

CKM FITS AS A FUNCTION OF LUMINOSITY (TIME)

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Possible scenarios for CKM fits in the years 2005 and 2010 are presented using B- and K-physics results from extrapolated luminosities for B-factories at the $\Upsilon(4S)$, for the hadron machines at Tevatron and LHC and for rare kaon decays. The study provides an estimate of what precision for the CKM matrix elements can be achieved if all relevant experiments and accelerators, including upgrades for the existing e^+e^- machines, reach their design goal. It helps to explore which type of future experiments are needed to cover all relevant physics topics related to the CKM matrix and the search of physics beyond the Standard Model.

Introduction

The first goal addressed by global CKM fits is *Metrol-ogy*, that is to find allowed ranges for CKM matrix elements and related quantities, assuming the Standard Model(SM) to be correct. Furthermore, one intends to *probe the validity of the Standard Model*, that is to quantify the agreement between the SM and the experimental information. Finally, within an extended theoretical framework, *e.g.*, Supersymmetry, one may search for specific signals of New Physics by pinning down the additional theoretical parameters. Every appropriate statistical approach may be used, though for our purpose the non-Bayesian method *Rfit*¹ is most convenient.

It is assumed in this study that accelerators and experiments, including the foreseen upgrades for the B-factories at the $\Upsilon(4S)$, are reaching the design luminosities. We attempt to understand what parts of relevant physics are then still missing or not well covered. As a consequence, these extrapolations are hypothetical, in particular, in those cases where the experiments are still to come! For observables with large statistics the systematic error, eventually to be determined from data, is taken from educated guess-work here. Rather than showing CKM fits as a function of luminosity three eras are considered: the present situation, and possible scenarios for the years 2005 and 2010. The first outlook shows possible achievements from the B-factories and from the Tevatron (TEV IIa+b) experiments before the LHC era. The second scenario takes place after several years of data taking by BTeV and the LHC experiments. This is the time range in which also results for the rare kaon decays, $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ and $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, can be expected.

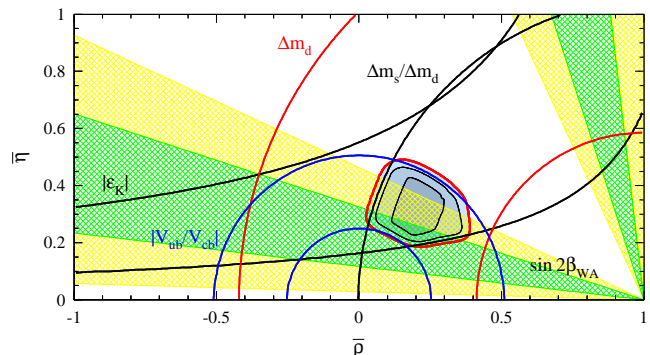


Figure 1: $\bar{\rho} - \bar{\eta}$ plane in 2001 ($\bar{\rho} = \rho(1 - \lambda^2/2)$, $\bar{\eta} = \eta(1 - \lambda^2/2)$).

Inventory

The Wolfenstein parameters² λ and A are presently measured with uncertainties of about 1% and 5%, respectively, whereas ρ and η are known with much less precision. This is because the information on the later stems from the measurements of the constraints from $|V_{ub}/V_{cb}|$, Δm_d , Δm_s and ϵ_K which suffer from dominant theoretical uncertainties: the inclusive and exclusive $|V_{ub}|$ measurements due to large systematic and model dependent errors; Δm_d , $\Delta m_s/\Delta m_d$ and ϵ_K due to uncertainties in the hadronic parameters $f_{B_d}\sqrt{B_d}$, $\xi = f_{B_s}\sqrt{B_s}/f_{B_d}\sqrt{B_d}$ and B_K . The power of the $\Delta m_s/\Delta m_d$ constraint is still not fully exploited since experiments were not able so far to significantly resolve the fast $B_s^0 - \bar{B}_s^0$ oscillations. Regardless of these uncertainties, it is a non-trivial fact that these constraints lead to a consistent picture in the $\bar{\rho} - \bar{\eta}$ plane (Fig. 1).

The measurement of $\sin 2\beta$ from neutral B-decays to CP-eigenstates containing charmonium gives an additional

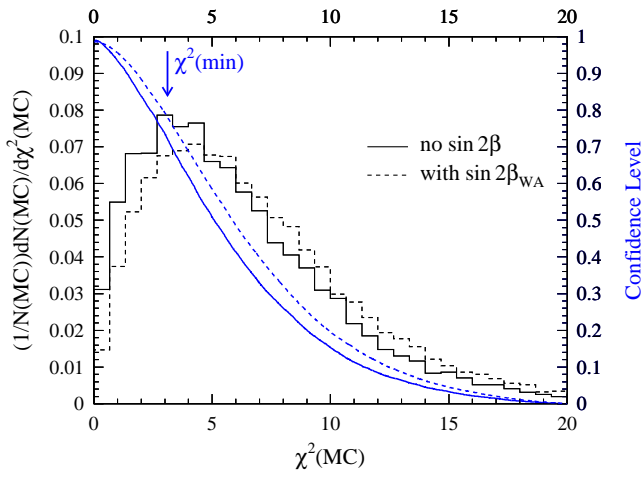


Figure 2: χ^2 distributions from the toy Monte Carlo simulation and corresponding CLs for the fit with and without $\sin 2\beta_{WA}$.

constraint. In striking contrast to the above mentioned measurements the current uncertainty of the $\sin 2\beta$ measurement is mainly of statistical nature. The most competitive results are coming from the B-factories; the world average reads $\sin 2\beta_{WA} = 0.48 \pm 0.16$.

Drawn in Fig. 1 are the 5% confidence level (CL) contours^{1a} for the constraints from $|V_{ub}/V_{cb}|$, Δm_d , Δm_s and ϵ_K and the 90%, 32% and 5% CL contours for the fit without using $\sin 2\beta_{WA}$. The 32% and 5% CL contours for $\sin 2\beta_{WA}$ indicate that the measurement is consistent with the allowed range obtained by the fit.

The agreement between data and the SM can be gauged by means of a test statistics which is interpreted using a toy Monte Carlo simulation described in Ref. ¹. The resulting χ^2 distribution from the simulation for the fit with and without $\sin 2\beta_{WA}$ and the corresponding CLs are shown in Fig. 2, indicating that no deviation from the SM is currently observed.

Extrapolation to the future

Extrapolations were obtained using mainly Refs. ³. Updated prospects can be found in these proceedings⁴. The hypothetical constraints on $\bar{\rho} - \bar{\eta}$ for 2005 and 2010 are shown in Figs. 3 and 4.

For 2005, it is assumed that BaBar and Belle are able to collect an integrated luminosity of 1000 fb^{-1} due to accelerator and detector upgrades and that a considerable part of the expected luminosity of 15 fb^{-1} at TEV II has been collected at that time. This would allow to measure $\sin 2\beta$ to better than 0.02. The precision on Δm_d will be

^aThe statistical interpretation of *confidence level* within Rfit is described in more detail in these proceedings¹. For the fit output the term *confidence level* is understood to be an upper bound for a confidence level, *i.e.*, it corresponds to the best set of theoretical parameters at a given parameter space point, *e.g.*, in $\bar{\rho} - \bar{\eta}$.

Table 1: Possible accuracies of quantities related to the CKM matrix as a function of time. If two errors are given the first accounts for statistical and accountable systematic uncertainties whereas the second error stands for theoretical uncertainties obtained from educated guess-work and is considered as a range in Rfit.

Element	2001	2005	2010
Belle, BaBar	$\approx 30 \text{ fb}^{-1}$	1000 fb^{-1}	4000 fb^{-1}
CLEO	$\approx 10 \text{ fb}^{-1}$		
TEV II		15 fb^{-1}	
$ V_{ub} $	$\pm 20\%$	$\pm 10\%$	$\pm 10\%$
$ V_{cb} $	$\pm 5\%$	$\pm 5\%$	$\pm 3\%$
Δm_d (ps^{-1})	± 0.014		
Δm_s (ps^{-1})	> 15.0	$\pm 0.2\%$	
m_t ($\bar{M}S$) (GeV)	± 5.0	± 3.0	± 1.0
m_c (GeV)	± 0.1		
B_K	$\pm 0.06 \pm 0.13$	$\pm 0.03 \pm 0.07$	
$f_{B_d} \sqrt{B_d}$ (MeV)	$\pm 28 \pm 28$	$\pm 10 \pm 10$	
ξ	$\pm 0.03 \pm 0.05$	$\pm 0.015 \pm 0.025$	
$\sin 2\beta$ from	± 0.16	$\pm 0.01 \pm 0.01$	$\pm 0.005 \pm 0.005$
$B \rightarrow J/\psi K_s$	$\Upsilon(4S)$	$\Upsilon(4S)$	+BTeV/LHCb
and others	+TEV II	+TEV II	+CMS/ATLAS
α from	-	$\pm 5^\circ$	$\pm 2^\circ$
$B \rightarrow \rho\pi(\pi\pi)$	-	$\Upsilon(4S)$	+BTeV/LHCb
γ from	-	$\pm 10^\circ$	$\pm 6^\circ$
$B_{d(s)} \rightarrow D_{(s)}K$	-	$\Upsilon(4S)$	+BTeV/LHCb
		+TEV II	
$K_L \rightarrow \pi^0 \nu \bar{\nu}$	Limit	KOPI0/KAMI	BR \cdot ($\pm 7\%$)
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$	1 eV (E787)	E949, CKM	BR \cdot ($\pm 5\% \pm 4\%$)

improved at the B-factories resulting in a small improvement of the Δm_d constraint. If the frequency for $B_s^0 - \bar{B}_s^0$ oscillations is not considerably larger than the range of values predicted by the CKM constraints¹ then Δm_s will be measured by CDF and D0 at TEV II to a very good precision and the uncertainty from the $\Delta m_s/\Delta m_d$ constraint will be dominated by the QCD parameter ξ . The top mass is expected to be measured to a precision of 3 GeV at TEV II. The theoretical uncertainty on $|V_{ub}|$ may be reduced to the 10% level⁴. Some theoretical improvement from lattice QCD on B_K , $f_{B_d} \sqrt{B_d}$ and ξ can be expected. We assume a reduction of the uncertainties on these parameters by a factor of two. Measurements of α

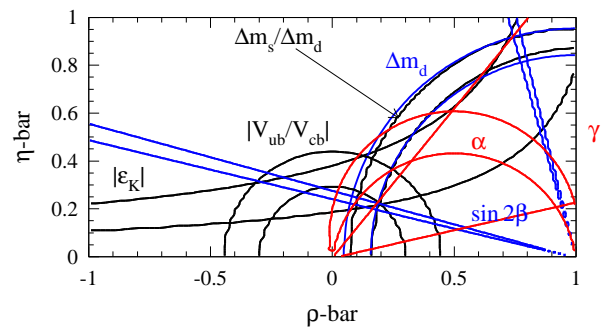


Figure 3: Hypothetical $\bar{\rho} - \bar{\eta}$ plane in 2005.

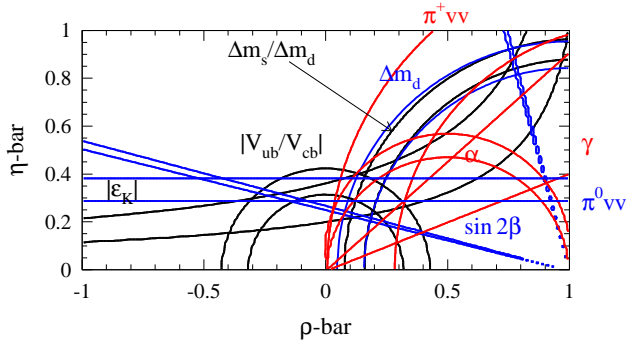


Figure 4: Hypothetical $\bar{\rho} - \bar{\eta}$ plane in 2010.

are possible if a Dalitz plot analysis in $B \rightarrow 3\pi$ and/or the penguin pollution in $B \rightarrow \pi\pi$ can be managed. A measurement of γ , though less precise and without resolving all ambiguities, can be achieved using $B_{d(s)} \rightarrow D_{(s)}K$ decays. Under these assumptions the allowed range in the $\bar{\rho} - \bar{\eta}$ plane is then already impressively reduced, to the point that it can not be seen in Fig. 3.

In 2010, an enormous amount of data will be collected by B-TeV, LHCb, ATLAS and CMS which will lead to a further improvement of $\sin 2\beta$. Nevertheless, the B-factories can still be competitive if they achieved their luminosity goals. In particular, the dedicated B-hadron experiments will provide significant improvements on the angles α and γ . At this stage, systematic and theoretical errors on this quantity will most likely dominate. The error on the top mass can be reduced at the top factory LHC. Theoretical developments are hard to predict. One may hope that, *e.g.*, $|V_{cb}|$ can be further improved to the 3% level. Without new theoretical techniques the uncertainty on $|V_{ub}|$ will most likely be limited at the 10% level. Additional constraints of high quality will be introduced if experiments at FNAL and BNL will succeed in measuring the theoretically quite clean rare kaon decays, $K_L \rightarrow \pi^0 \nu \bar{\nu}$ and $K^+ \rightarrow \pi^+ \nu \bar{\nu}$. The metrological knowledge may reach a remarkable precision: the allowed range in $\bar{\rho} - \bar{\eta}$ (Fig. 4) being almost point-like.

These considerations are certainly not complete as several channels, *e.g.*, rare B-decays, or bounds on γ from charmless two-body B-decays, have not been taken into account, yet. Moreover, the impact of LHCb and BTeV is clearly underestimated since many measurements, *e.g.*, the rich potential of the channel $B_s \rightarrow \psi\phi$, are still not incorporated. With an improvement of the theoretical understanding, the direct CP-violating observable ϵ'/ϵ could provide additional information. Prospects for experiments running on the $\Upsilon(5S)$ resonance were also not considered here.

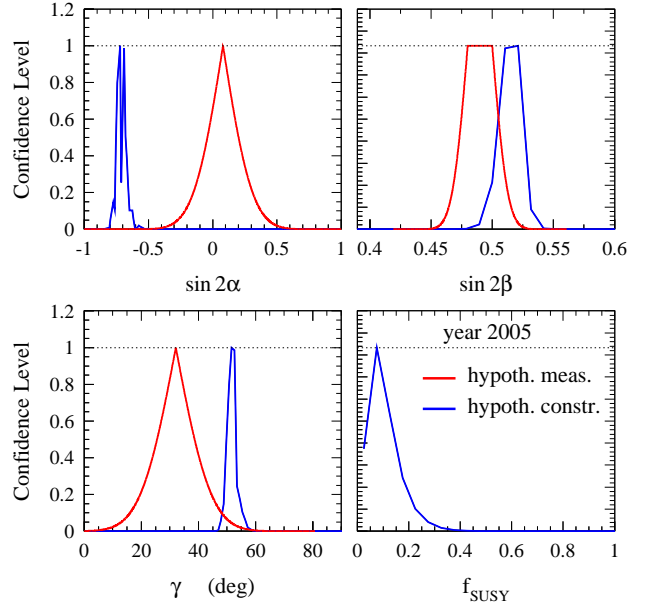


Figure 5: Comparison between CL for hypothetical measurements (light grey) in 2005 and the fit output (dark grey). Also shown is the CL for the parameter f_{SUSY} (see text).

Deviation from the SM

In this section we consider a scenario in which inconsistencies between several measurements occur. For the hypothetical measurements of the unitarity triangle angles, $\sin 2\beta$ is fixed at the current world average, and values of $\gamma = 32^\circ$ and $\sin 2\alpha = 0.1$ were chosen.

Supersymmetric models are attractive candidates for physics beyond the SM. However, even the minimal supersymmetric extension of the SM (MSSM) already contains a large number of parameters. In a simple model given by Ali and London⁵ only one parameter, here denoted by f_{SUSY} , is introduced which modifies the top-exchange box-diagrams in ϵ_K and $B^0 - \bar{B}^0$ -mixing. As a consequence, the model is mainly sensitive to the angle γ . For the example chosen, the CL s of the hypothetical measurements are compared to the (upper bounds of) CL s of the fit (Fig. 5). Due to its precision $\sin 2\beta$ would pull the fit result towards the measurement. A disagreement would be observed for α . The parameter f_{SUSY} would be found to be consistent with zero (Fig. 5) whereas the CL s for the fit (Fig. 6) would be small, meaning that the simple model could not accommodate such measurements. The inconsistency would be pronounced even more for the extrapolated precisions in 2010 (Fig. 6).

The example illustrates that a disagreement between data and the SM does not necessarily imply an understanding of the data. Although the CKM fit is a powerful tool to detect a failure of the SM it does not tell us what kind of New Physics rules the behaviour of the

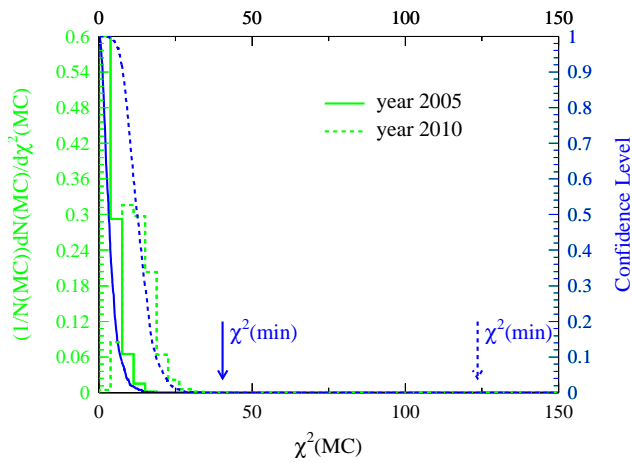


Figure 6: χ^2 toy Monte Carlo distributions and corresponding CL in case of the example chosen for 2005 and 2010.

observables. It is unlikely that an eventual extension of the SM is as simple as the model above described. Hence various toy models representing distinct “classes” of SM extensions are desirable. These models should contain a sufficient but not too large number of parameters to provide a rich CKM-phenomenology. This would help to study possible scenarios of SM failures beforehand.

Conclusion

It is the predominant goal of the ongoing B and K physics efforts to determine the CKM matrix elements as precisely as possible. A lot of different observables can be measured during the next decade. The SM picture of CP violation can be tested with high sensitivity since the four independent CKM matrix elements have to describe all data on the same basis. For some parameters redundant information from different measurements will be obtained hence providing the potential to detect hints for New Physics. For example, a comparison between $\sin 2\beta$ measured in $B \rightarrow \phi K_S$ (if manageable) and $B \rightarrow J/\psi K_S$ could allow to pin down New Physics contributions in $b \rightarrow s$ penguins. However, it’s hard to predict what precision for such a comparison is needed since the eventual SM extension, e.g., a SUSY model, has to be specified.

Many measurements not affected by large theoretical or systematic uncertainties need to be accumulated. This is certainly the case for $\sin 2\beta$, γ , rare kaon decays and also α if the penguin pollution can be determined from data. Moreover, theoretical uncertainties ought to be reduced where possible. One might benefit from theoretical improvements, e.g., unquenched lattice QCD calculations although it is hard to predict what precision can eventually be achieved. Experimental results could help in this respect. A measurement of the ratio f_{D_s}/f_{D_d} at

a τ /charm factory is useful to gauge the calculation of ξ . The decay $B^+ \rightarrow \tau^+ \nu_\tau$ would measure the product $f_{B_d} \cdot |V_{ub}|$ and thus strengthen the constraint on $\bar{\rho} - \bar{\eta}$ from Δm_d . Measurements of $|V_{ub}|$ with a theoretical uncertainty on the order 10% seem to be possible. It is an important issue for the inclusive measurements of $|V_{ub}|$ and $|V_{cb}|$ to pin down the size of possible violations of quark-hadron duality, that is to quantify the validity of the Heavy Quark Expansion.

In 2005, the constraints in the $\bar{\rho} - \bar{\eta}$ plane could be already strong if the B-factories succeeded their upgrades and the TEV II programme proceeds as expected. Due to the additional impact from hadron machines and rare kaon decays the metrological knowledge will be remarkable in 2010. If on this time scale the CKM matrix is still consistent with the SM the metrological phase might reach an end. However, if deviation from the SM is observed or a direct signal for New Physics is detected during the next ten years, e.g., at the LHC, the question of required precision for particular observables would find a more quantitative answer. Clearly, the situation has to be regularly addressed, in particular in light of a “Beyond 10^{34} B-factory”. Very challenging measurements like $B \rightarrow X_{d,s} \nu \bar{\nu}$ should be re-considered according to these evaluations.

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