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Recent results of the Unitarity Triangle from B-factories and perspectives for a superB

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Summary. — This paper reports a selection of results obtained at the B-factories, focusing on the measurements of the sides and the angles of the Unitarity Triangle. The high luminosity achieved at these machines allowed to perform high-precision measurements, and verify the Standard Model (SM). Projects to build a *superB* factory have been presented: with even higher precision, new physics scenarios can be explored and constrained.

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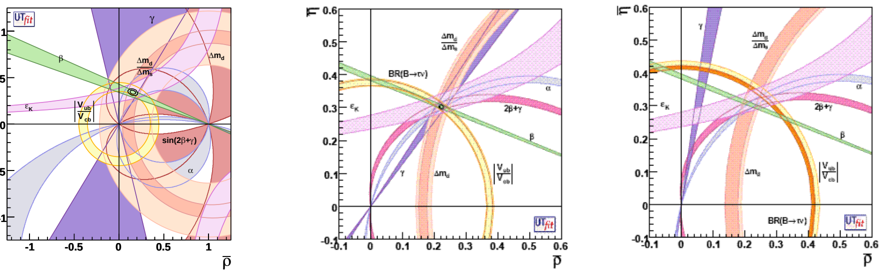
1. – Introduction

The *BaBar* and *Belle* experiments performed precise measurements of the sides and the angles of the Unitarity Triangle (UT), thanks to the beam asymmetry, that allowed to measure the amplitude $A(t)$ as a function of time; and the high luminosity achieved, that made it possible also to perform good measurements of rare B-meson decays. The recent results of the angles and sides of the UT will be shown in the next section. Finally, the possibility to improve the precision with which we know those results will be shown, in the perspective to analyze New Physics (NP) processes in a new Super Flavour Factory (SFF); and a comparison with the expected measurements at LHCb experiment (next coming) will be given, in order to highlight that the new SFF is a complementary rather than competitor project to LHCb.

2. – The Unitarity Triangle

The determination of the UT angles and sides is a fundamental test to establish the Standard Model of the elementary particles. In fig. 1(a) the main constraints to the UT are summarized, by combining together the measurements performed in different experiments, in several analyses. In this paper we will summarize in few tables the main results of the measurements of α, β and γ in the *BaBar* and *Belle* experiments. Later we will present the measurements of V_{ub} and V_{cb}.

The angle β (ϕ_1) is historically the first measured at the B factories, by analyzing the *golden channel* $B^0 \to J/\psi K^0_S$, and in particular the determination of $\sin(2\beta)$ was done, studying the time-dependent CP asymmetries to CP eigenstates. The most precise

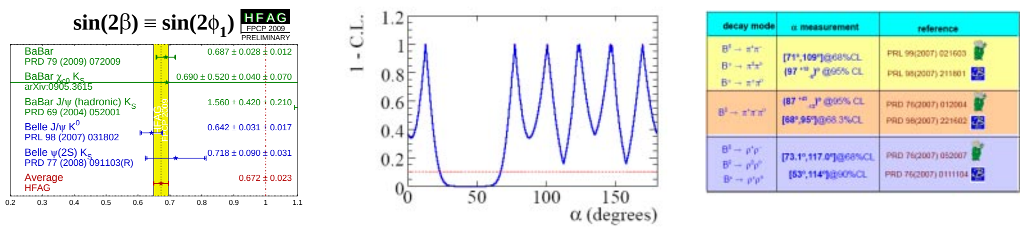


(a) $\bar{\rho}$-$\bar{\eta}$ plane today (b) $\bar{\rho}$-$\bar{\eta}$ plane in a SFF scenario: SM established (c) $\bar{\rho}$-$\bar{\eta}$ plane in a SFF scenario of NP

Fig. 1. – (a) A UTfit plot [1] representing the allowed regions for ($\bar{\rho}$-$\bar{\eta}$). The closed contours at 68% and 95% probability are shown. The full lines correspond to 95% probability regions for the constraints, given by the measurements of $|V_{ub}|/|V_{cb}|$, e_K, Δm_d, $\Delta m_d/\Delta m_s$, α, β, γ, $\Delta\Gamma_d/\Gamma_d$, $\Delta\Gamma_s/\Gamma_s$, A^d_{SL}, and the dimuon asymmetry from D^0. In (b, c) two different SFF scenarios are presented, as discussed in sect. **3.**

measurement was performed from the *BaBar* experiment [2], and the HFAG average now is $(21.0\pm0.9)^\circ$. The $\sin(2\beta)$ measurements performed recently at the B factories are reported in fig. 2(a). The measurement of β today is well known. It was performed in several decay channels, different experiments: we can study it in the transition at quark level $b\to c\bar{c}s$, $b\to c\bar{c}d$ and $b\to s$ *penguin* (here a NP scenario is still opened). Thanks to these analyses, the Δt oscillation plot is rather evident now [2]. Other interesting analyses where both, *BaBar* and *Belle*, performed the measurement of β are the Dalitz analyses of $B\to K_S\pi\pi$ and $B\to K_SKK$, and also the analysis of $B\to D^{*+}D^{*-}$: in the latter *BaBar* and *Belle* obtained consistent results, since in the measurement of the parameter $C=-A$ [3] they are shifted from the world average; in the former analyses, the 2 experiments are still not in perfect agreement each other [4]: more data are needed to obtain more precise measurements and clarify.

The measurement of the angle α (ϕ_2) represents a very complicated measurement, because of the penguin pollution when analyzing the transition at quark level $b\to u\bar{u}d$, where both, tree level Feynman diagram and penguin diagram, interfere. In fact, from a time-dependent CP analysis we obtain the measurement of $\alpha_{\rm eff}$, and not directly the



(a) (b) (c)

Fig. 2. – (a) $\sin(2\beta)$ and (b) α measurements performed at the *BaBar* experiment. In the plot of (b) the standard peak is in the interval $(71^\circ, 109^\circ)$ [5]. In (c) a summary of the α measurements at the B-factories is reported [6].

measurement of the angle α. This measurement can be resolved up to a 8-fold ambiguity (see fig. 2(b)). The analysis performed is an isospin-triangle analysis, that allows to determinate several parameters and to obtain the measurement of α. From the experimental point of view, the main analyses that allowed to determinate the α measurement are the analyses of $B^0 \to \pi^+\pi^-$, $B^0 \to \pi^0\pi^0$, $B^+ \to \pi^+\pi^0$ (6 observable, 6 parameters) [5], and $B^0 \to \rho^+\rho^-$, $B^0 \to \rho^0\rho^0$, $B^+ \to \rho^+\rho^0$ (5 observable, 6 parameters) [7]. In fig. 2(c) a summary of the angle α measurements in the recent analyses performed from the *BaBar* and *Belle* experiment is shown.

The measurement of the angle γ (ϕ_3) of the UT is possible as well at the B-factories. This measurement represents the most theoretically clean among all the other angle measurements, because it is performed by analyzing the interference between the transition at quark level $b \to c$ and $b \to u$, that is a tree level transition. Then, there is not penguin pollution, or all the problems related to such measurements. From the experimental point of view, to extract γ in a B factory means to analyze the decay $B^\pm \to DK^\pm$. With D we mean all the reconstructed final states, accessible to both, D^0 and $\bar{D}^0$. In analyzing such decays, the extraction of the weak phase (γ), the strong phase (δ_B) and the suppression factor (r_B) are done. It is important to note that the only non-changing parameter in analyzing $B^\pm \to D^{(*)}K^\pm$ is the weak phase γ. Three methods were optimized to extract γ, labelled with the name of their authors: ADS, GLW, GGSZ [8]. The ADS method takes into account the decay $D \to K^\pm\pi^\mp$ in both B decays, Cabibbo-allowed and double Cabibbo suppressed. In fact, the amplitude of $B^- \to D^0(K^+\pi^-)K^-$ is comparable with the amplitude of $B^- \to \bar{D}^0(K^-\pi^+)K^-$: in this way the extraction of γ is possible [9]. The GLW method analyzes the D decay to CP-eigenstates [10]. The GGSZ Dalitz analysis method performs this analysis with $D \to K_S\pi^+\pi^-$ and $D \to K_S K^+K^-$ [11]. By combining all the results obtained from the $B^\pm \to DK^\pm$, $B^\pm \to D^*K^\pm$ and $B^\pm \to DK^*$, the final measurement of γ that we obtained in *BaBar* is $(76 \pm 22 \pm 5 \pm 5)^\circ$, and in *Belle* $(76^{+12}_{-13} \pm 4 \pm 9)^\circ$. The difference in the statistics error evalueted from *BaBar* and *Belle* is due not only to the larger statistics available in *Belle*, but also to the assumption (from *Belle*) of a higher δ_B value as hypothesis.

The precision that we measured the UT angles at the B-factories led to the conclusion that the Unitarity Triangle is close, so no new physics has been found. From fig. 1 we see that a crucial test is a precise determination of the V_{ub}/V_{cb}, because it can allow to observe deviations from the CKM mechanism due to NP.

Many analyses were performed at the B-factories, measuring: $|V_{cb}|$ from spectral momenta; form factors $\times$ $|V_{cb}|$, from the decay $B \to D^{(*)}l\nu$; inclusive $|V_{ub}|$; $|V_{ub}|$ from exclusive semi-leptonic charmless B-decays.

In analyzing semi-leptonic decays we can find tree level dyagrams, theoretically clean, otherwise QCD current must be included. It makes these analyses complicated: in fact the main sistematics uncertainity in the measurements of $|V_{ub}|$ and $|V_{cb}|$ comes from theoretical model uncertainity. The main results of $|V_{ub}|$ and $|V_{cb}|$ analyses are summarized in ref. [12]. A very precision measurement of $|V_{ub}|$ was performed at Fermilab, using a fit to lattice points and the BaBar data: $|V_{ub}| = (3.38 \pm 0.35) \times 10^{-3}$.

Nowaday we know inclusive $|V_{cb}|$ at 2% precision; it is limited from the form factor knowledgment. In the exclusive measurements we obtained a value shifted 2σ from the corresponding inclusive measurements. Also, we know inclusive $|V_{ub}|$ at 8% precision, and the exclusive measurement is limited by the form factor knowledgment. We need of more data and progress in theoretical calculations to solve the puzzle. In addition, the transition $b \to d\gamma$ and $b \to s\gamma$, for the measurement of $|V_{td}|/|V_{ts}|$, are almost full explored, and the *BaBar* and *Belle* data are consistent: they establish the SM. But the fit is still not good, so more data and more precision need. These problems, and higher precision to test more precisely the SM, definitively demand for a new generation of B-factories.

3. – Perspective of a super flavour factory

The physics case of a SFF collecting an integrated luminosity of 50–70 ab^{-1} was presented. It represents only one of the advanced projects of a superB machine. The SM of elementary particles have been very successful in explaining a wide variety of existing experimental data. But it is fair to say that the flavour sector in SM is much less understood than its gauge sector. Yukawa interactions provide a phenomenological description of the flavour processes which, while successful so far, leaves most fundamental question unsolved. The search for evidence of physics beyond the SM is the main goal of particle physics in the next years. LHC and CERN will start soon looking for the Higgs boson, the last missing. At the same time it will be intensively search for NP, for which there are solid theoretical motivations related to the quantum stabilization of the Fermi scale to expect an appearance at energy around 1 TeV. Then, Flavour Physics is the best candidate as tool for NP searches through quantum effects.

The SFF should not be seen in competition with LHC*b* at CERN, but rather more a complementary project by which it will be possible to perform high-precision measurements in a sector where LHCb will not have the same level of precision.

As conclusion of this short report, the plots of fig. 1(b, c) can be reported, showing 2 possible scenarios that can be verified if a SFF machine will be built: SM established (fig. 1(b)), or the door of NP definitively opened (fig. 1(c)), when a precision higher than a factor 10 will be reached.

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