UPDATED RESULTS ON THE CKM MATRIX AND THE UNITARITY TRIANGLE

Including results presented up to
Moriond 09

P r e l i m i n a r y

March 15th, 2009

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], S. Descotes-Genon [f], R. Itoh [e], A. Jantsch [g], H. Lacker [d], S. Monteil [c], V. Niess [c], J. Ocariz [h], S. T'Jampens [a], V. Tisserand [a], K. Trabelsi [e]

[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 Corpusculaire 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

[d] *Humboldt-Universität zu Berlin,*
Institut für Physik, Newtonstr. 15,
D-12489 Berlin, Germany
e-mail: lacker@physik.hu-berlin.de

[e] *High Energy Accelerator Research Organization, KEK*
1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan
e-mail: ryosuke.itoh@kek.jp, karim.trabelsi@kek.jp

[f] *Laboratoire de Physique Théorique*
Bâtiment 210, Université Paris-Sud 11, F-91405 Orsay Cedex, France
(UMR 8627 du CNRS associée à l'Université de Paris-Sud 11)
e-mail: Sebastien.Descotes-Genon@th.u-psud.fr

[g] *Max-Planck-Institut für Physik*
(Werner-Heisenberg-Institut)
Föhringer Ring 6, 80805 München, Germany
e-mail: jantsch@mppmu.mpg.de

[h] *Laboratoire de Physique Nucléaire et de Hautes Energies,*
IN2P3/CNRS, Université Pierre et Marie Curie Paris 6
et Université Denis Diderot Paris 7, F-75252 Paris, France
e-mail: Ocariz@in2p3.fr

Parameter	Value ± Error(s)	Reference	Errors GS	TH
$\|V_{ud}\|$ (nuclei)	0.97418 ± 0.00026	[1]	$\star$	-
$\|V_{us}\|$ ($K_{\ell 3}$)	0.2246 ± 0.0012	[2]	$\star$	-
$\|V_{ub}\|$	$(3.87 \pm 0.09 \pm 0.46) \times 10^{-3}$	[3, 4]	$\star$	$\star$
$\|V_{cb}\|$	$(40.59 \pm 0.38 \pm 0.58) \times 10^{-3}$	[3]	$\star$	$\star$
$\|\varepsilon_K\|$	$(2.229 \pm 0.010) \times 10^{-3}$	[5]	$\star$	-
Δm_d	(0.507 ± 0.005) ps^{-1}	[3]	$\star$	-
Δm_s	(17.77 ± 0.12) ps^{-1}	[6]	$\star$	-
$\sin(2\beta)_{[c\bar{c}]}$	0.671 ± 0.023	[3]	$\star$	-
$S^{+-}_{\pi\pi}$, $C^{+-}_{\pi\pi}$, $C^{00}_{\pi\pi}$	Inputs to isospin analysis	[3]	$\star$	-
$\mathcal{B}_{\pi\pi}$ all charges	Inputs to isospin analysis	[3]	$\star$	-
$S^{+-}_{\rho\rho,L}$, $C^{+-}_{\rho\rho,L}$, $S^{00}_{\rho\rho}$, $C^{00}_{\rho\rho}$	Inputs to isospin analysis	[3]	$\star$	-
$\mathcal{B}_{\rho\rho,L}$ all charges	Inputs to isospin analysis	[3]	$\star$	-
$B^0 \to (\rho\pi)^0 \to 3\pi$	Time-dependent Dalitz analysis	[7, 8]	$\star$	-
$B^- \to D^{(*)}K^{(*)-}$	Inputs to GLW analysis	[3]	$\star$	-
$B^- \to D^{(*)}K^{(*)-}$	Inputs to ADS analysis	[3]	$\star$	-
$B^- \to D^{(*)}K^{(*)-}$	GGSZ Dalitz analysis	[3]	$\star$	-
$\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau)$	$(1.73 \pm 0.35) \times 10^{-4}$	[9]	$\star$	-
$\overline{m}_c(m_c)$	$(1.286 \pm 0.013 \pm 0.040)$ GeV	[12]	$\star$	$\star$
$\overline{m}_t(m_t)$	$(165.02 \pm 1.16 \pm 0.11)$ GeV	[10]	$\star$	$\star$
B_K	$0.721 \pm 0.005 \pm 0.040$	[16]	$\star$	$\star$
$\alpha_S(m_Z^2)$	0.1176 ± 0.0020	[5]	-	$\star$
η_{cc}	Calculated from $\overline{m}_c(m_c)$ and α_S	[17]	-	$\star$
η_{ct}	0.47 ± 0.04	[18]	-	$\star$
η_{tt}	0.5765 ± 0.0065	[17, 18]	-	$\star$
$\eta_B(\overline{\rm MS})$	0.551 ± 0.007	[19]	-	$\star$
f_{B_s}	$(228 \pm 3 \pm 17)$ MeV	[16]	$\star$	$\star$
B_s	$1.23 \pm 0.03 \pm 0.05$	[16]	$\star$	$\star$
f_{B_s}/f_{B_d}	$1.196 \pm 0.008 \pm 0.023$	[16]	$\star$	$\star$
B_s/B_d	$1.05 \pm 0.02 \pm 0.05$	[16]	$\star$	$\star$

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.*

References

[1] I.S. Towner and J.C. Hardy, Phys. Rev. **C 77**, 025501 (2008), arxiv:0710.3181 [nucl-th].

[2] FlaviaNet Working Group on Kaon Decays, arXiv:0801.1817 [hep-ph].

[3] The Heavy Flavor Averaging Group (HFAG),
Moriond 2009 averages, http://www.slac.stanford.edu/xorg/hfag, and references therein.

[4] For the inclusive average we are taking the BLNP number. (The DGE result is very close to the BLNP result. The uncertainties between BLNP and DGE are hard to compare.) 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.
We use only branching fractions measured for $B \to \pi \ell \nu$. We average the results obtained from the two unquenched Lattice calculations and the LCSR calculation for the form factor quoted by HFAG [3] in such a way that the smallest theoretical error is kept.
Also for the average between the inclusive and exclusive result we keep the smallest theoretical error.

[5] Particle Data Group (C. Amsler *et al.*), Phys. Lett. **B 667**, 1 (2008).

[6] For this only the CDF measurement (Phys. Rev. Lett. **97**, 242003 (2006)) has been used as it currently dominates the world average which still needs to be determined by HFAG.

[7] B. Aubert *et al.*, Phys. Rev. **D 76**, 012004 (2007), hep-ex/0703008.

[8] A. Kusaka *et al.*, Phys. Rev. Lett. **98**, 221602 (2007), hep-ex/0701015.

[9] B. Aubert *et al.*, Phys. Rev. **D 77**, 011107(R) (2008); arXiv:0708.2260 [hep-ex]
B. Aubert *et al.*, arXiv:0809.4027 [hep-ex]
K. Ikado *et al.*, Phys. Rev. Lett. **97**, 251802 (2006), hep-ex/0604018.
I. Adachi *et al.*, arXiv:0809.3834 [hep-ex].

[10] The world average of the top quark mass measurements performed at the Tevatron [11] interpreted as a pole mass is translated into $m_t(m_t)$ in the $\overline{\mathrm{MS}}$ at 1-loop order.

[11] The Tevatron Electroweak Working Group and for the CDF and D0 collaborations, “Combination of CDF and D0 Results on the Mass of the Top Quark”, arXiv:0808.1089v1 [hep-ex].

[12] We take $\overline{m}_c(m_c) = (1.286 \pm 0.013)$ GeV from an analysis by Kuhn and Steinhauser [13]. We assign an additional theoretical uncertainty of 0.040 GeV in order to take into account: a) an observed difference in analyses with participation of the same authors for the central value when using a somehow different extraction method [14, 15], and b) in order to take into account a likely over-optimistic error range for the gluon condensate in this analysis. This input is consistent with $\overline{m}_c(m_c) = (1.265 \pm 0.060 \pm 0.050)$ GeV translated from the kinetic charm mass obtained from fits to data from lepton energy and hadronic mass moments in $B \to X_c \ell \nu$ decays combined with photon energy moments measured in $B \to X_s \gamma$ decays: $m_c^{kin} = (1.165 \pm 0.050)$ GeV [3].

[13] J. H. Kuhn, M. Steinhauser and C. Sturm, Nucl. Phys. B **778** (2007) 192 [arXiv:hep-ph/0702103].

[14] I. Allison *et al.* [HPQCD Collaboration], Phys. Rev. D **78** (2008) 054513 [arXiv:0805.2999 [hep-lat]].

[15] M. Steinhauser, "Precise Determinations of the Charm Quark Mass, arXiv:0809.1925 [hep-ph].

[16] CKMfitter group summer08 average.

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

[18] S. Herrlich and U. Nierste, Nucl. Phys. **B 419**, 292 (1994).

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

Summer08 average of lattice QCD inputs for CKM fits

The CKMfitter group

Several hadronic inputs are required for the fits presented by CKMfitter, and we mostly rely on lattice QCD simulations to estimate these quantities. The presence of results from different collaborations with various statistics and systematics make it all the more necessary to combine them in a careful way. We explain below the procedure that we have chosen to determine these lattice averages.

1 Method of averaging

We collect the relevant calculations of the quantity that we are interested in: we take only unquenched results with 2 or 2+1 dynamical fermions, even those from proceedings without a companion article (flagged with a star). In these results, we separate the error estimates into a Gaussian part and a flat part that is treated à la Rfit. The Gaussian part collects the uncertainties from purely statistical origin, but also the systematics that can be controlled and treated in a similar way (e.g., interpolation or fitting in some cases). The remaining systematics constitute the Rfit error. If there are several sources of error in the Rfit category, we add them linearly [1].

The Rfit model is simple but also very strict. It amounts to assuming that the theoretical uncertainty is rigorously constrained by a mathematical bound that is our only piece of information. If Rfit is taken stricto sensu and the individual likelihoods are combined in the usual way (by multiplication), the final uncertainty can be underestimated, in particular in the case of marginally compatible values.

We correct this effect by adopting the following averaging recipe. We first combine the Gaussian uncertainties by combining likelihoods restricted to their Gaussian part. Then we assign to this combination the smallest of the individual Rfit uncertainties. The underlying idea is twofold:

- the present state of art cannot allow us to reach a better theoretical accuracy than the best of all estimates
- this best estimate should not be penalized by less precise methods (as it would happen be the case if one would take the dispersion of the individual central values as a guess of the combined theoretical uncertainty).

It should be stressed that the concept of a theoretical uncertainty is ill-defined, and the combination of them even more. Thus our approach is only one among the alternatives that can be found in the literature. In contrast to some of the latter, ours is algorithmic and can be reproduced.

2 Decay constants

2.1 Charmed mesons

f_{D_s}

[1] keeping in mind that in many papers in the literature, this combination is done in quadrature and the splitting between different sources is not published.

Reference	Article	N_f	Mean	Stat	Syst
CP-PACS00	[3]	2	267	13	$^{+27}_{-17}$
MILC02	[4]	2	241	5	$^{+41}_{-30}$
ETMC08*	[5]	2	248	3	8
HPQCD03	[6]	2+1	290	20	64
FNAL-MILC07*	[7]	2+1	254	8	11
HPQCD07	[1]	2+1	241	1.4	5.3
Our average			242.8	1.2	5.3

f_{D_s}/f_D

Reference	Article	N_f	Mean	Stat	Syst
CP-PACS00	[3]	2	1.182	0.039	$^{+0.087}_{-0.046}$
MILC02	[4]	2	1.14	0.01	$^{+0.06}_{-0.07}$
ETMC08*	[5]	2	1.211	0.035	0.005
FNAL-MILC07*	[6]	2+1	1.183	0.011	0.024
HPQCD07	[1]	2+1	1.164	0.006	0.020
Our average			1.1633	0.0046	0.005

2.2 Beauty mesons

f_{B_s}

Reference	Article	N_f	Mean	Stat	Syst
CP-PACS01	[8]	2	242	9	$^{+53}_{-34}$
MILC02	[4]	2	217	6	$^{+58}_{-31}$
JLQCD03	[9]	2	215	9	$^{+19}_{-15}$
HPQCD03	[6]	2+1	260	7	39
FNAL-MILC07*	[7]	2+1	240	5	26
Our average			228	3	17

f_{B_s}/f_B

Reference	Article	N_f	Mean	Stat	Syst
CP-PACS01	[8]	2	1.179	0.018	0.023
MILC02	[4]	2	1.16	0.01	$^{+0.8}_{-0.4}$
JLQCD03	[9]	2	1.13	0.03	$^{+0.17}_{-0.02}$
HPQCD05	[10]	2+1	1.20	0.03	0.01
FNAL-MILC07*	[7]	2+1	1.218	0.022	0.043
Our average			1.196	0.008	0.023

Given the very small (and controversial) systematic error quoted by HPQCD05, we keep it in the average but (arbitrarily) assign the second largest theoretical uncertainty to the final number.

3 Meson mixing

3.1 Kaon mixing

$B_K^{\bar{\rm MS}}(2{\rm GeV})$

Reference	Article	N_f	Mean	Stat	Syst
JLQCD08	[11]	2	0.537	0.004	0.040
HPQCD/UKQCD06	[12]	2+1	0.618	0.018	0.179
RBC/UKQCD07	[13]	2+1	0.524	0.010	0.028
Our average			0.525	0.0036	0.028

3.2 $B_{d,s}$ mixing

$\hat{B}_s$

Reference	Article	N_f	Mean	Stat	Syst
JLQCD03	[9]	2	1.299	0.034	$^{+0.122}_{-0.095}$
HPQCD06	[14]	2+1	1.168	0.105	0.140
RBC/UKQCD07*	[15]	2+1	1.21	0.05	0.05
Our average			1.23	0.03	0.05

$\hat{B}_{B_s}/\hat{B}_{B_d}$

Reference	Article	N_f	Mean	Stat	Syst
JLQCD03	[9]	2	1.017	0.016	$^{+0.076}_{-0.017}$
Our average			1.05	0.02	0.05

References

[1] E. Follana, C. T. H. Davies, G. P. Lepage and J. Shigemitsu [HPQCD Collaboration and UKQCD Collaboration], Phys. Rev. Lett. **100**, 062002 (2008) [arXiv:0706.1726 [hep-lat]].

[2] S. R. Beane, P. F. Bedaque, K. Orginos and M. J. Savage, Phys. Rev. D **75**, 094501 (2007) [arXiv:hep-lat/0606023].

[3] A. Ali Khan *et al.* [CP-PACS Collaboration], Phys. Rev. D **64** (2001) 034505 [arXiv:hep-lat/0010009].

[4] C. Bernard *et al.* [MILC Collaboration], Phys. Rev. D **66**, 094501 (2002) [arXiv:hep-lat/0206016].

[5] B. Blossier, V. Lubicz, C. Tarantino and S. Simula, arXiv:0810.3145 [hep-lat].

[6] M. Wingate, C. T. H. Davies, A. Gray, G. P. Lepage and J. Shigemitsu, Phys. Rev. Lett. **92**, 162001 (2004) [arXiv:hep-ph/0311130].

[7] C. Bernard *et al.* [Fermilab Lattice, MILC and HPQCD Collaborations], PoS **LAT2007**, 370 (2007).

[8] A. Ali Khan *et al.* [CP-PACS Collaboration], Phys. Rev. D **64**, 054504 (2001) [arXiv:hep-lat/0103020].

[9] S. Aoki *et al.* [JLQCD Collaboration], Phys. Rev. Lett. **91**, 212001 (2003) [arXiv:hep-ph/0307039].

[10] A. Gray *et al.* [HPQCD Collaboration], Phys. Rev. Lett. **95**, 212001 (2005) [arXiv:hep-lat/0507015].

[11] S. Aoki *et al.* [JLQCD Collaboration], Phys. Rev. D **77** (2008) 094503 [arXiv:0801.4186 [hep-lat]].

[12] E. Gamiz, S. Collins, C. T. H. Davies, G. P. Lepage, J. Shigemitsu and M. Wingate [HPQCD Collaboration and UKQCD Collaboration], Phys. Rev. D **73**, 114502 (2006) [arXiv:hep-lat/0603023].

[13] D. J. Antonio *et al.* [RBC Collaboration and UKQCD Collaboration], Phys. Rev. Lett. **100**, 032001 (2008) [arXiv:hep-ph/0702042].

[14] E. Dalgic *et al.*, Phys. Rev. D **76**, 011501 (2007) [arXiv:hep-lat/0610104].

[15] C. Albertus *et al.* [RBC and UKQCD Collaborations], PoS **LAT2007**, 376 (2007).