CKM fitter FPCP 06

UPDATED RESULTS ON THE CKM MARTIX AND THE UNITARITY TRIANGLE

Including results presented up to
FPCP 06, Vancouver, Canada

P r e l i m i n a r y

April 14, 2006

The CKMfitter Group

Abstract

This document provides the collection of up-to-date inputs to the global CKM analysis, and numerical results obtained with the use of the fit package CKMfitter. The statistical method employed is the frequentist approach *R*fit. Detailed background information on the methodology and the treatment of experimental and theoretical uncertainties is provided in:

CP VIOLATION AND THE CKM MATRIX:
ASSESSING THE IMPACT OF THE ASYMMETRIC *B* FACTORIES
By CKMfitter Group
Eur. Phys. J. **C41**, 1-131, 2005 [hep-ph/0406184]

The CKMfitter Group

J. Charles[b], O. Deschamps[c], A. Höcker[g], A. Jantsch[e], H. Lacker[e], J. Malclès[f], S. Monteil[c], J. Ocariz[f], S. Pruvot[d], A. Robert[c], L. Roos[f], S. T'Jampens[a], V. Tisserand[a], K. Trabelsi[h]

[a] *Laboratoire d'Annecy-Le-Vieux de Physique des Particules*
9 Chemin de Bellevue, BP 110, F-74941 Annecy-le-Vieux Cedex, France
(UMR 5814 du CNRS-IN2P3 associée à l'Université de Savoie)
e-mail: tisserav@lapp.in2p3.fr, tjamp@lapp.in2p3.fr

[b] *Centre de Physique Théorique,*
Campus de Luminy, Case 907, F-13288 Marseille Cedex 9, France
(UMR 6207 du CNRS associée aux Universités d'Aix-Marseille I et II
et Université du Sud Toulon-Var; laboratoire affilié à la FRUMAM-FR2291)
e-mail: charles@cpt.univ-mrs.fr

[c] *Laboratoire de Physique Corpusulaire de Clermont-Ferrand*
Université Blaise Pascal
24, avenue des Landais F-63177 Aubiere Cedex
(UMR 6533 du CNRS-IN2P3 associée à l'Université Blaise Pascal)
e-mail: odescham@in2p3.fr, monteil@clermont.in2p3.fr, arobert@in2p3.fr

[d] *Laboratoire de l'Accélérateur Linéaire,*
Bât. 200 BP34 F-91898 Orsay, France
(UMR 8607 du CNRS-IN2P3 associée à l'Université Paris XI)
e-mail: pruvot@lal.in2p3.fr

[e] *Technische Universität Dresden,*
Institut für Kern- und Teilchenphysik, D-01062 Dresden, Germany
e-mail: h.lacker@physik.tu-dresden.de

[f] *Laboratoire de Physique Nucléaire et de Hautes Energies*
4 place Jussieu, F-75252 Paris Cedex 05, France
(UMR 7585 du CNRS-IN2P3 associée aux Universités Paris VI et VII)
e-mail: malcles@lpnhep.in2p3.fr, ocariz@in2p3.fr, lroos@lpnhep.in2p3.fr

[g] *CERN, PH Department*
CH-1211 Geneva 23, Switzerland
e-mail: andreas.hocker@cern.ch

[h] *University of Hawaii*
Honolulu, Hawai, 96822
e-mail: karim@phys.hawaii.edu

References

[1] Results presented at the San Diego CKM workshop, http://ckm2005.ucsd.edu/ hep-ph/0512039

[2] The Heavy Flavor Averaging Group (HFAG), Winter 2006 averages, http://www.slac.stanford.edu/xorg/hfag/

[3] For the inclusive average we are taking the BLNP number. The DGE result is very close to. The theoretical error on the inclusive average is obtained by adding linearly the contributions from weak annihilation, subleading shape functions and the HQE uncertainty on m_b.

[4] O. Buchmüller and H. Flächer, Fit to Moment Measurements from $B \to X_c \ell \nu$ and $B \to X_s \gamma$ Decays using Heavy Quark Expansions in the Kinetic Scheme, hep-ph/0507253 (2005)

[5] Average of η_{+-} between KTeV and KLOE:
KTeV collaboration (T. Alexopoulos *et al.*), Phys. Rev. D, volume 70 092006,
KLOE collaboration (F. Ambrosino *et al.*), hep-ex/0603041 (2006)
ε_K calculated from η_{+-} and $Re(\epsilon'/\epsilon)$ [10]

[6] HFAG Winter 06 and CDF Result http://fpcp2006.triumf.ca/

[7] B. Aubert *et al.*, BABAR-CONF-04/038, hep-ex/0408099 (2004)

[8] The CDF Collaboration, the D0 Collaboration, and the Tevatron Electroweak Working Group, Combination of CDF and D0 Results on the Top-Quark Mass, hep-ex/0603039 (2006)

[9] *BABAR* Collaboration (B. Aubert *et al.*), Phys.Rev. D73 (2006) 057101, Belle Collaboration (K. Ikado *et al.*), hep-ex/0604018 (2006)

[10] Particle Data Group (S. Eidelman *et al.*), Phys. Lett. **B592**, 1 (2004), and 2005 partial update for the 2006 edition available on http://pdg.lbl.gov/

[11] S. Herrlich and U. Nierste, Nucl. Phys. **B419**, 292 (1994)

[12] U. Nierste, private communication (2003)

[13] G. Buchalla, A.J. Buras and M.E. Lautenbacher, Rev. Mod. Phys. **68**, 1125 (1996)

A special thank to A. J. Buras, M. Gorbahn, U. Haisch, U. Nierste for providing to the CKMfitter group their NNLO QCD corrections for the $K^+ \to \pi^+ \nu \bar{\nu}$ decay (hep-ph/0603079).

Parameter	Value ± Error(s)	Reference	Errors GS	Errors TH
$\|V_{ud}\|$ (nuclei)	0.97377 ± 0.00027	[1]	$\star$	-
$\|V_{us}\|$ ($K_{\ell 3}$ and $K_{\mu 2}$)	0.2257 ± 0.0021	[10]	$\star$	-
$\|V_{ub}\|$ (incl.)	$(4.45 \pm 0.23 \pm 0.39) \times 10^{-3}$	[2, 3]	$\star$	$\star$
$\|V_{ub}\|$ (excl.)	$(3.94 \pm 0.28 \pm 0.51) \times 10^{-3}$	[10]	$\star$	$\star$
$\|V_{cb}\|$ (incl.)	$(41.70 \pm 0.70) \times 10^{-3}$	[10]	$\star$	-
$\|V_{cb}\|$ (excl.)	$(41.18 \pm 1.71) \times 10^{-3}$	[2]	$\star$	-
$\|\varepsilon_K\|$	$(2.221 \pm 0.008) \times 10^{-3}$	[5]	$\star$	-
Δm_d	(0.507 ± 0.004) ps^{-1}	[2]	$\star$	-
Δm_s	Amplitude spectrum+CDF -LogL	[6]	$\star$	-
$\sin(2\beta)_{[c\bar{c}]}$	0.687 ± 0.032	[2]	$\star$	-
$S^{+-}_{\pi\pi}$	-0.50 ± 0.12	[2]	$\star$	-
$C^{+-}_{\pi\pi}$	-0.37 ± 0.10	[2]	$\star$	-
$C^{00}_{\pi\pi}$	-0.28 ± 0.39	[2]	$\star$	-
$\mathcal{B}_{\pi\pi}$ all charges	Inputs to isospin analysis	[2]	$\star$	-
$S^{+-}_{\rho\rho,L}$	-0.22 ± 0.22	[2]	$\star$	-
$C^{+-}_{\rho\rho,L}$	-0.02 ± 0.17	[2]	$\star$	-
$\mathcal{B}_{\rho\rho,L}$ all charges	Inputs to isospin analysis	[2]	$\star$	-
$B^0 \to (\rho\pi)^0 \to 3\pi$	Time-dependent Dalitz analysis	[7]	$\star$	-
$B^- \to D^{(*)}K^{(*)-}$	Inputs to GLW analysis	[2]	$\star$	-
$B^- \to D^{(*)}K^{(*)-}$	Inputs to ADS analysis	[2]	$\star$	-
$B^- \to D^{(*)}K^{(*)-}$	GGSZ Dalitz analyses	[2]	$\star$	-
$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau)$	Experimental likelihoods	[9]	$\star$	-
$\overline{m}_c(m_c)$	$(1.24 \pm 0.037 \pm 0.095)$ GeV	[4]	$\star$	$\star$
$\overline{m}_t(m_t)$	(162.3 ± 2.2) GeV	[8]	$\star$	-
m_{K^+}	(493.677 ± 0.016) MeV	[10]	-	-
Δm_K	$(3.4833 \pm 0.0066) \times 10^{-12}$ MeV	[10]	-	-
m_{B_d}	(5.2794 ± 0.0005) GeV	[10]	-	-
m_{B_s}	(5.3696 ± 0.0024) GeV	[10]	-	-
m_W	(80.423 ± 0.039) GeV	[10]	-	-
G_F	1.16639×10^{-5} GeV^{-2}	[10]	-	-
f_K	(159.8 ± 1.5) MeV	[10]	-	-
B_K	$0.79 \pm 0.04 \pm 0.09$	[1]	$\star$	$\star$
$\alpha_s(m_Z^2)$	0.1176 ± 0.0020	[10]	-	$\star$
η_{ct}	0.47 ± 0.04	[11]	-	$\star$
η_{tt}	0.5765 ± 0.0065	[11, 12]	-	$\star$
$\eta_B(\overline{\rm MS})$	0.551 ± 0.007	[13]	-	$\star$
f_{B_d}	(191 ± 27) MeV	[1]	$\star$	-
B_d	1.37 ± 0.14	[1]	$\star$	-
$\xi^{(a)}$	$1.24 \pm 0.04 \pm 0.06$	[1]	$\star$	$\star$

$^{(a)}$anticorrelated theory error with $f_{B_d}\sqrt{B_d}$.

Table 1: *Inputs to the standard CKM fit. If not stated otherwise: for two errors given, the first is statistical and accountable systematic and the second stands for systematic theoretical uncertainties. The last two columns indicate*R*fit treatment of the input parameters: measurements or parameters that have statistical errors (we include here experimental systematics) are marked in the "GS" column by an asterisk; measurements or parameters that have systematic theoretical errors are marked in the "TH" column by an asterisk. Upper part: experimental determinations of the CKM matrix elements. Middle upper part: CP-violation and mixing observables. Middle lower part: parameters used in SM predictions that are obtained from experiment. Lower part: parameters of the SM predictions obtained from theory.*

Observable	central $\pm$ CL $\equiv 1\sigma$	$\pm$ CL $\equiv 2\sigma$	$\pm$ CL $\equiv 3\sigma$
λ	$0.2272\,^{+0.0010}_{-0.0010}$	$^{+0.0020}_{-0.0020}$	$^{+0.0030}_{-0.0030}$
A	$0.809\,^{+0.014}_{-0.014}$	$^{+0.029}_{-0.028}$	$^{+0.044}_{-0.042}$
$\bar{\rho}$	$0.197\,^{+0.026}_{-0.030}$	$^{+0.050}_{-0.087}$	$^{+0.074}_{-0.133}$
$\bar{\eta}$	$0.339\,^{+0.019}_{-0.018}$	$^{+0.047}_{-0.037}$	$^{+0.075}_{-0.057}$
J $[10^{-5}]$	$3.05\,^{+0.18}_{-0.18}$	$^{+0.45}_{-0.36}$	$^{+0.69}_{-0.54}$
$\sin(2\alpha)$	$-0.25\,^{+0.17}_{-0.15}$	$^{+0.49}_{-0.28}$	$^{+0.71}_{-0.42}$
$\sin(2\alpha)$ (meas. not in fit)	$-0.23\,^{+0.55}_{-0.16}$	$^{+0.72}_{-0.32}$	$^{+0.83}_{-0.45}$
$\sin(2\beta)$	$0.716\,^{+0.024}_{-0.024}$	$^{+0.048}_{-0.049}$	$^{+0.074}_{-0.075}$
$\sin(2\beta)$ (meas. not in fit)	$0.752\,^{+0.057}_{-0.035}$	$^{+0.105}_{-0.073}$	$^{+0.135}_{-0.112}$
α (deg)	$97.3\,^{+4.5}_{-5.0}$	$^{+8.7}_{-14.0}$	$^{+13.7}_{-20.7}$
α (deg) (meas. not in fit)	$96.5\,^{+4.9}_{-16.0}$	$^{+9.9}_{-21.2}$	$^{+14.6}_{-25.3}$
α (deg) (dir. meas.)	$100.2\,^{+15.0}_{-8.8}$	$^{+22.7}_{-18.2}$	$^{+32.0}_{-28.1}$
β (deg)	$22.86\,^{+1.00}_{-1.00}$	$^{+2.03}_{-1.97}$	$^{+3.22}_{-2.93}$
β (deg) (meas. not in fit)	$24.4\,^{+2.6}_{-1.5}$	$^{+5.1}_{-3.0}$	$^{+6.9}_{-4.5}$
β (deg) (dir. meas.)	$21.7\,^{+1.3}_{-1.2}$	$^{+2.6}_{-2.4}$	$^{+4.1}_{-3.6}$
$\gamma \simeq \delta$ (deg)	$59.8\,^{+4.9}_{-4.1}$	$^{+13.9}_{-7.9}$	$^{+20.8}_{-12.1}$
$\gamma \simeq \delta$ (deg) (meas. not in fit)	$59.8\,^{+4.9}_{-4.2}$	$^{+14.1}_{-8.0}$	$^{+21.0}_{-12.3}$
$\gamma \simeq \delta$ (deg) (dir. meas.)	$63\,^{+35}_{-25}$	$^{+62}_{-40}$	$^{+100}_{-54}$
β_s (deg)	$1.045\,^{+0.061}_{-0.057}$	$^{+0.151}_{-0.114}$	$^{+0.238}_{-0.177}$
$\sin(2\beta_s)$	$0.0365\,^{+0.0021}_{-0.0020}$	$^{+0.0053}_{-0.0040}$	$^{+0.0083}_{-0.0062}$
$\sin\theta_{12}$	$0.2272\,^{+0.0010}_{-0.0010}$	$^{+0.0020}_{-0.0020}$	$^{+0.0030}_{-0.0030}$
$\sin\theta_{13}$ $[10^{-3}]$	$3.82\,^{+0.15}_{-0.15}$	$^{+0.31}_{-0.30}$	$^{+0.49}_{-0.44}$
$\sin\theta_{23}$ $[10^{-3}]$	$41.78\,^{+0.63}_{-0.63}$	$^{+1.26}_{-1.26}$	$^{+1.90}_{-1.89}$
R_u	$0.391\,^{+0.015}_{-0.015}$	$^{+0.031}_{-0.029}$	$^{+0.049}_{-0.044}$
R_t	$0.872\,^{+0.033}_{-0.028}$	$^{+0.095}_{-0.054}$	$^{+0.143}_{-0.082}$
Δm_d (ps^{-1}) (meas. not in fit)	$0.394\,^{+0.097}_{-0.097}$	$^{+0.219}_{-0.132}$	$^{+0.361}_{-0.162}$
Δm_s (ps^{-1})	$17.34\,^{+0.49}_{-0.20}$	$^{+0.65}_{-0.35}$	$^{+0.78}_{-0.49}$
Δm_s (ps^{-1}) (meas. not in fit)	$21.7\,^{+5.9}_{-4.2}$	$^{+9.7}_{-6.8}$	$^{+13.1}_{-9.1}$
ϵ_K $[10^{-3}]$ (meas. not in fit)	$2.46\,^{+0.63}_{-0.88}$	$^{+1.05}_{-1.05}$	$^{+1.50}_{-1.20}$
f_{B_d} (MeV) (lattice value not in fit)	$183\,^{+10}_{-10}$	$^{+21}_{-20}$	$^{+34}_{-28}$
$\xi^{\Delta m_{d,s}}_{SU(3)}$ (lattice value not in fit)	$1.061\,^{+0.122}_{-0.047}$	$^{+0.213}_{-0.083}$	$^{+0.324}_{-0.119}$
B_K (lattice value not in fit)	$0.722\,^{+0.251}_{-0.084}$	$^{+0.348}_{-0.157}$	$^{+0.461}_{-0.216}$
m_c (GeV/c^2) (meas. not in fit)	$0.81\,^{+0.93}_{-0.36}$	$^{+1.08}_{-0.36}$	$^{+1.23}_{-0.81}$
m_t (GeV/c^2) (meas. not in fit)	$150\,^{+27}_{-21}$	$^{+57}_{-35}$	$^{+79}_{-46}$

Table 2: *Fit results.*

Observable	central $\pm$ CL $\equiv 1\sigma$	$\pm$ CL $\equiv 2\sigma$	$\pm$ CL $\equiv 3\sigma$
$\mathcal{B}(B^+ \to \tau^+\nu_\mu)$ $[10^{-5}]$	$9.6\,^{+1.5}_{-1.5}$	$^{+3.3}_{-2.9}$	$^{+5.4}_{-4.0}$
$\mathcal{B}(B^+ \to \mu^+\nu_\mu)$ $[10^{-7}]$	$4.32\,^{+0.58}_{-0.57}$	$^{+1.27}_{-1.12}$	$^{+2.05}_{-1.62}$
$\mathcal{B}(K^0_{\rm L} \to \pi^0\nu\overline{\nu})$ $[10^{-11}]$	$2.58\,^{+0.48}_{-0.40}$	$^{+1.01}_{-0.68}$	$^{+1.53}_{-0.93}$
$\mathcal{B}(K^+ \to \pi^+\nu\overline{\nu})$ $[10^{-11}]$	$7.5\,^{+1.8}_{-2.0}$	$^{+2.5}_{-2.4}$	$^{+3.2}_{-2.7}$
$\lvert V_{ud}\rvert$	$0.97383\,^{+0.00024}_{-0.00023}$	$^{+0.00047}_{-0.00047}$	$^{+0.00071}_{-0.00071}$
$\lvert V_{us}\rvert$	$0.2272\,^{+0.0010}_{-0.0010}$	$^{+0.0020}_{-0.0020}$	$^{+0.0030}_{-0.0030}$
$\lvert V_{ub}\rvert$ $[10^{-3}]$	$3.82\,^{+0.15}_{-0.15}$	$^{+0.31}_{-0.29}$	$^{+0.49}_{-0.44}$
$\lvert V_{ub}\rvert$ $[10^{-3}]$ (meas. not in fit)	$3.64\,^{+0.19}_{-0.18}$	$^{+0.39}_{-0.36}$	$^{+0.60}_{-0.55}$
$\lvert V_{cd}\rvert$	$0.22712\,^{+0.00099}_{-0.00103}$	$^{+0.00199}_{-0.00205}$	$^{+0.00300}_{-0.00307}$
$\lvert V_{cs}\rvert$	$0.97297\,^{+0.00024}_{-0.00023}$	$^{+0.00048}_{-0.00047}$	$^{+0.00071}_{-0.00071}$
$\lvert V_{cb}\rvert$ $[10^{-3}]$	$41.79\,^{+0.63}_{-0.63}$	$^{+1.26}_{-1.27}$	$^{+1.89}_{-1.90}$
$\lvert V_{cb}\rvert$ $[10^{-3}]$ (meas. not in fit)	$44.9\,^{+1.2}_{-2.8}$	$^{+2.4}_{-5.7}$	$^{+3.8}_{-7.7}$
$\lvert V_{td}\rvert$ $[10^{-3}]$	$8.28\,^{+0.33}_{-0.29}$	$^{+0.92}_{-0.57}$	$^{+1.38}_{-0.86}$
$\lvert V_{ts}\rvert$ $[10^{-3}]$	$41.13\,^{+0.63}_{-0.62}$	$^{+1.25}_{-1.24}$	$^{+1.87}_{-1.86}$
$\lvert V_{tb}\rvert$	$0.999119\,^{+0.000026}_{-0.000027}$	$^{+0.000052}_{-0.000054}$	$^{+0.000078}_{-0.000082}$
$\lvert V_{td}/V_{ts}\rvert$	$0.2011\,^{+0.0081}_{-0.0065}$	$^{+0.0230}_{-0.0127}$	$^{+0.0345}_{-0.0195}$
$\lvert V_{ud}V^*_{ub}\rvert$ $[10^{-3}]$	$3.72\,^{+0.15}_{-0.14}$	$^{+0.30}_{-0.29}$	$^{+0.48}_{-0.43}$
$\arg\left[V_{ud}V^*_{ub}\right]$ (deg)	$59.8\,^{+4.9}_{-4.0}$	$^{+13.9}_{-7.8}$	$^{+20.9}_{-12.1}$
$\arg\left[-V_{ts}V^*_{tb}\right]$ (deg)	$1.043\,^{+0.061}_{-0.057}$	$^{+0.151}_{-0.114}$	$^{+0.238}_{-0.176}$
$\lvert V_{cd}V^*_{cb}\rvert$ $[10^{-3}]$	$9.49\,^{+0.15}_{-0.15}$	$^{+0.30}_{-0.30}$	$^{+0.45}_{-0.45}$
$\arg\left[-V_{cd}V^*_{cb}\right]$ (deg)	$0.0339\,^{+0.0021}_{-0.0020}$	$^{+0.0050}_{-0.0040}$	$^{+0.0077}_{-0.0060}$
$\lvert V_{td}V^*_{tb}\rvert$ $[10^{-3}]$	$8.27\,^{+0.33}_{-0.29}$	$^{+0.93}_{-0.57}$	$^{+1.38}_{-0.85}$
$\arg\left[V_{td}V^*_{tb}\right]$ (deg)	$-22.84\,^{+1.00}_{-0.99}$	$^{+1.98}_{-2.02}$	$^{+2.93}_{-3.21}$
${\rm Re}\lambda_c$	$-0.22098\,^{+0.00095}_{-0.00091}$	$^{+0.00188}_{-0.00184}$	$^{+0.00282}_{-0.00275}$
${\rm Im}\lambda_c$ $[10^{-4}]$	$-1.377\,^{+0.080}_{-0.084}$	$^{+0.161}_{-0.203}$	$^{+0.244}_{-0.310}$
${\rm Re}\lambda_t$ $[10^{-4}]$	$-3.11\,^{+0.13}_{-0.14}$	$^{+0.26}_{-0.36}$	$^{+0.39}_{-0.57}$
${\rm Im}\lambda_t$ $[10^{-4}]$	$1.377\,^{+0.084}_{-0.080}$	$^{+0.203}_{-0.161}$	$^{+0.310}_{-0.244}$

Table 3: *Fit results.*