PROCEEDINGS OF SCIENCE

CP Violation and CKM Measurements

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Measurement of *CP* violation has become a standard tool of flavor physics to scrutinize the Standard Model (SM) and search for physics beyond, thanks to the huge datasets collected by B-factories, Belle and BaBar, and hadron collider experiments. The initial goal of B-factories to confirm the Cabibbo-Kobayashi-Maskawa (CKM) picture has been accomplished by the precision measurement of the angle ϕ_1/β with the final datasets, and measurements of *CP* violation phenomena are now expanded to all different kind of B meson decay modes. All three sides and angles of the unitary triangle are measured and overconstrained with about 10% accuracy. *CP* violation measurements on charm hadrons and τ leptons are also stepping into an interesting stage, as they would be a clear sign of physics beyond the CKM picture. In near future, we expect more results from coming LHCb data and the next generation e^+e^- B-factory.

36th International Conference on High Energy Physics,
July 4-11, 2012
Melbourne, Australia

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PoS(ICHEP2012)019

1. Introduction

Gauge interaction with the Kobayashi-Maskawa (KM) mechanism [1] has been one of the most successful building blocks of the Standard Model (SM), as demonstrated by observation of *CP* violation in *B* decays at B-factories and numerous other measurements in the last decade. Misalignment between mass and weak eigenstates generates mixing beyond generations, $(d,s,b) \neq (d',s',b') = V_{\mathrm{CKM}}(d,s,b)$, which is represented by a 3×3 matrix V_{CKM}. The irreducible complex phase in the CKM matrix is the only known source of *CP* violation to date.

Many *B* meson decay modes provide possibility to access this complex phase in terms of *CP* violation measurements. *CP* violation occurs as a result of interference between more than one quark diagrams with different CKM matrix elements and comparable amplitudes. In particular, loop diagrams are interesting as in the SM they are formed by heavy weak boson and top quark, and as they may also be populated by even heavier postulated particles beyond the SM. On the other hand, tree diagrams are dominated by the SM contribution and can be used as a reference.

Unitarity of the CKM matrix provides three triangle relations in the complex plane, of which the *b*-*d* triangle, $V_{ub}^*V_{ud}+V_{cb}^*V_{cd}+V_{tb}^*V_{td}=0$ has the three sides with about the same size, and can be verified by a rich set of *CP* conserving and violating observables. Three angles of the triangle are defined as $\phi_1 \equiv \beta \equiv -\arg(V_{cb}^*V_{cd}/V_{tb}^*V_{td})$, $\phi_2 \equiv \alpha \equiv -\arg(V_{tb}^*V_{td}/V_{ub}^*V_{ud})$ and $\phi_3 \equiv \gamma \equiv -\arg(V_{ub}^*V_{ud}/V_{cb}^*V_{cd})$. These three angles can be all measured by using *B* meson decays for example into $J/\psi K_S^0$, $\pi^+\pi^-$, DK, respectively. Lengths of three sides, especially $|V_{td}|$, $|V_{cb}|$ and $|V_{ub}|$, as $|V_{ud}|$ and $|V_{cd}|$ are well known and $|V_{tb}|$ is expected to be almost unity, are also measured with $B\overline{B}$ mixing, semileptonic $b\to c\ell\nu$ decays, and $b\to u\ell\nu$ decays, respectively. Tree measurements on $|V_{cb}|$, $|V_{ub}|$ and ϕ_3 provide the SM reference point of the triangle apex, while loop measurements on $|V_{td}|$, ϕ_1 and ϕ_2 provide consistency checks of the SM.

Another relation, $V_{us}^*V_{ub}+V_{cs}^*V_{cb}+V_{ts}^*V_{tb}=0$ (*s*-*b* triangle), which may be accessible with B_s decays in the future, is less visible, as the angle is only as large as 1°. The last relation, $V_{ud}^*V_{us}+V_{cd}^*V_{cs}+V_{td}^*V_{ts}=0$ (*d*-*s* triangle) is even more squashed and almost invisible.

The SM predicts that *CP* violation is much smaller in any charm meson decays, and there is no SM mechanism to generate *CP* violation in τ lepton decays. In other words, these decay modes are ideal to search for a new weak phase that may be provided by physics beyond the SM. As B-factories and hadron colliders produce equally huge amount of charm and τ events, they are now providing very interesting results.

After about a decade of operation, two B-factory experiments, Belle and BaBar, collected in total 1.24 billion $B\overline{B}$ events at the $\Upsilon(4S)$ resonance, and even more charm and τ decays at various energies between $\Upsilon(1S)$ and $\Upsilon(5S)$. Although the data taking has stopped, these huge datasets are still a valuable source of new results. Now, LHCb has successfully started up and have already collected 1.0 fb^{-1} of data in 2011 and adding more. In some of the all charged track final state modes, LHCb is already surpassing Belle and BaBar results. There are also other players: lower energy e^+e^- collides CLEO-c and BESIII, and hadron collider experiments CDF, D0, ATLAS and CMS, also contributing the CKM and *CP* violation measurements.

This review covers the state of the art CKM measurements through *CP* violation in *B* meson decays in loop processes and tree processes, and latest search results for *CP* violation in charm and τ decays.

2. CKM measurements with loop processes

What has driven the B-factory is the time-dependent *CP* violation in the $B\overline{B}$ mixing, which in the SM is a box diagram forming a loop and hence may be affected by physics beyond the SM. Measurements of ϕ_1 and ϕ_2 belong to this category.

2.1 ϕ_1 measurements with $b \to c\bar{c}s$

Time-dependent *CP* asymmetry measurement in the $B \to J/\psi K_S^0$ channel is a beautiful setup that combines $B\overline{B}$ mixing, $b \to c\bar{c}s$ transition and $K\overline{K}$ mixing to generate a *CP* asymmetric sine modulation in the decay rate, $\Gamma(B^0(\overline{B}^0) \to J/\psi K_S^0) \propto e^{-t/\tau_B}(1 \pm \sin 2\phi_1 \sin \Delta m_d t)$, where ϕ_1 is one of the angles of the unitarity triangle. As a time-integrated measurement cancels this asymmetry, a decay time measurement for the 1.5 ps lifetime is needed. Although the $B \to J/\psi K_S^0$ is rather easy to detect with $J/\psi \to \ell^+\ell^-$ and $K_S^0 \to \pi^+\pi^-$, the branching fraction including the subsequent decays is quite small and requires at least 30 fb^{-1} of $B\overline{B}$ events. And as the final state is a *CP*-eigenstate, the flavor of the accompanying B meson has to be identified.

This was actually the starting point of the two B-factory experiments, Belle and BaBar. The asymmetry was not visible with about 10 fb^{-1} data in 2000, but it was soon observed with about 30 fb^{-1} of data as expected, and it has been the history of Belle and BaBar to improve the precision until the final datasets.

The latest results from Belle [2] is shown in Fig. 1. Here the decay time distribution is smeared by the resolution function. Unbinned maximum likelihood fit is performed, allowing also a cosine term modulation,

$$\mathscr{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \times \left\{1 + q\left[\mathscr{S}_f \sin(\Delta m \Delta t) + \mathscr{A}_f \cos(\Delta m \Delta t)\right]\right\}, \tag{2.1}$$

where $\mathscr{S}_f = \sin 2\phi_1$ when $\mathscr{A}_f = 0$ for the final state $f = J/\psi K_S^0$ if tiny contributions from sub-dominant diagrams are neglected. Including more modes such as $\psi(2S)K_S^0$, $\chi_{c1}K_S^0$ and $J/\psi K_L^0$, and including the similar results from BaBar [3] and less sensitive results from other experiments, the world average of $\sin 2\phi_1$, ϕ_1 and $\mathscr{A}_f$ by HFAG are now

$$\sin 2\phi_1 = 0.68 \pm 0.02, \quad \phi_1 = (21.4 \pm 0.8)^\circ, \quad \mathscr{A}_f = -0.005 \pm 0.017. \tag{2.2}$$

The errors are still statistics dominated, and as LHCb can hardly improve it due to the limited flavor tagging capability, it will be the homework for the next generation B-factory to further improve the already precise ϕ_1 measurement.

2.2 Other ϕ_1 measurements

A similar time-dependent *CP* asymmetry measurement can be performed on many other B decay modes which are similarly sensitive to ϕ_1.

One example is the $b \to c\bar{c}d$ transition, which includes $B^0 \to D^+D^-$, $B^0 \to D^{*+}D^{*-}$ and $B^0 \to D^\pm D^{*\mp}$ decay modes. Here, only D^+D^- is a *CP*-eigenstate, and the time-dependent asymmetry can be directly interpreted as ϕ_1. The other modes are more complicated, as $D^{*+}D^{*-}$ is a mix of *CP*-odd and even final states due to polarization, and $D^\pm D^{*\mp}$ is a mix of D^+D^{*-} and D^-D^{*+} and

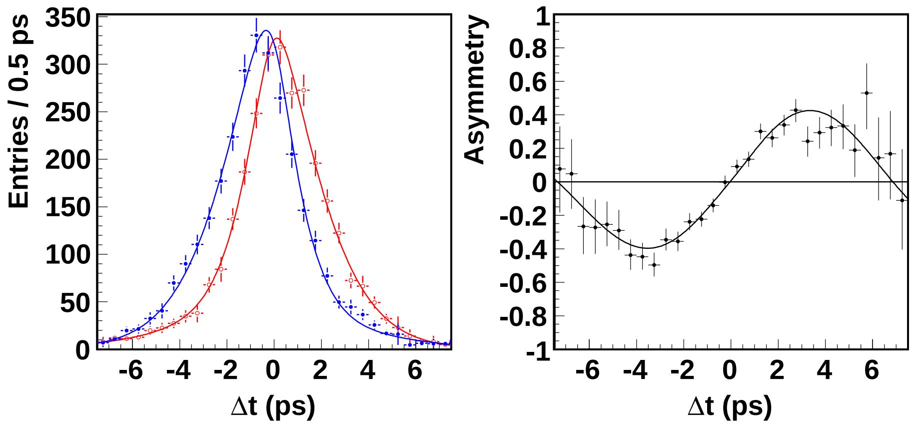

Figure 1: Decay time distribution (left) of $B^0 \to J/\psi K_S^0$ (red open circle) and $\overline{B}^0 \to J/\psi K_S^0$ (blue filled circle) and their asymmetry (right) measured by Belle with the final 772 million $B\overline{B}$ dataset. Only good flavor-tag sample is shown.

hence not a pure *CP*-eigenstate. These modes are still equally or even more sensitive to ϕ_1 because the slow pion from $D^{*\pm}$ makes the data sample much cleaner. Belle has reported the first 5σ observation of *CP* violation in the $D^{*+}D^{*-}$ mode, with the *CP*-odd fraction of $(14 \pm 2 \pm 1)\%$ [4], while BaBar has developed a new partial reconstruction technique for the $D^{*+}D^{*-}$ mode in which one of D^* is tagged only by the slow pion [5]. All the measurements of $D^{(*)+}D^{(*)-}$ are consistent with each other, although the statistical power is still limited compared to the $b \to c\overline{c}s$ modes.

Another example is the charmless decays through the $b \to q\overline{q}s$ transition ($q = u, d, s$). The main contribution is from a penguin loop diagram which may be altered by physics beyond the SM, and there used to be a large discrepancy in the measured ϕ_1^{eff} value from the ϕ_1 value from $b \to c\overline{c}s$, in particular in the $B \to \phi K_S^0$ mode. The latest addition was made by BaBar in the $B \to K^+K^-K_S^0$ modes in which the K^+K^- mass combination is separated into ϕ, $f_0(980)$ and the others [6], and they report

$$\phi_1^{\text{eff}}(\phi K_S^0) = (21 \pm 6 \pm 2)^\circ, \quad \phi_1^{\text{eff}}(K^+K^-K_S^0) = (20.3 \pm 4.3 \pm 1.2)^\circ, \tag{2.3}$$

in very good agreement with ϕ_1 from $b \to c\overline{c}s$. The asymmetry plot for $B \to \phi K_S^0$ is shown in Fig. 2. There are numerous decay modes of this class for some of which marginal deviations have been previously reported, but no evidence of deviation has remained today.

2.3 ϕ_2 measurements

The decay mode $B \to \pi^+\pi^-$ is a $b \to u\overline{u}d$ process, and as far as there is only the dominant tree diagram, a time dependent asymmetry measurement provides $\mathscr{S}_{\pi\pi} = \sin 2\phi_2$ and $\mathscr{A}_{\pi\pi} = 0$. Unfortunately it is not the case as a $b \to d$ penguin diagram with a different CKM phase is not negligible and the measured phase $\phi_2^{\text{eff}} = \phi_2 + \kappa$ is no more the angle ϕ_2.

This difficulty can be solved by an isospin analysis that disentagles the contributions of various diagrams from two triangular relations between $A(B^0 \to \pi^+\pi^-)$, $A(B^0 \to \pi^0\pi^0)$ and $A(B^+ \to \pi^+\pi^0)$, and $A(\overline{B}^0 \to \pi^+\pi^-)$, $A(\overline{B}^0 \to \pi^0\pi^0)$ and $A(B^- \to \pi^-\pi^0)$, where A is the amplitude of

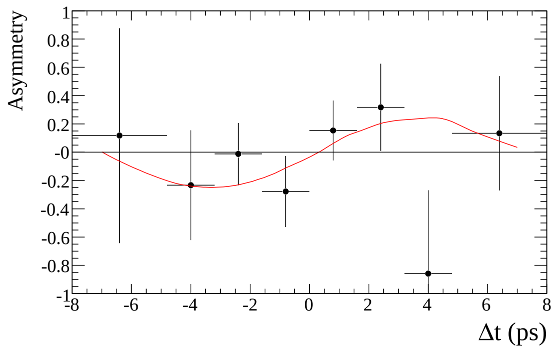

Figure 2: BaBar's time-dependent *CP* asymmetry measurement for $B \to \phi K^0_S$ with 468 million $B\overline{B}$ dataset.

the process. Therefore, branching fractions for all charge combinations of $B \to \pi\pi$ have to be measured, including the time-integrated *CP* asymmetry of $B \to \pi^0\pi^0$. This relies on the isospin symmetry, which is broken due to the contributions from electroweak penguin diagram, mass difference between u and d quarks and π-$\eta^{(\prime)}$ mixing, but the effect to ϕ_2 is only as large as 2° and can be neglected or included in the systematic error for the moment. The same analysis can be applied to the $B \to \rho\rho$ modes, once the polarization is resolved.

The $B^0 \to \pi^+\pi^-\pi^0$ decay mode contains $\rho^+\pi^-$, $\rho^-\pi^+$ and $\rho^0\pi^0$ final states which interfere in the Dalitz plot plane. Decay amplitudes to these final states are sensitive to ϕ_2, and the value of ϕ_2 can be directly disentangled from a time-dependent Dalitz plot analysis. In addition, measurements of $B^\pm \to \rho^\pm\pi^0$ and $B^\pm \to \rho^0\pi^\pm$ can be used for a further improvement.

All three of $B \to \pi\pi$, $\rho\rho$ and $\rho\pi$ are analyzed by Belle and BaBar. Each of the results has multiple solutions due to the intrinsic multifold ambiguities, but the combined result fixes it to a single solution,

$$\phi_2 = (88.7^{+4.6}_{-4.2})^\circ \tag{2.4}$$

of which the $\rho\rho$ result provides the most stringent bound. There are still more Belle and BaBar analyses to be completed with the final dataset, and LHCb will contribute to the charged particle only final states.

A new result from LHCb with 0.7 fb^{-1} now provides the first significant 3.2σ measurement for a mixing-induced *CP* asymmetry measurement at a hadron collider [7],

$$\mathscr{S}_{\pi\pi} = 0.56 \pm 0.17 \pm 0.03, \quad \mathscr{A}_{\pi\pi} = 0.11 \pm 0.21 \pm 0.03, \quad \text{(LHCb)} \tag{2.5}$$

from 5359 ± 59 events and tagging efficiency of $(2.3 \pm 0.1)\%$. A drastic improvement of ϕ_2 is a homework for the next generation B-factories.

3. CKM measurements with tree processes

The third angle ϕ_3 is determined in a tree process. In addition, here we discuss the pure leptonic decay $B^+ \to \tau^+\nu$ as it is sensitive to the unitarity triangle. The state of the art semileptonic decays used to determine $|V_{cb}|$ and $|V_{ub}|$ is discussed elsewhere [8] and is omitted from this review.

3.1 ϕ_3 measurements with $B \to DK$

The decay mode $B^- \to D^0 K^-$ is a singly Cabibbo suppressed tree $b \to c\bar{u}s$ process, and there is no other significant contribution. However, there is an almost equally suppressed similar decay mode $B^- \to \overline{D}{}^0 K^-$ from the $b \to u\bar{c}s$ transition, and as D^0 and $\overline{D}{}^0$ can mix in the hadronic decay mode, they interfere and produce direct CP asymmetry between B^- and B^+. This asymmetry is sensitive to the angle ϕ_3, and it can be extracted using various techniques.

The first technique is the Gronau-London-Wyler (GLW) method, using the D meson decaying into a CP-eigenstate K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0$, etc. One of the decay mode provides two observables (A_{cp} and R_{cp}) while there are three unknown quantities, and more than one modes are needed to resolve ϕ_3. LHCb is now providing the most precise measurements on the GLW measurements in $B^- \to D_{CP}K^-$ [9], with

$$A_{cp} = 0.145 \pm 0.032 \pm 0.010, \quad R_{cp} = 1.007 \pm 0.038 \pm 0.012. \tag{3.1}$$

LHCb has also reported the first measurement of the GLW mode $B^0 \to D_{cp}K^{*0}$ mode [10]. This mode is considered to be very sensitive to ϕ_3, and as expected, a large CP asymmetry is observed,

$$A_{cp} = -0.47^{+0.24}_{-0.25} \pm 0.02, \quad R_{cp} = 1.42^{+0.41}_{-0.35} \pm 0.07, \tag{3.2}$$

although the error is still large. Other D_{CP} modes with K_S^0 or π^0 are not easy at LHCb and the results are provided only from Belle and BaBar.

The second technique is the Atwood-Dunietz-Soni (ADS) method, using the D meson decaying into a doubly Cabibbo suppressed (DCS) mode, such as $D^0 \to K^+\pi^-$, $K^+\pi^-\pi^0$, etc. Similar to the GLW method, a single mode provides two constraints for three unknowns, and more than one modes are needed to resolve ϕ_3. LHCb has reported the most precise measurement for the $B^- \to DK^-$, $D \to K^+\pi^-$ channel,

$$A_{cp} = -0.52 \pm 0.15 \pm 0.02, \quad R_{ADS} = (1.52 \pm 0.20 \pm 0.04) \times 10^{-2}. \tag{3.3}$$

There is a 4σ evidence of CP violation as shown in Fig. 3.

The third technique is a Dalitz plot method using $D^0(\overline{D}{}^0) \to K_S^0\pi^+\pi^-$. The decay rate for B^+ (B^-) as a function of the Dalitz plot position can be described by the size of the D^0 Dalitz plane amplitude $|A|$ and its mirror image $|\overline{A}|$ ($\overline{D}{}^0$ Dalitz plane amplitude $|\overline{A}|$ and its mirror image $|A|$), their strong phase difference δ_D, and the ratio and phase of amplitudes, r_B and δ_B of $B^+ \to D^0K^+$ to $B^+ \to \overline{D}{}^0K^+$ ($B^- \to \overline{D}{}^0K^-$ to $B^- \to D^0K^-$), as

$$P^{\pm} = |A|^2 + r_B^2|\overline{A}|^2 + 2|A||\overline{A}|(x_{\pm}\cos\theta_D + y_{\pm}\sin\theta_D) \tag{3.4}$$

where $x_{\pm} = r_B\cos(\delta_B \pm \phi_3)$ and $y_{\pm} = r_B\sin(\delta_B \pm \phi_3)$. This method provides the best direct determination of ϕ_3,

$$\phi_3 = (66 \pm 12)^{\circ}. \tag{3.5}$$

Here, the knowledge of the D^0 Dalitz amplitude is crucial, and introduces a systematic error on how the D^0 decay is modeled. A workaround is to directly measure the D^0 Dalitz amplitude using the CP correlated $D^0\overline{D}{}^0$ decay sample at the $\phi(3770)$ energy. Such information in bins of the Dalitz plane has been provided by CLEO-c. Belle has performed a model-independent measurement of ϕ_3 with this method [11], and proved the validity of the method at a slight cost of the statistics.

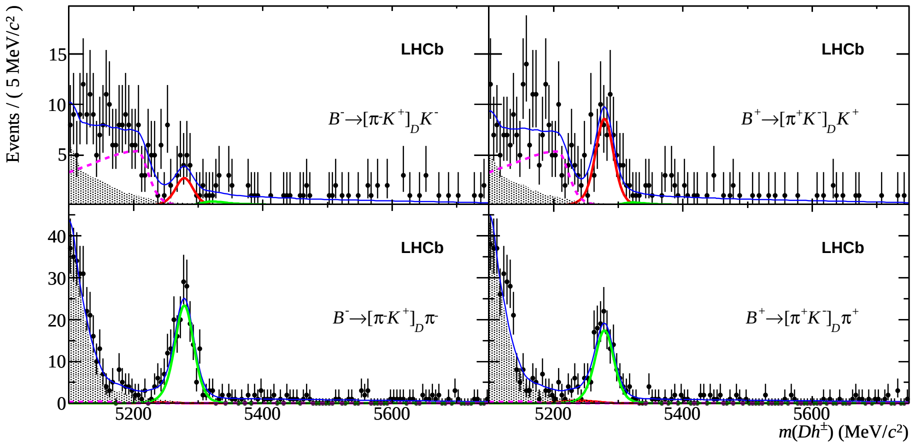

Figure 3: LHCb's measurement of ADS decay mode of $B \to DK$.

3.2 $B \to \tau\nu$ and CKM parameters

The branching fraction of a purely leptonic B decay, $B \to \ell\nu$, is proportional to $f_B^2|V_{ub}|^2$ in the SM, where f_B is the B meson decay constant. At the same time, $B \to \ell\nu$ is also sensitive to charged Higgs boson of the type-II Higgs-doublet model which replaces the weak boson and could deviate the branching fraction. Due to the helicity suppression, the decay with a τ lepton has the largest branching fraction and it is the only purely leptonic decay so far for which evidence was seen, while for the muon and electron mode only upper limits are set.

$B \to \tau\nu$ is sensitive to the $|V_{ub}|$ with information of f_B from Lattice QCD calculations, which is unfortunately not precise enough to be competitive with other determinations. However, the same f_B appears in the B mixing parameter Δm_d, which is precisely measured. By factoring out f_B, one can predict $\mathscr{B}(B \to \tau\nu)$ from other CKM measurements such as the angle ϕ_1.

Reconstruction of $B \to \tau\nu$ is not trivial as there are at least two missing neutrinos in the final state. Two techniques have been developed to measure $B \to \tau\nu$ by tagging the other B meson in the event. One is to fully reconstruct a set of as many hadronic decay channels as possible and the other is to reconstruct $B \to D^{*0}\ell\nu$ decays with one more missing neutrino. In either case the event signature is the visible τ decay products, e.g., in $\tau \to \ell\bar{\nu}\nu$, $\tau \to \pi\nu$ or $\tau \to \rho\nu$ decays and no other activity in the detector, which is evaluated as the extra energy in the electromagnetic calorimeter to peak at zero.

Both methods have been applied by Belle and BaBar, and evidence of the $B \to \tau\nu$ decay has been reported. Moreover, all four measurements have given consistent branching fractions that are larger than the SM expectation. This corresponds to a 2.8σ tension between direct and indirect $\mathscr{B}(B \to \tau\nu)$ determination.

BaBar has finalized the measurement with the hadronic tag using the full dataset of 468M $B\overline{B}$ [12], and measured the branching fraction to be $\mathscr{B}(B \to \tau\nu) = (1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4}$, which is consistent with the previous measurements. The BaBar average with the semileptonic tag analysis becomes $(1.79 \pm 0.48) \times 10^{-4}$.

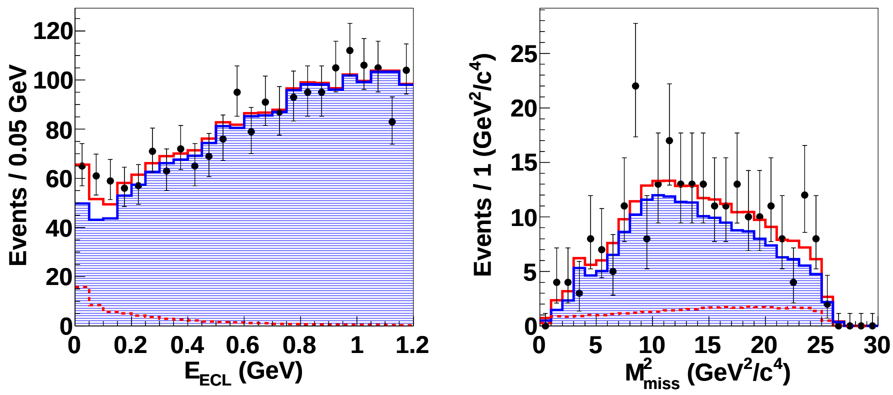

Figure 4: Belle's measurement of $B \to \tau\nu$ with the hadronic tag method using the final dataset.

Belle has updated the measurement with the hadronic tag using the full dataset of 772M $B\overline{B}$ with various improvements in the analysis [13]. The dataset corresponds to 72% increase from the previous 449M $B\overline{B}$ dataset. The majority of the events have been reprocessed with a new tracking algorithm with a significantly improved slow track reconstruction efficiency. A new hadronic-tag algorithm based on a NeuroBayes neural network program with significantly improved tag efficiency is applied. A new K_L^0 veto is added to suppress the background events with a K_L^0 which escapes the tracking and calorimetry devices. In addition to the calorimeter energy, the missing mass of the event is included as an additional fit parameter. In total, 3.7 times larger efficiency is achieved and the expected statistical error is halved for the same branching fraction. The fit results are shown in Fig. 4. The branching fraction is found to be $\mathscr{B}(B \to \tau\nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$, which is much smaller than the previous result. The Belle average is $(0.96 \pm 0.26) \times 10^{-4}$.

All results are compared in Fig. 5. The new world average is $(1.15 \pm 0.23) \times 10^{-4}$, which is no more inconsistent with the SM expectation, but the difference between measurements is somewhat puzzling.

4. *CP* violation in charm and τ

B-factories have been producing large samples of charm hadrons and τ lepton pair events, and they can be also studied at hadron colliders. Accumulation of the statistics of charm and τ events is now making searches of *CP* violation more interesting, as it can be a clearer sign of physics beyond the SM than those in *B* decays.

4.1 Direct *CP* violation in $D^0 \to K^+K^-$ and $\pi^+\pi^-$

Measuring *CP* violation in charm decay is less simple than that in *B* decays due to non-negligible production rate and detection efficiency asymmetries. However, such asymmetries cancel out by measuring the difference of *CP* asymmetries in two decay channels.

Recently LHCb reported evidence of non-zero *CP* asymmetry difference, $\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-) = (-0.82 \pm 0.21 \pm 0.11)\%$ [14]. As these final states are *CP*-eigenstates,

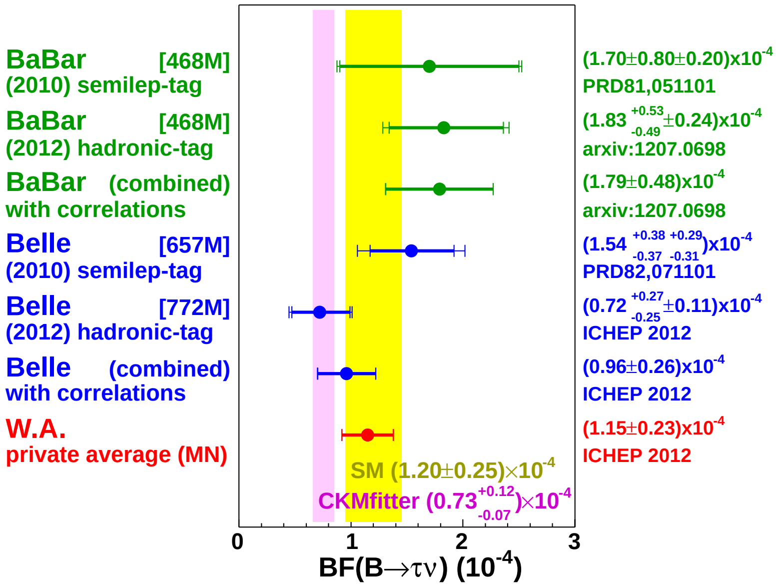

Figure 5: Comparison of $B \to \tau \nu$ branching fraction measurements.

the flavor of the initial state is tagged by the slow pion of $D^{*+} \to D^0\pi^+$. The production asymmetry and the slow pion detection asymmetry are canceled in ΔA_{CP}.

CDF confirmed this tendency, $\Delta A_{CP} = (-0.62 \pm 0.21 \pm 0.10)\%$ [15]. In the case of CDF there is no production asymmetry, and individual A_{CP} can be measured after correcting for the slow pion asymmetry. Belle's measurement also has a similar tendency, $\Delta A_{CP} = (-0.87 \pm 0.41 \pm 0.06)\%$. CDF, BaBar and Belle reported individual A_{CP} for $D^0 \to K^+K^-$ and $D^0\pi^+\pi^-$, but none of them is significantly deviated from zero. BaBar has not reported the difference, but the tendency is in the opposite direction with a large error.

The HFAG average

$$\Delta A_{CP} = (-0.678 \pm 0.147)\% \tag{4.1}$$

is deviated from zero by more than 4σ. In order to understand the nature of the difference in the direct *CP* asymmetry, one has to find A_{CP} in other charm meson decay modes.

4.2 Direct *CP* violation in $D^+ \to K^0_S\pi^+$

An interesting direct *CP* violation measurement is performed by Belle [16] and BaBar [17] on $D^+ \to K^0_S\pi^+$. Including the less sensitive CLEO and FOCUS results, the world average is

$$A_{CP}(D^+ \to K^0_S\pi^+) = (-0.41 \pm 0.09)\%, \tag{4.2}$$

deviating from zero by more than 4σ. However, this includes the *CP* asymmetry in K^0_S mixing, $(-0.332 \pm 0.006)\%$, which is slightly modified in the contribution to the measurement of $A_{CP}(D^+ \to K^0_S\pi^+)$ in a detector dependent way due to the finite acceptance and $K^0/\overline{K}^0$ cross-section difference with the detector material. After subtracting the K^0_S mixing asymmetry, intrinsic asymmetry in D^+ decay is consistent with zero.

4.3 Direct *CP* violation in $\tau \to K_S^0 \pi^+ n(\pi^0)\nu$

A similar search can be performed in τ decays with a K_S^0 in the final state. In order to search for intrinsic *CP* asymmetry in τ decays, the K_S^0 asymmetry contribution has to be subtracted.

Belle has searched for *CP* asymmetry in $\tau \to K_S^0 \pi^+ \nu$ and found the intrinsic *CP* asymmetry is consistent with zero [18]. BaBar performed the direct A_{CP} measurement in $\tau \to K_S^0 \pi^+ n(\pi^0)\nu$ where $n = 0,1,2$, and found uncorrected $A_{CP} = (-0.36 \pm 0.23 \pm 0.11)\%$ [19]. This has the sign opposite from the SM expectation of $(+0.36 \pm 0.01)\%$ and deviate from the SM by 2.8σ. *CP* asymmetry search with a higher statistics data sample would be interesting in the future e^+e^- B-factory.

5. Summary

Today, all the CKM unitarity triangle sides and angles are measured after 10 years of operation of two B-factories, Belle and BaBar, although the data analysis has not been completed yet. And now LHCb is opening new doors in many channels. One of the new highlights is that the branching fraction of $B \to \tau\nu$ is not settled yet as Belle's new result has drug down the tension.

In general, we have observed that the unitarity triangle is closing at the 10% accuracy. This may still be a coincidence, but it seems to search for physics beyond the SM we need a better precision. Fortunately we expect more results from LHCb in the coming years, and the next generation e^+e^- B-factory, SuperKEKB, is under construction.

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