PROCEEDINGS OF SCIENCE

Tau results from B factories

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Recent measurements on τ physics at the B factories are reviewed, in particular for the τ lifetime, the branching fractions and spectral functions of high multiplicity τ decay channels, and the study of lepton flavour violation in τ decays. They are based on the high-statistics data samples of the BABAR and Belle experiments.

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1. Introduction

In e^+e^- collisions at a center of mass energy around the $\Upsilon(4S)$ resonance, the 0.92 nb cross section for $\tau^+\tau^-$ pair production is of the same order as the 1.1 nb cross section for $B\bar{B}$ pair production. Consequently, the B factories are also τ factories. In a decade, the two experiments, BABAR [1] at SLAC and Belle [2] at KEK, with an integrated luminosity of more than half an attobarn and about one attobarn respectively, have accumulated very large samples of $\tau^+\tau^-$ pairs, nearly two orders of magnitude more than was obtained by experiments of the previous generation. This huge data sample allows precision tests of the Standard Model and searches for New Physics effects.

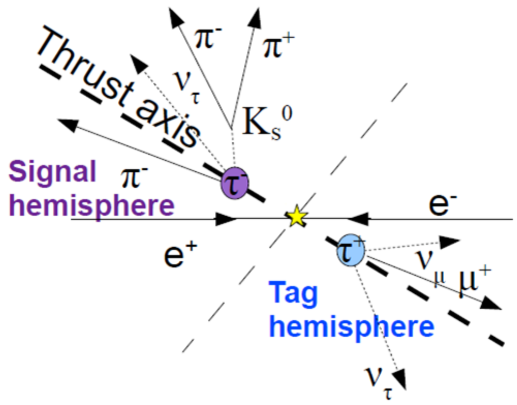

Figure 1: A typical τ pair event, with a muon prong on one side and three pion prongs on the other side.

Figure 1 illustrates the principle of most analyses in τ physics. In a τ pair event, the decay products from the τ^+ are well separated from those of the τ^-. Hence, events are divided into two hemispheres along the thrust axis of the event. One hemisphere is used to tag the event as a τ pair event with one-prong (i.e. track from a charged particule) decays (85% of the τ decays), usually only leptonic one-prong decays (35% of the τ decays), while the other one is used to search for a specific signal. Various variables, from kinematics or event shape, are used to discriminate against the non τ pair backgrounds.

Section 2 presents a recent measurement of the τ lifetime. Section 3 gives an update on the measurement of spectral functions, which are important for the measurement of the CKM matrix element V_{us}. Section 4 presents several measurements of branching fractions for high multiplicity τ decay modes. Finally, lepton flavour violation is discussed in Section 5.

2. τ lifetime

The τ lifetime is an important ingredient to check charged lepton universality: whether the couplings to the W boson of the three charged leptons, g_e for the electron, g_μ for the muon, and g_τ for the τ lepton, are the same. This can be done from the τ leptonic branching fractions. The average values for the ratios $g_\tau/g_e = 1.0024 \pm 0.0021$ and $g_\tau/g_\mu = 1.0006 \pm 0.0021$, calculated by the Heavy Favour Averaging Group [3], are compatible with 1 within the error, which is at the 2 per mil level.

The Belle collaboration has published a new measurement of the τ lifetime this year [4]. The analysis, based on a sample of 650 million τ pairs, selects events where both τ leptons decay to three charged pions and a neutrino. The three tracks give good vertex resolution. Then, a fit is performed on the decay length divided by the $\beta\gamma$ value of the τ. The fit is illustrated in figure 2, where the contribution of the background is shown. This background accounts for about 2% of the selected sample and its dominant source is the *uds* continuum.

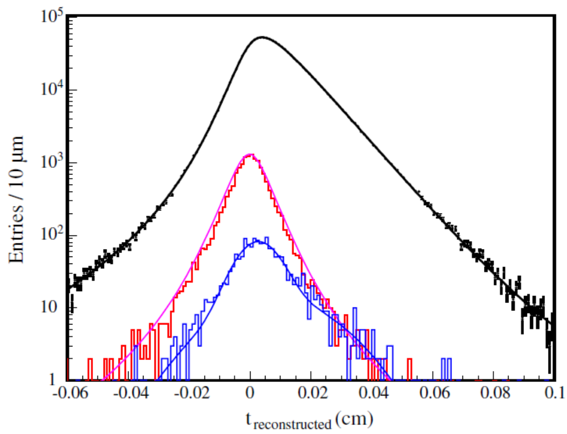

Figure 2: The measured τ decay length divided by $\beta\gamma$ from the Belle experiment. The data are shown in black, the MC prediction for the *uds* and $\gamma\gamma$ (*b* and *c*) backgrounds in red (blue). The solid lines illustrate the results of the fit.

The analysis gives a measured lifetime of the τ of $(290.17 \pm 0.53 \pm 0.33)$ fs. The main systematic is due to uncertainty on the alignment of the silicon vertex detector. The result is in agreement with and more precise than previous measurements. The analysis can also measure separately the lifetime of τ^+ and τ^- for the first time and obtain the difference between the two lifetimes. If non-zero, this would be a violation of the CPT symmetry. The relative difference between the τ^+ and τ^- lifetimes is found to be smaller than 7×10^{-3} at 90% confidence level, compatible with CPT conservation. Finally, as mentioned before, the τ lifetime value is an input to the test of lepton universality. The new τ lifetime results in $g_\tau/g_e = 1.0031 \pm 0.0016$ and $g_\tau/g_\mu = 1.0013 \pm 0.0016$. The values are slightly increased while the errors are reduced by a factor 1.3, as the uncertainty on the τ lifetime is a substantial source of the systematic error.

3. Spectral functions

There is some tension in the measurements of V_{us}, as illustrated in figure 3, between the ones coming from CKM unitarity or kaon physics and the ones from τ physics. The one coming from $\tau \to s$ inclusive is 3.4 σ away from CKM unitarity. To resolve the issue, it is important to measure precisely the spectral functions of the strange τ decays, which are an ingredient to the analysis.

Preliminary measurements of the hadronic spectra in all $\tau^- \to h^-h^-h^+\nu_\tau$, where h is either a pion or a kaon, have been performed by BABAR [5]. They are obtained after using Bayesian unfolding to remove detector effects in the mass distributions, as illustrated in figure 4. These measurements are also crucial to tune the τ Monta Carlo generators, like Tauola.

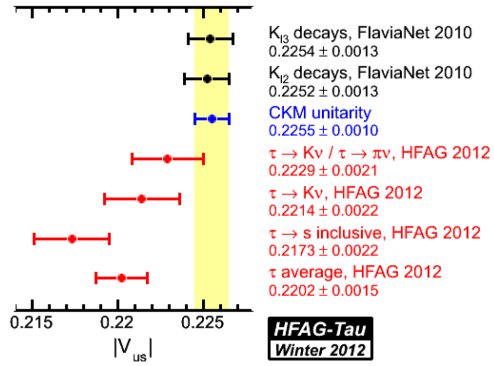

Figure 3: The various measurements of V_{us} from K_{l3} and K_{l2} decays by FlaviaNet in black, from the unitarity constraint of the CKM matrix in blue, and from τ physics in red.

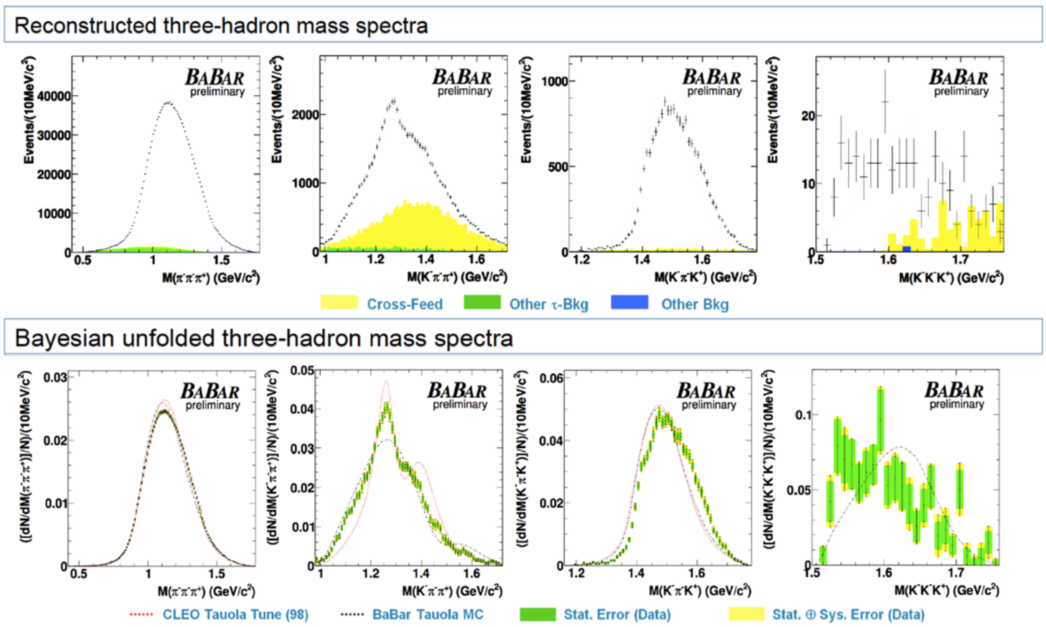

Figure 4: Hadronic invariant mass spectra measured by the BABAR experiment. The reconstructed invariant mass distributions are shown in the top row and the unfolded invariant mass spectra in the bottom row for the (first column) $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ (second column) $\tau^- \to K^-\pi^-\pi^+\nu_\tau$ (third column) $\tau^- \to K^-\pi^-K^+\nu_\tau$ (fourth column) $\tau^- \to K^-K^-K^+\nu_\tau$ channels.

4. Branching fractions

The large statistics of τ pairs allows the study of rare high multiplicity τ decay modes. 23 three-prong or five-prong modes involving $f_1(1285)$, η, and ω resonances have been measured by the BABAR experiment [6] using its full sample of 430 million τ pairs. They include $\tau^- \to (3\pi)^-\eta\nu_\tau$, $\tau^- \to (3\pi)^-\omega\nu_\tau$, and $\tau^- \to \pi^- f_1(1285)\nu_\tau$. The measurements are given in table 1. A new limit has also been placed on the $\tau^- \to \pi^-\eta'\nu_\tau$ channel, a second class hadronic current (SCC) decay mode, forbidden in the Standard Model with perfect isospin symmetry: $B(\tau^- \to \pi^-\eta'\nu_\tau) < 4 \times 10^{-6}$. No evidence for such SCC modes has been seen so far.

Decay mode	branching ratio (10^{-5})
$\tau^- \to \pi^-\pi^-\pi^+\eta\nu_\tau$	$22.5 \pm 0.7 \pm 1.2$
$\tau^- \to \pi^-\pi^0\pi^0\eta\nu_\tau$	$20.1 \pm 3.4 \pm 2.2$
$\tau^- \to \pi^-\pi^-\pi^+\omega\nu_\tau$	$8.4 \pm 0.4 \pm 0.6$
$\tau^- \to \pi^-\pi^0\pi^0\omega\nu_\tau$	$7.3 \pm 1.2 \pm 1.2$
$\tau^- \to \pi^- f_1 \nu_\tau$ with $f_1 \to 2\pi^+2\pi^-$	$5.2 \pm 0.3 \pm 0.4$
$\tau^- \to \pi^- f_1 \nu_\tau$ with $f_1 \to \pi^+\pi^-\eta$	$12.6 \pm 0.6 \pm 0.6$

Table 1: Measured branching fraction from *BABAR*. Here f_1 stands for $f_1(1285)$.

Decay modes with at least one K_s^0 have been investigated by *BABAR* [7] on 430 million τ pairs and by Belle [8] on 616 million τ pairs. K_s^0 candidates are reconstructed from $\pi^+\pi^-$ pairs with a displaced vertex. The branching fractions of the various modes have been measured with much better precision than in the past, as illustrated in figure 5.

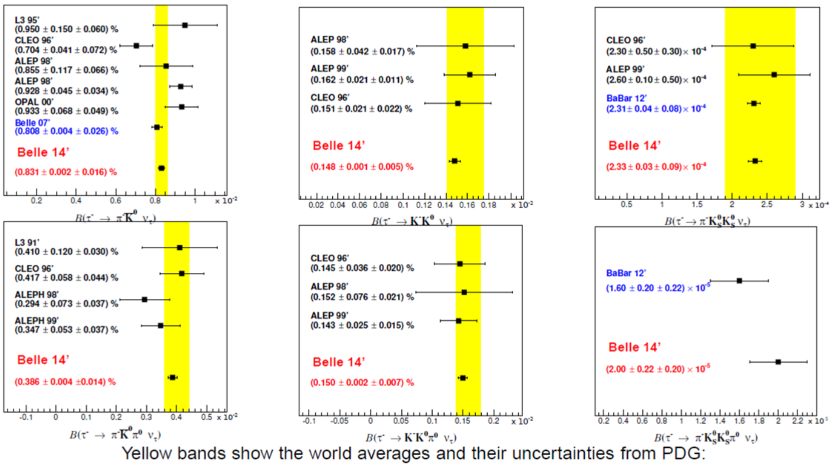

Figure 5: Branching fraction measurements in (top left) $\tau^- \to \pi^- K^0 \nu_\tau$, (top center) $\tau^- \to K^- K^0 \nu_\tau$, (top right) $\tau^- \to \pi^- K_s^0 K_s^0 \nu_\tau$, (bottom left) $\tau^- \to \pi^- K^0 \pi^0 \nu_\tau$, (bottom center) $\tau^- \to K^- K^0 \pi^0 \nu_\tau$, and (bottom right) $\tau^- \to \pi^- K_s^0 K_s^0 \pi^0 \nu_\tau$. The yellow bands show the PDG world averages before the new measurements.

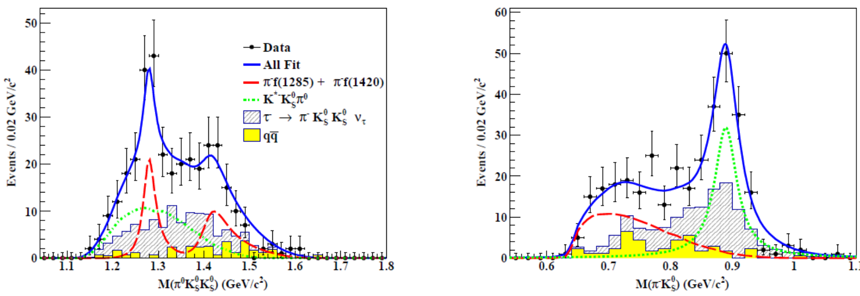

Figure 6: Invariant mass of the (left) $\pi^0 K_s^0 K_s^0$ and (right) $\pi^- K_s^0$ subsystems for $\tau^- \to \pi^- K_s^0 K_s^0 \pi^0 \nu_\tau$ candidates by the Belle experiment. The points with error bars are the data. The solid line is the result from the fit, while the dashed (dotted) line shows the contribution from $f_1(1285)\pi^-\nu_\tau$ and $f_1(1420)\pi^-\nu_\tau$ ($K^*(892)^- K_s^0 \pi^0 \nu_\tau$).

The dynamics of the $\tau^- \to \pi^- K_s^0 K_s^0 \pi^0 \nu_\tau$, measured for the first time, has also been studied. Figure 6 illustrates a simultaneous fit of $M(\pi^0 K_s^0 K_s^0)$ and $M(\pi^- K_s^0)$ from Belle, showing that this decay goes through $K^*(892)^- K_s^0 \pi^0 \nu_\tau$, $f_1(1285)\pi^- \nu_\tau$, and $f_1(1420)\pi^- \nu_\tau$, in 54%, 34%, and 12% of the cases, respectively.

5. Lepton flavour violation

Lepton flavour violation is only allowed in the Standard Model via neutrino oscillation. However, it is extremely small (of the order of 10^{-54}). On the contrary, several models of New Physics predict branching fractions for lepton flavour violating modes in the range from 10^{-10} to 10^{-8}. So the experimental observation of such modes would be an unambiguous sign of New Physics.

The Belle collaboration has investigated the 14 lepton flavour violating modes $\tau \to lhh'$ [9], where l is an electron or a muon while h and h' are charged pions or kaons:

- $\tau^- \to l^- h^+ h'^-$ (8 modes)
- $\tau^- \to l^+ h^- h'^-$ (6 modes)

The six latter modes also violate lepton number conservation.

Candidate τ pair events are tagged with one-prong decays. The signal is then searched in the (M, ΔE) plane, as illustrated in figure 7 for the example of the $\tau^- \to \mu^+ \pi^- \pi^-$ channel. It should be noted that, as there is no neutrino in the final states, the resolution in the mass M and energy difference ΔE with the beam energy is not affected here by the usual undetected neutrino in τ decays. No significant signal is found in any of the searched channels, leading to upper limits improved upon previous results by a factor of 1.8, on average.

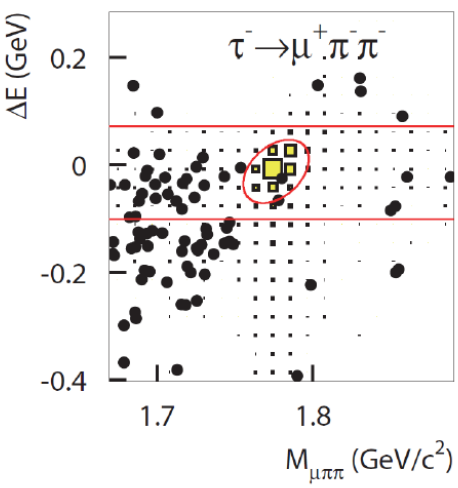

Figure 7: Scatter plot in the (M, ΔE) plane for $\tau^- \to \mu^+ \pi^- \pi^-$ decays by the Belle experiment. The black points are the data and the yellow squares show the expectation from signal Monte Carlo.

Figure 8 summarises the status of upper limits placed on branching fractions in all lepton flavour violating τ decay modes. The channels discussed above can be seen in the lhh column. BABAR and Belle have reached limits of a few 10^{-7} to a few 10^{-8}. The future super B factory will be able to reach 10^{-9} and even 10^{-10} in channels like $\tau^- \to l^+ l^- l^-$ with no irreducible backgrounds.

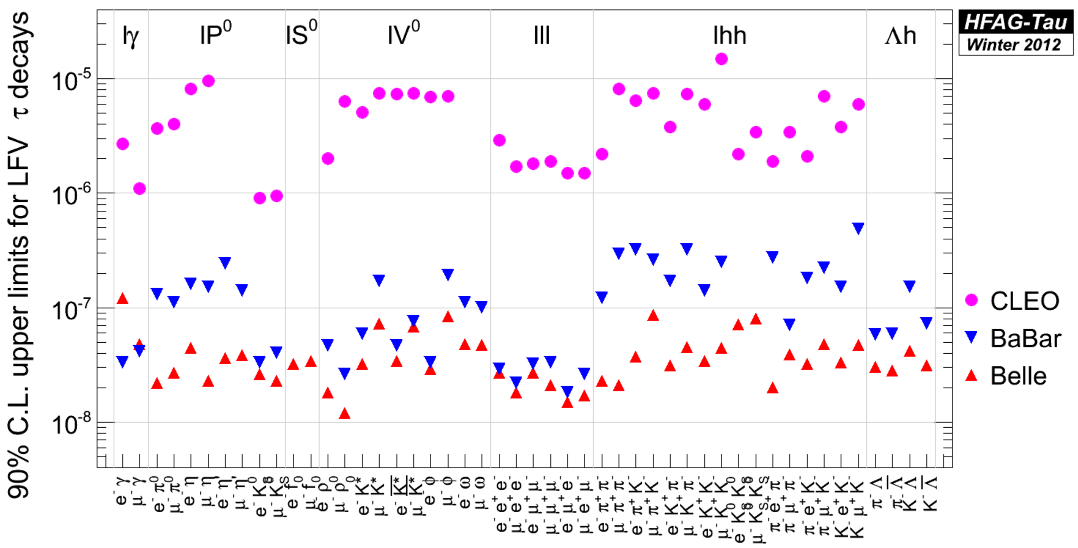

Figure 8: Limits for lepton flavour violating decays by the (circles) CLEO, (downward triangles) BABAR, and (upward triangles) Belle experiments.

6. Summary

The high statistics of τ pairs at the B factories allows precision tests of the Standard Model and searches for New Physics. In this article have been presented recent measurements of the τ lifetime, spectral functions, branching ratios of high multiplicity processes, and lepton flavour violation in τ decays.

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