming at reaching $\mathcal{O}(100)$ events with the SM branching ratio of $\sim 10^{-10}$. In Japan, one has the on-going E391A experiment at KEK. The expected reach for $K_L \to \pi^0\nu\nu$ is 10^{-9}, not sufficient to probe the SM expectation of 10^{-11}, although there is New Physics potential. But E391A should be viewed as the pilot study for the more ambitious E14 proposal to the J-PARC facility, which aims at eventually reaching below 10^{-12} sensitivity to probe BSM. These are clean modes theoretically, so the challenge is for experiment.

6 τ: LFV and $(B-L)$V

Before concluding, we touch upon exciting developments in rare tau decays: radiative decays which have $b \to s$ echoes, and the enigmatic (if found) baryon number violating decays.

6.1 $\tau \to \ell\gamma$, $\ell\ell\ell'$

The $\tau \to \ell\gamma$ processes are extremely suppressed in SM by the very light neutrino mass. This opens up the opportunity to probe BSM, just like the venerable $\mu \to e\gamma$ (where there is the fabulous MEG experiment at PSI). Observation of lepton flavor violating (LFV) decays would definitely mean New Physics! Again, the favorite is SUSY, ranging from sneutrino-chargino loops, exotic Higgs, R-parity violation, ν_R in SO(10), or large extra dimensions (LED). Predictions for $\tau \to \mu\gamma$, $\ell\ell\ell$, $\ell\ell\ell'$, ℓM^0 (where M^0 is a neutral meson) could reach the 10^{-7} level. The models are often well motivated from observed near maximal ν_μ-ν_τ mixing, or interesting ideas such as baryogenesis through leptogenesis. The great progress in neutrino physics of the past decade has stimulated a lot of interest in these LFV decays.

Experimentally, the stars are again the B factories: B factories are also τ (and charm) factories, with $\sigma_{\tau\tau} \sim 0.9\,\mathrm{nb}$ which is comparable to $\sigma_{bb} \sim 1.1\,\mathrm{nb}$. With steady increase in data, the B factories have pushed the limits from 10^{-6} of the CLEO era, reaching down to 10^{-8}level. For example, with the 535 fb^{-1} analysis by Belle [?] the limits on $\tau \to \ell\ell\ell'$ modes such as $\mu^+e^-e^-$ and $e^+\mu^-\mu^-$ have reached 2×10^{-8}, with BaBar not far behind [?]. Thus, some models or the parameter space are now ruled out.

To probe deeper into the parameter space of various LFV rare τ decays, a Super B factory would be very helpful. In the near future, LHCb can compete in the all charged track modes.

6.2 $\tau \to \Lambda\pi$, $p\pi^0$

A somewhat wild idea is to search for baryon number violation (BNV) in τ decay, i.e. involving the 3rd generation. This was pointed out in Ref. [?], but the same reference argued that, by linking to the extremely stringent limit on proton decay, BNV ($B-L$ violating to be more precise) involving higher generations are in general too small to be observed. This did not stop Belle from conducting a search [?], followed by BaBar [?]. So far, no signal is found, as expected.

7 Discussion and Conclusion

The last subsection brings us to"wilder" speculations, which we have shunned so far. In the SUSY conference, however, ideas range widely, if not wildly. To this author, from an experimental point of view, the question is identifying the smoking gun, or else it is better to stick to the simplest explanation of an effect that requires New Physics. That has been our guiding principle.

Perhaps the wildest idea this year, and probably the one bringing in the most insight, is about "unparticle physics" [?]. Without discussing what this is, it has clearly stimulated much interest. On the flavour and CPV front, for example, there is the suggestion that unparticles could generate DCPV in unexpected places [?]. Sure enough, this observation may be stimulated by the 3.2σ indication [?] of DCPV in $B^0 \to D^-D^+$ by Belle (though the BaBar result is consistent with zero [?]) that is otherwise very difficult to explain. But searching for DCPV in the $B^+ \to \tau^+\nu$ mode is also suggested [?], which is interesting. If I may speculate, maybe unparticles could generate BNV in the modes of the previous subsection. In any case, new ideas such as these stimulate search efforts in otherwise unmotivated places, hence are very valuable.

To summarize, I have covered a rather wide range of probes of TeV scale physics via heavy flavour processes. At the moment, we have two hints for New Physics: in the $\Delta\mathcal{S}$ difference between TCPV in $B \to J/\psi K^0$ vs penguin dominant $b \to s\bar{q}q$ modes; and in the experimentally established difference in DCPV between $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ modes. These are large CPV effects, but they are not unequivocal, either in experimentation, or in interpretation. Because of this, the thing to watch in 2008-2009, in my opinion, is whether Tevatron could see a hint for *large* mixing-dependent CPV in $B_s \to J/\psi\phi$, which would be unequivocal as evidence for BSM. If a hint is seen, it can be quickly confirmed by LHCb. If Tevatron fails to see any indication for $\sin 2\Phi_{B_s}$, LHCb can probe down to SM expectation rather quickly, but things would become more and more boring. Other processes emphasized in this report that has good potential for New Physics search are: direct CPV in $B^+ \to J/\psi K^+$; $B \to \tau\nu$; $b \to s\gamma$; $\mathcal{A}_{FB}(B \to K^*\ell^+\ell^-)$; $B_s \to \mu\mu$; D^0 mass mixing and CPV; and $\tau \to \ell\gamma$.

The B factories have not yet exhausted their bag of surprises, but a Super B factory is needed to better cover all the above subjects (except $B_s \to \mu\mu$). Before that, we will attain some new heights with LHCb.

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