MAN/HEP/2006/40

RARE B AND τ DECAYS AND SEARCHES FOR NEW PHYSICS

R. J. BARLOW
School of Physics and Astronomy, Manchester University, Manchester M13 9PL, UK
**E-mail: Roger.Barlow@Manchester.ac.uk*

New results on rare decays of B mesons and τ leptons are summarised. Measurement are generally in excellent agreement with the Standard Model predictions, the only exceptions being the polarisation of vector particles in B decays and the non-appearance of CP violation in $B^{\pm} \to K^{\pm}\pi^0$.

Keywords: B decay; Tau decay; New Physics.

1. Introduction

Many new results on rare decays have been presented at this conference, and are reviewed here. Most (but not all) come from the B factory experiments *BABAR* and Belle. Results presented are generally preliminary.

1.1. *Rare Decays*

Theories 'Beyond the Standard Model' predict new particles with masses beyond the range of present accelerators. Such particles must exist not only on mass shell, waiting to be discovered directly at the LHC or the ILC, but must also exist off mass shell, contributing through loop corrections to the amplitudes of currently observable processes. These corrections are small, suppressed by the large particle masses, and are masked by the Standard Model amplitudes unless these are also suppressed by some means. So the search for rare decays is interesting not because of their scarcity value, but because they are a good place to look for deviations from the Standard Model predicted in the New Physics offered by BSM theories.

Some rare decays are forbidden by Standard Model conservation laws such as lepton number conservation, or because they occur as a Flavour Changing Neutral Current and cannot exist at the lowest order (tree level). It is arguable whether decays that are allowed but suppressed by a large factor, such as the Cabbibo angle, or V_{ub}, are 'rare'; the selection of topics that follow has been made to avoid overlap with other summary talks rather than being a rigorous classification.

Measurement of decays with branching ratios at the level 10^{-6} clearly needs millions of events. These have been provided by the B factories at SLAC and KEK. When these were originally proposed, some doubted whether the design luminosities would ever be achieved. In fact they were rapidly reached, the $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ barrier was broken, and both machines have gone through continuous improvement as the machine physicists faced and overcame new problems. Results now being shown are from several hundreds of millions of $B\overline{B}$ pairs.

1.2. *Experimental Techniques*

Isolating a rare decay mode in millions of events is a challenge. The cuts used must preserve the signal while removing the overwhelming background. To call this "Finding a needle in a haystack" is a severe understatement. Backgrounds arise not only from other B decays but also from other event species: even on the peak of the resonance the cross section for $e^+e^- \to \Upsilon(4S)$ is only 1.05 nb[1], compared to a combined $e^+e^- \to q\overline{q}$ cross section (the continuum background) of 3.49

nb. A number of techniques are used which are common to many analyses.

1.2.1. *Continuum suppression*

Events in which an $\Upsilon(4S)$ decays to 2 heavy B mesons are isotropic in the centre of mass system, whereas events from the light $q\overline{q}$ continuum tend to be collimated into two jets. The discrepancy is not sharp: gluon radiation broadens $q\overline{q}$ events, and a $\Upsilon(4S)$ decay may by chance produce collimated particles. Event shape information is used to separate the $\mathrm{B\overline{B}}$ signal: there are many well-known measures for this, such as thrust, sphericity, and the Fox-Wolfram moments. No single quantity gives all the information, but their linear combination in a Fisher Discriminant[2] is found to provide the best information to enable continuum background suppression, and is used in cuts or fitting, as appropriate in a specific analysis.

1.2.2. *Energy and Momentum*

A reconstructed B meson must have the correct mass, and its energy must equal to the beam energy (in the centre of mass system). These constraints are generally applied as a requirement on the total energy

$$\Delta E = E_B - \sum_i E_i \qquad (1)$$

and then the 'energy-substituted mass' is found using the *measured* cms momenta and the *correct* energy

$$M_{ES} = \sqrt{E_B^2 - (\sum_i \vec{p}_i)^2}. \qquad (2)$$

The substitution of the correct energy in Eq. 2 means that the two variables are essentially uncorrelated, which they would not be if the simple measured mass were used. They are used as the final stage of analyses, where a small area round the ideal $\Delta E = 0, M_{ES} = 5.279\,\mathrm{GeV/c^2}$ point is defined as the signal region. The final result is obtained by event counting or curve fitting, either to the two histograms or to the combined two dimensional distribution.

1.2.3. *Sidebands*

The ΔE and M_{ES} distributions outside the signal region are populated by continuum events and from B decays to other channels. These are not always reliably predicted by Monte Carlo simulations, so the size of the background is estimated by fitting the distributions to empirical curves well outside the signal region, and extrapolating them inside.

1.2.4. *Blind Analysis*

In searching for rare decays it is tempting to tune the cuts to maximise the signal. Learning from past experience[3], an increasing number of analyses are now performed blind. The analysis cuts and techniques are developed using simulated events and the real data outside the 'signal box'. which is masked out. Only when the final cuts are decided does the analysis 'open the box' to count or fit the number of signal events.

1.2.5. *Small Signal Statistics*

A typical analysis has an observed signal commensurate with expected background. It has uncertainties on the background estimate and possibly also on the reconstruction efficiency. There are many different statistical techniques for extracting limits on signal from such data[4]. The variation in their results is a reminder that such figures are not to be interpreted too rigorously.

1.2.6. *Single B-beam technique*

Another technique for difficult channels is to require the unambiguous reconstruction of a B decay in an established channels, such as $\mathrm{D}^*\pi$. Then whatever remains in the event must also comprise a complete B meson decay. However even using many decay channels the efficiency for this reconstruction is low, around 0.5%, so it needs the high statistics of a B (or, even better, a super-B) factory.

2. Leptonic Decays

Leptonic decays of B mesons are strongly suppressed through CKM matrix elements, and processes involving new particles may have comparable amplitudes. Some examples are shown in Figure 1. They have the advantage that they are free of final-state hadronic interactions.

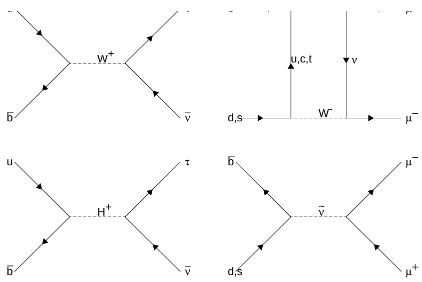

Fig. 1. Standardmodel leptonic decays and their BSM counterparts

2.1. $B^- \rightarrow \tau^- \overline{\nu_\tau}$

The branching ratio for the decay of a B^+ meson to a charged lepton ($\ell = e, \mu, \tau$) and the corresponding neutrino is, according to the Standard Model[5]:

$$BR = \frac{G_F^2 m_B}{8\pi} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_b^2 |V_{ub}|^2 \tau_B. \quad (3)$$

For the decay to a τ this (taking standard values for f_B and V_{ub}) gives a prediction of $(1.89 \pm 0.40) \times 10^{-4}$, which is a reasonably large number Unfortunately this is a difficult measurement as the decay involves at least two neutrinos in the production and decay of the τ. This means energy/momentum/mass constraints give no information, and one has to use the single-B beam technique, identifying the B decay in the other half of the event. Belle[6,7] select events with fully reconstructed B mesons (using 180 possible decay modes) and a possible τ decay. *BABAR*[5] identify a D or D* decay and a charged lepton compatible with the inclusive $B \rightarrow D\ell\nu X$ decay.

When a B decays hadronically to only 1 (or 3) charged particles, most of the energy from its mass must be in neutral particles, and will be detected in the calorimeter. So both experiments plot the extra calorimeter energy, unassociated with the charged tracks, detected in these events. There is good agreement between the data and Monte Carlo predictions of background away from zero, indicating that the processes and the detectors are well modelled. They seek an excess at zero detected energy, which would indicate that energy is going to neutrinos.

Belle have such an excess which is significant at the $3.5\,\sigma$ level and corresponds to a branching ratio of $BR = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$. The *BABAR* signal is $BR = (0.88^{+0.68}_{-0.67} \pm 0.11) \times 10^{-4}$. This on its own is compatible with zero and could be reported as a 90% confidence level upper limit of 1.80×10^{-4}. But it is compatible with the Belle result and a simple numerical combination[8] gives a value $(1.36 \pm 0.48) \times 10^{-4}$. This is very close to the Standard Model prediction and leaves little scope for contributions from New Physics.

An example of the implications this is in a 2 Higgs doublet model[9] in which the standard model prediction is modified by a factor $r_h = \left(1 - \frac{m_B^2}{m_H^2} tan^2\beta\right)^2$. Measurements which agree with the standard model force M_H to be large, or $tan\beta$ to be small, apart from an implausible scenario in which $m_B tan\beta \approx \sqrt{2} m_H$.

It should be pointed out that the previous Belle result has been withdrawn. This indicated a branching ratio lower than the standard model prediction, which occasioned a flurry of theoretical interest. However they have corrected the values used for their efficiencies and the revised figure is presented here.

2.2. $B^- \rightarrow \mu^- \overline{\nu}_\mu$ *and* $e^- \overline{\nu}_e$

The decay of a B to a light lepton (μ or e) is much easier experimentally as there is only one neutrino in the final state. Again the single-B beam technique is used, and events selected in which the only other track is a charged lepton. The signal B undergoes a 2 body decay so, in its rest frame, the lepton has a unique energy. This is reconstructed in the event and the broad background spectrum is well described by Monte Carlo with no hint of a signal. *BABAR*[5,10] put 90% confidence level limits on the branching ratio of 7.9×10^{-6} for the electron decay and 6.2×10^{-6} for the muon decay.

These limits are well above all predictions. The decay of a spinless B to two spin half particles is inhibited by helicity suppression (just like the decay of a charged pion) in the standard model and in BSM scenarios.

2.3. $B^0 \rightarrow \ell^+ \ell^- \gamma$

The decay $B^0 \rightarrow \ell^+\ell^-$, where the ℓ is a μ or an e, is also helicity suppressed. The emission of a photon from the initial state can avoid the helicity suppression, though even so the Standard Model predictions are of order 10^{-10}. BaBar[5,11] have searched for this and see no events in the $ee\gamma$ channel. They get 3 events in the $\mu\mu\gamma$ channel, but this is compatible with the expected background. The corresponding 90% confidence limits are 0.7×10^{-7} for $B^0 \rightarrow e^+e^-\gamma$ and 3.4×10^{-7} for $B^0 \rightarrow \mu^+\mu^-\gamma$.

2.4. $B \rightarrow K^* \nu \overline{\nu}$

Belle [6,12] have searched for the decay $B \rightarrow K^*\nu\overline{\nu}$ by a technique similar to the $\tau\nu$ channel: the other B is reconstructed explicitly, the K^* is identified, and the distribution of unassociated calorimeter energy is plotted in the hope of finding an excess at zero. There is no such signal visible and they place a 90% confidence level limit on the branching ratio of 3.4×10^{-4}, still well above the Standard Model prediction[13] of 1.3×10^{-5}.

This is actually a very general search, as any process $B \rightarrow K^*X$, where X is an unobservable particle, will give a signal. This is relevant for Dark Matter candidates[14].

2.5. $B^0 \rightarrow \mu^+ \mu^-$

CDF[15] have placed limits on the decay $B^0 \rightarrow \mu^+\mu^-$ by searching for pair of identified muons with the correct mass. Their experimental resolution is good enough to distinguish the B^0_d and B^0_s masses. In their central-central region they observe one event in the B^0_s region and two for the B^0_d, compatible with expected backgrounds, and overall they get 95% confidence level limits of 1.0×10^{-7} and 3.0×10^{-8} respectively.

This is an example of a channel where hadron machines beat the e^+e^- 'B factories'. The Tevatron produces far more B mesons than KEK-B or PEP-II, and the LHC will produce many times more again. Backgrounds are enormously larger, but a clear signal and a good trigger can beat that.

3. Radiative Decays

Radiative B decays have long been studied as a potential discovery of New Physics. The Standard Model decay (Fig.2: the photon

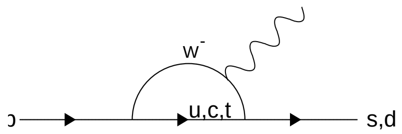

Fig. 2. Radiative decays in the Standard Model

can be radiated from any charged particle) is a Flavour Changing Neutral Current and suppressed by the CKM elements at the vertices. Beyond the Standard Model diagrams can replace the W with a charged Higgs, and involve supersymmetric particles in the loop.

3.1. $b \to s\gamma$ *inclusive*

The inclusive measurements are now mature. The process has been been measured by fully inclusive techniques and by summing over many exclusive modes. The current world average from HFAG is[16] $BR(b \to s\gamma) = (3.55 \pm 0.34^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$. The errors on this are smaller than those on the latest NLO Standard Model theoretical predictions[17] of $(3.61^{+0.37}_{-0.46}) \times 10^{-4}$. There is not much room for new physics here, indeed this agreement presents a constraint on the parameter space of New Physics models.

3.2. $b \to s\gamma$ *exclusive*

For the individual channels the theoretical predictions are generally harder and, given the agreement in the inclusive branching ratio, it is unlikely that this will produce any surprises. However one can also measure CP violation in these channels, and any nonzero asymmetry would be a sign of New Physics.

For example, Belle[18] report a new measurement of the decay $\mathrm{B}^0 \to \mathrm{K}^0_s \pi^0 \gamma$ based on 532 million B mesons. The results of a time-dependent fit (discussed in section 4) are $S = -0.10 \pm 0.31 \pm 0.07, A = -0.20 \pm 0.20 \pm 0.06$, compatible with zero for both direct and indirect CP.

3.3. $b \to s\ell^+\ell^-$

In the related decays to a lepton pair rather than a photon (Fig. 3) there are three Standard Model amplitudes, separable through their different kinematics expressed through the different Wilson Coefficients $C_i(q^2)$ in the expansion

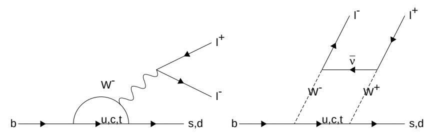

Fig. 3. Radiative decays to lepton pairs in the Standard Model

$$V_{kl} \times \sum_{i=1}^{10} C_i(q^2)\mathcal{O}_i \qquad (4)$$

where the V_{kl} are the CKM factors, $\mathcal{O}_i$ are the local operators, and q^2 is the mass of the dilepton. The contribution from a photon is in the coefficient C_7, that from the vector part of the Electroweak (W,Z) process is in C_9, and that from the axial part is in C_{10}. These have been studied in the $\mathrm{K}\ell^+\ell^-$ and $\mathrm{K}^*\ell^+\ell^-$ channels through the distributions in angular variables, particularly θ^*, the angle of the $\ell^+\ell^-$ pair in their own rest frame. The C_{10} term interferes with the C_7 and C_9 terms to give an angular asymmetry. According to the Standard Model this should be zero at the B mass, but negative below it and positive above. Measurements from *BABAR*[19,20] and Belle[21] do indeed indicate a positive asymmetry at high masses but also tend to show positive values at the lower masses. This is an interesting area – the *BABAR* limit excludes the standard model at the 90% confidence level – but the statistics are still very small.

3.4. $b \to d\gamma$

$b \to d$ FCNC decays are rarer than their $b \to s$ equivalents as the CKM factors are smaller. They have now been observed in the decay $\mathrm{B} \to \rho\gamma$. *BABAR*[19,22] report the first observation of the charged mode $\mathrm{B}^+ \to \rho^+\gamma$ at this conference: Belle[23] had earlier seen the neutral $\mathrm{B}^0 \to \rho^0\gamma$. Results are shown in Table 1

Table 1. Results on $b \to d\gamma$ decays

$BR \times 10^{-6}$	*BABAR*	Belle
$B^+ \to \rho^+\gamma$	$1.06^{+0.35}_{-0.31} \pm 0.09$	$0.55^{+0.42+0.09}_{-0.36-0.08}$
$B^0 \to \rho^0\gamma$	$0.77^{+0.21}_{-0.19} \pm 0.07$	$1.25^{+0.37+0.07}_{-0.33-0.06}$
$B^+ \to \omega\gamma$	< 0.84	$0.58^{+0.43+0.14}_{-0.31-0.10}$

Comparison of this result with the equivalent decay $B \to K^*\gamma$ is a measurement of the relative strengths of the t quark to the d and the s, as the t is the dominant contributor to the loop. This yields a value for $|V_{td}/Vts|$ of $0.171^{+0.018+0.017}_{-0.021-0.014}$ for the *BABAR* results and $0.199^{+0.026+0.018}_{-0.025-0.015}$ for Belle.

This quantity is the length of one side of the unitarity triangle, also measured (with rather more accuracy) through $B\overline{B}$ mixing. The two different methods give compatible results, which is a non-trivial test of the correctness of the theory.

3.5. $b \to d\ell^+\ell^-$

Predicted branching ratios for this process are small - at the level of 10^{-8}. *BABAR*[19,24] have performed a search for the decays $B^0 \to \pi^0\ell^+\ell^-$ and $B^+ \to \pi^+\ell^+\ell^-$, with ℓ being a μ or e. A combined result, assuming that the B^+ rate is twice the B^0 rate, places a 90% confidence upper limit at 7.9×10^{-8}. While still some distance from the region of interest, it is very impressive that measurements can be made of branching ratios this small.

4. Charmless Hadronic decays

Decays in which the b quark decays to a u, through the V_{ub} CKM element, and/or an s or d through a gluonic penguin, are technically rare. However many modes are now observed, some of which are fully discussed in other talks in this session. Our interest focuses on the 2 body decays to π and K scalar mesons, and to the ρ, f and K^* vector mesons.

Results are presented on the branching fractions themselves and on the time-integrated CP violation asymmetry A_{CP}. This is actually measured in 3 different ways, depending on the channel. For the decays of charged B mesons it is simply the proportional difference between the B^+ and B^- decay rates. For neutral B decays to states which are 'self-tagging' such that one knows whether the decaying particle is a B^0 or $\overline{B}^0$ it is again the difference between the rates to the two different states. Both of these are obtained by simple arithmetic. For other neutral B decays it is found from the symmetric term in the time-dependent fit (called C by *BABAR* and S by Belle). This is more involved, but uses a technique which is well understood and standard through the studies of CP violation in $B \to \psi K^0_S$ and other channels used in the determination of β/ϕ_1

4.1. *2 body* πK *channels*

Several new results were presented at this conference[25,26] and are presented in Table 2 and Fig. 4[27]. We pick out some points of interest.

4.1.1. $K\pi$ *CP violation*

The observation of direct CP violation in the $K^\pm\pi^\mp$ channel is confirmed by both

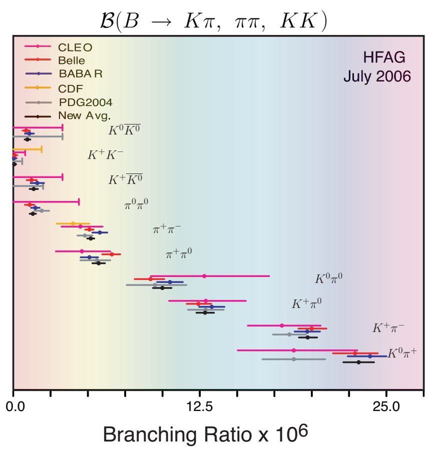

Fig. 4. Branching ratios to 2 body πK combinations, produced by HFAG

Table 2. 2 body π-K decays

	BABAR		Belle	
	$BR \times 10^{-6}$	A_{CP}	$BR \times 10^{-6}$	A_{CP}
$B^+ \to \pi^+\pi^0$	$5.12 \pm 0.47 \pm 0.29$	$-0.019 \pm 0.088 \pm 0.014$	$6.6 \pm 0.4^{+0.4}_{-0.5}$	$0.07 \pm +0.06 \pm 0.01$
$B^0 \to \pi^+\pi^-$	$5.8 \pm 0.4 \pm 0.3$	$-0.15 \pm 0.11 \pm 0.03$	$5.1 \pm 0.2 \pm 0.2$	$+0.55 \pm 0.08 \pm 0.05$
$B^0 \to \pi^0\pi^0$	$1.48 \pm 0.26 \pm 0.12$	$-0.33 \pm 0.36 \pm 0.08$	$1.1 \pm 0.3 \pm 0.1$	$+0.44^{+0.73+0.04}_{-0.62-0.06}$
$B^0 \to K^+\pi^-$	$19.7 \pm 0.6 \pm 0.6$	$-0.108 \pm 0.024 \pm 0.007$	$20.0 \pm 0.4^{+0.9}_{-0.8}$	$-0.093 \pm 0.018 \pm 0.008$
$B^0 \to \pi^0\pi^0$	$10.5 \pm 0.7 \pm 0.5$	$+0.20 \pm 0.16 \pm 0.03$	$9.2^{+0.7+0.6}_{-0.6-0.7}$	$-0.05 \pm 0.14 \pm 0.05$
$B^+ \to K^+\pi^0$	$13.3 \pm 0.56 \pm 0.64$	$+0.16 \pm 0.41 \pm 0.010$	$12.4 \pm 0.5^{+0.7}_{-0.6}$	$+0.07 \pm 0.03 \pm 0.01$
$B^+ \to K^0\pi^+$	$23.9 \pm 1.1 \pm 1.0$	$0.40 \pm 0.41 \pm 0.06$	$0.86^{+0.24}_{-0.21} \pm 0.09$	$-0.57^{+0.72}_{-0.65} \pm 0.13$
$B^0 \to K^0\overline{K^0}$	$1.08 \pm 0.28 \pm 0.11$	$+0.40 \pm 0.41 \pm 0.06$	$0.86^{+0.24}_{-.21} \pm 0.09$	$-0.57^{+0.72}_{-0.65} \pm 0.13$
$B^0 \to K^+K^-$	< 0.40		< 0.25	
$B^+ \to \overline{K^0}K^+$	$1.61 \pm 0.44 \pm 0.09$	$0.10 \pm 0.26 \pm 0.03$	$1.22^{+0.33+0.13}_{-0.28-0.16}$	$+0.13^{+0.23}_{-0.24} \pm 0.02$

experiments[28,29,30,31]. The agreement between the *BABAR* and Belle values is excellent. The plots in the references given illustrate very effectively that there really is direct CP violation in B decays.

This is explained if a decay occurs through more than one amplitude of comparable size with different strong and weak phases. It was expected that any such asymmetry in the $B^0 \to K^+\pi^-$ decay should also appear, with equal strength, in $B^+ \to K^+\pi^0$ decay[32]. However both experiments agree that this is very small. The difference is too large to be ascribed to experimental resolution. The explanation may be due to a larger than expected contribution from colour-suppressed tree diagrams, but it is a possible sign of New Physics.

4.1.2. *The Lipkin Sum Rule*

From isospin symmetry, and assuming the $b \to s$ penguin diagram is dominant in $B \to K\pi$ decays, Lipkin[33] predicts that the ratio

$$R = 2\frac{\Gamma(B^+ \to K^+\pi^0) + \Gamma(B^0 \to K^0\pi^0)}{\Gamma(B^+ \to K^0\pi^+) + \Gamma(B^0 \to K^+\pi^-)} \quad (5)$$

should be $1 + \mathcal{O}(10^{-2})$. Measurements[34] did at one time give a result of 1.25 ± 0.10. However the present value [27] is 1.06 ± 0.05, so the 2.5 sigma deviation has been reduced to one which is entirely consistent with the prediction.

4.1.3. *The "Kπ" puzzle*

Another prediction for the ratios of decay rates is that of Buras and Fleischer[35] who define

$$R_n = \frac{1}{2}\frac{\Gamma(B^0 \to K^+\pi^-)}{\Gamma(B^0 \to K^0\pi^0)} \quad (6)$$

$$R_c = 2\frac{\Gamma(B^+ \to K^+\pi^0)}{\Gamma(B^+ \to K^0\pi^+)}. \quad (7)$$

R_N and R_c should be equal to one another, and close to 1. Again, in the past apparent deviations have sparked interest, earning this discrepancy the name of the "K π puzzle". However the latest values have removed the discrepancy[25] and the HFAG averages[27] are $R_n = 0.99 \pm 0.07$ and $R_c = 1.11 \pm 0.07$, compatible with each other and with the Standard Model predictions.

4.2. B $\to$ *VV and polarisation*

Much data has now been accumulated on the decay of B mesons to two vector (Spin 1) particles. If, as is naïvely expected, such a decay is dominated by a tree or a penguin amplitude, then the vector mesons should be 100% longitudinally polarised. However the data do not confirm this, particularly for decays to the heavier vector mesons.

Thus the new measurement[36,37] of the decay $B^0 \to \rho^0\rho^0$ measures a longitudinal polarisation

$$f_L = 0.86^{+0.11}_{-0.13} \pm 0.05$$

whereas that of the decay[26,38] $B^+ \to \rho^+ K^{*0}$ gives only

$$F_L = 0.52 \pm 0.10 \pm 0.04$$

and CDF have measured $F_L = 0.572 \pm 0.026 \pm 0.015$ for the decay $B \to \psi K^*$ and $F_L = 0.571 \pm 0.097 \pm 0.050$ for $B \to \phi K^*$, confirming in an entirely different environment the (more accurate) measurements from *BABAR* and Belle.

It is likely that the solution to this "polarisation puzzle" lies in a fuller consideration of the QCD processes in the decay. It is important that this be understood as the polarisation affects the CP decomposition of these states, and thus their use for determination of the CKM angles

5. Rare Tau Decays

The decays of the τ lepton offer good prospects for probing beyond the Standard Model. Its large mass means that there are many decay channels that are allowed kinematically but forbidden in the Standard Model, due to lepton number conservation or for other reasons. They could however be produced by New Physics. The large mass of the τ also gives it, in appropriate schemes, a large coupling to Higgs particles, boosting such possible effects.

The B factories are also τ factories. Their cross section for τ pair production is $0.89nb$, and they have accumulated 1.5 billion τ leptons between them.

The τ pair events are quite distinct from $B\overline{B}$ production, but they can be confused with the low-multiplicity end of the $q\overline{q}$ pair production. Any analysis of a particular channel has to suppress background from these hadronic events as well as backgrounds from other τ decays. The general technique is to split the event into 2 hemispheres in some way, usually using the thrust axis, and identify ('tag') one side as a standard τ decay. Some analyses use only 1 prong decays, while others include 3 prongs; within the 1 prongs, some analyses use only the leptonic decays, with an identified electron or muon, and others also include the decays to $\pi\nu\nu$ and perhaps $\rho\nu\nu$.

The other ('signal') hemisphere is then analysed to search for the desired decay. In the case of lepton-number violating decays in which there are no neutrinos produced, this is aided by the energy/momentum and mass constraints, requiring all the decay products to have the invariant mass of the τ, with half the CMS energy.

Results have been reviewed at this conference by Hayasaka[40]. Many channels have been studied and limits on branching ratios placed generally at the level of 10^{-7}. Just 3 analyses will be mentioned here

5.1. *Lepton-number violating τ decays*

Observation of the radiative decay of the τ to a lighter lepton would be a clear signal of New Physics. Within the standard model it occurs through neutrino mixing with branching ratio $\approx 10^{-40}$. In supersymmetric models it occurs through processes such as that shown in Fig. 5

The value of the branching ratio for $\tau \to \mu\gamma$ decay is

$$3.6 \times 10^{-6} \left(\frac{tan\beta}{60}\right)^2 M_{SUSY}^{-4} \qquad (8)$$

where M_{SUSY} is in TeV. The new 90% confidence limits presented by Belle[40,41] are

The lepton-number violating decay with a produced η is of particular interest as it can occur through the leptonic couplings of the MSSM pseudoscalar Higgs, A^0, which has a strong coupling to the η through its $s\overline{s}$ com-

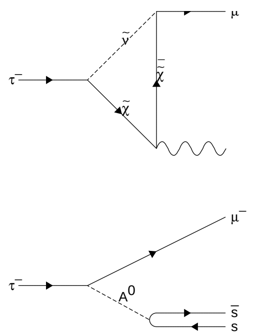

Fig. 5. Lepton-number violating decays of the τ

Table 3. Lepton number violating τ decays

Channel	Limit
$\tau \rightarrow e\gamma$	12×10^{-8}
$\tau \rightarrow \mu\gamma$	4.5×10^{-8}
$\tau \rightarrow e\mathrm{K}^0_S$	5.6×10^{-4}
$\tau \rightarrow \mu\mathrm{K}^0_S$	4.9×10^{-4}

ponent. The branching ratio for $\tau \rightarrow \mu\eta$ decay is

$$BR = 8.4 \times 10^{-7} \left(\frac{100}{M_A}\right)^4 \left(\frac{tan\beta}{60}\right)^6 \quad (9)$$

where M_A is in GeV. A new 90% CL limit of 0.65×10^{-7} is reported by Belle [40,42]. These limits are important for excluding large values of $\tan\beta$

5.2. *Baryon-number violating τ decays*

BaBar presented new results[40,43] on decays of the τ to a Λ (or $\overline{\Lambda}$) baryon accompanied by a charged pion or kaon. The $\tau^0- \rightarrow \Lambda h^-$ decays conserve the quantum number B-L, whereas the decays to the $\overline{\Lambda}$ do not. Both are potentially important: the former as they are allowed (at a low level) within the Standard Model, the latter as they may be necessary for the baryogenesis of the universe. Backgrounds are of order one event, and only one signal event is seen in one of the four channels. Limits are shown in Table 4

Table 4. Baryon and Lepton number violating τ decays

Channel	Background	N_{obs}	Limit at 90% CL
$\tau \rightarrow \overline{\Lambda}\pi^-$	0.42 ± 0.42	0	5.94×10^{-8}
$\tau \rightarrow \Lambda\pi^-$	0.56 ± 0.56	0	5.76×10^{-8}
$\tau \rightarrow \overline{\Lambda}\mathrm{K}^-$	0.26 ± 0.26	0	7.19×10^{-8}
$\tau \rightarrow \Lambda\mathrm{K}-$	0.12 ± 0.12	1	14.6×10^{-8}

5.3. *Lepton-number violating Upsilon decays*

Finally there is a limit from CLEO[44] on the decay $\Upsilon(1S) \rightarrow \mu\tau$. The τ is detected through the electron decay channel, so such decays would appear as $e - \mu$ events with a muon energy slightly less than that from $\Upsilon \rightarrow \mu^+\mu^-$ decay. Such decays do appear as a background, where a muon and a radiated photon fake an electron signal, but the muon momentum resolution is good enough to discriminate. The branching ratio limit of 6.2×10^{-6} puts a limit on the lepton violation scale of around 1 TeV.

6. Conclusions

The conference has seen many new results on rare decays, and some apparent discrepancies which caused interest at previous conferences have disappeared, now that more statistics have clarified the situation. The Kπ puzzle is a puzzle no more, and neither is the Lipkin ratio. The low value for the B $\rightarrow \tau\nu$ branching ratio, reported earlier this year, has been revised upwards.

The only puzzles remaining are the appearance of direct CP violation in $\mathrm{B}^0 \rightarrow \mathrm{K}^{\pm}\pi^{\mp}$ but not $\mathrm{B}^+ \rightarrow \mathrm{K}^+\pi^0$ decays, and the transverse polarisation of heavier mesons in B $\rightarrow VV$ decays. Both of these are well established experimentally. It is, however, unlikely (though not impossible) that New Physics is required to explain them.

Large areas of parameter space in SUSY and other New Physics models are being ruled out. These measurements will inform future high energy results: the interpretation of any signal seen at the LHC (or the Tevatron) will be framed by the need to be compatible with these low energy results.

So the Standard Model survives again. But as more rare decay modes are measured with ever greater precision, these tests become increasingly stringent. The Standard Model is being stressed by these measurements – and a Super B factory will stress it even further. It cannot continue to escape forever.

Acknowledgments

I am grateful to the many parallel session speakers who provided material for this talk, and to my colleagues in *BABAR* for advice and assistance in preparing it.

References

1. P. Harrison and H. Quinn (Eds.) *The BaBar Physics Book* SLAC-R-504 (1998).
2. G. Cowan *Statistical Data Analysis*, page 53, Clarendon Press (1998).
3. P. Harrison, *Blind Analysis*, in Proc. Conf. Advanced Statistical Techniques in Particle Physics (Ed. M. R. Whalley and L. Lyons), IPPP/02/39 (2002).
4. For recent developments see the BIRS workshop on Statistical Problems in High Energy Physics and Astronomy `www.pims.math.ca/birs/birspages.php` (2006).
5. R. Sekula, these proceedings and B. Aubert *et al.* (the BaBar collaboration), hep-ex/0608019.
6. T Browder, these proceedings.
7. K. Ikado *et al.* (the Belle collaboration) hep-ex/0604018.
8. R. Faccini, private communication.
9. W. S. Hou, *Phys. Rev.* **D48**, 2342 (1993).
10. B. Aubert *et al.* (the BaBar collaboration) hep-ex/0607119.
11. B. Aubert *et al.* (the BaBar collaboration) hep-ex/0607058.
12. K. Abe *et al.* (The Belle Collaboration) hep-ex/0608047.
13. G. Buchaller, G. Hiller and G. Isidori, Phys. Rev. **D63** 014015 (2001).
14. C. Bird *et al.*, Phys. Rev. Lett. **93** 201803 (2004).
15. S. Farrington, these proceedings.
16. The Heavy Flavour Averaging Group `http://www.slac.stanford.edu/xorg/hfag/rare/ichep06/radll/index.html`.
17. T. Hurth, these proceeedings, and H.M. Asatrian *et al.*, hep-ph/0605009.
18. A. Limosami, these proceeedings. Y. Ushiroda, K. Sumisawa *et al.* (The Belle collaboration) hep-ex/0608017.
19. D. Kovalskyi, these proceeedings.
20. B. Aubert *et al.* (the BaBar collaboration) Phys.Rev. D73 (2006) 092001.
21. K. Ikado, hep-ex-0605067 and 41st Rencontres de Moriond, La Thuile, 2006.
22. B. Aubert *et al.* (the BaBar collaboration) hep-ex/0607099.
23. D. Mohapatra *et al.* (the Belle Collaboration) hep-ex/0506079v3.
24. B. Aubert *et al.* (the BaBar Collaboration) hep-ex/0607048.
25. J. Dragic, these proceedings.
26. M. Bona, these proceedings.
27. The Heavy Flavour Averaging Group `http://www.slac.stanford.edu/xorg/hfag/rare/ichep06/charmless/index.html`.
28. E. Di Marco, these proceedings.
29. Y. Unno, these proceedings.
30. H. Ishino *et al.* (the Belle collaboration) hep-ex/0608035.
31. B. Aubert*et al.* (the BaBar Collaboration) hep-ex/0607106.
32. M. Gronau *Phys.Lett.* **B627**, 82 (2005).
33. H. J. Lipkin *Phys. Lett.* **B445**, 403 (1999).
34. J. Fry in Proc. XXI Int. Lepton Photon Symposium, World Scientific, 136 (2003).
35. A. Buras and R. Fleischer, *Phys J* **C45**, 701 (2006).
36. A. Telnov, these proceedings.
37. B. Aubert *et al.* (the BaBar Collaboration) hep-ex/0607097.
38. B. Aubert *et al.* (the BaBar Collaboration) hep-ex/0607057.
39. P. Bussey, these proceedings.
40. K. Hayasaka, these proceedings.
41. K. Abe *et al.* (the Belle Collaboration) hep-ex/0609049.
42. K.Abe *et al.*(the Belle Collaboration) hep-ex/0609013.
43. B. Aubert *et al.* (the BaBar Collaboration) hep-ex/0607040.
44. J. Duboscq (for the CLEO COllaboration), hep-ex/0610089.