CKM fitter
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UPDATED RESULTS ON THE CKM MARTIX AND THE UNITARITY TRIANGLE

Including results presented at
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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
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Parameter	Value ± Error(s)	Reference	Errors GS	Errors TH
$\|V_{ud}\|$ (nuclei)	0.9739 ± 0.0003	[1]	$\star$	$\star$
$\|V_{us}\|$ ($K_{\ell 3}$ and $K_{\mu 2}$)	0.2248 ± 0.0016	[1]	$\star$	$\star$
$\|V_{ub}\|$ (average)	$(4.22 \pm 0.11 \pm 0.24) \times 10^{-3}$	[2], our average [3]	$\star$	$\star$
$\|V_{cb}\|$ (incl.)	$(41.58 \pm 0.45 \pm 0.58) \times 10^{-3}$	[4]	$\star$	$\star$
$\|V_{cb}\|$ (excl.)	$(41.4 \pm 2.1) \times 10^{-3}$	[1, 2]	$\star$	-
$\|\varepsilon_K\|$	$(2.282 \pm 0.017) \times 10^{-3}$	[5]	$\star$	-
Δm_d	(0.509 ± 0.004) ps^{-1}	[2]	$\star$	-
Δm_s	Amplitude spectrum	[1]	$\star$	-
$\sin(2\beta)_{[c\bar{c}]}$	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]	$\star$	-
$\overline{m}_c(m_c)$	(1.3 ± 0.1) GeV	[10]	-	$\star$
$\overline{m}_t(m_t)$	(162.5 ± 2.8) GeV	[10]	$\star$	-
m_{K^+}	(493.677 ± 0.016) MeV	[10]	-	-
Δm_K	$(3.490 \pm 0.006) \times 10^{-12}$ 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]	$\star$	$\star$
$\alpha_s(m_Z^2)$	0.1187 ± 0.0020	[10]	-	$\star$
η_{ct}	0.47 ± 0.04	[11]	-	$\star$
η_{tt}	0.5765 ± 0.0065	[11, 12]	-	-
$\eta_B(\overline{\rm MS})$	0.551 ± 0.007	[13]	-	$\star$
$f_{B_d}\sqrt{B_d}$	$(223 \pm 33 \pm 12)$ MeV	[1]	$\star$	$\star$
$\xi^{(a)}$	$1.24 \pm 0.04 \pm 0.06$	[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	$0.22622\,^{+0.00100}_{-0.00100}$	$^{+0.00200}_{-0.00200}$	$^{+0.00299}_{-0.00301}$
A	$0.825\,^{+0.011}_{-0.019}$	$^{+0.023}_{-0.039}$	$^{+0.034}_{-0.051}$
$\bar{\rho}$	$0.207\,^{+0.036}_{-0.043}$	$^{+0.094}_{-0.100}$	$^{+0.127}_{-0.146}$
$\bar{\eta}$	$0.340\,^{+0.023}_{-0.023}$	$^{+0.048}_{-0.063}$	$^{+0.074}_{-0.077}$
J $[10^{-5}]$	$3.10\,^{+0.22}_{-0.21}$	$^{+0.45}_{-0.57}$	$^{+0.63}_{-0.68}$
$\sin 2(\alpha)$	$-0.28\,^{+0.24}_{-0.20}$	$^{+0.54}_{-0.48}$	$^{+0.76}_{-0.55}$
$\sin 2(\alpha)$ (meas. not in fit)	$-0.27\,^{+0.67}_{-0.41}$	$^{+0.88}_{-0.54}$	$^{+1.03}_{-0.60}$
$\sin 2(\beta)$	$0.724\,^{+0.018}_{-0.018}$	$^{+0.040}_{-0.052}$	$^{+0.066}_{-0.076}$
$\sin 2(\beta)$ (meas. not in fit)	$0.742\,^{+0.072}_{-0.026}$	$^{+0.108}_{-0.061}$	$^{+0.125}_{-0.095}$
α (deg)	$98.1\,^{+6.3}_{-7.0}$	$^{+16.8}_{-15.7}$	$^{+20.2}_{-22.4}$
α (deg) (meas. not in fit)	$97\,^{+13}_{-19}$	$^{+18}_{-26}$	$^{+22}_{-32}$
α (deg) (dir. meas. only)	$98.6\,^{+12.6}_{-8.1}$	$^{+22.6}_{-16.4}$	$^{+32.1}_{-26.0}$
β (deg)	$23.22\,^{+0.74}_{-0.77}$	$^{+1.70}_{-2.12}$	$^{+2.89}_{-3.01}$
β (deg) (meas. not in fit)	$23.9\,^{+3.3}_{-1.1}$	$^{+5.1}_{-2.5}$	$^{+6.1}_{-3.8}$
β (deg) (dir. meas. only)	$21.7\,^{+1.3}_{-1.2}$	$^{+2.6}_{-2.4}$	$^{+4.1}_{-3.6}$
$\gamma \simeq \delta$ (deg)	$58.6\,^{+6.8}_{-5.9}$	$^{+15.7}_{-15.1}$	$^{+22.5}_{-18.6}$
$\gamma \simeq \delta$ (deg) (meas. not in fit)	$57.3\,^{+7.3}_{-12.9}$	$^{+17.4}_{-16.1}$	$^{+25.2}_{-19.1}$
$\gamma \simeq \delta$ (deg) (dir. meas. only)	$63\,^{+15}_{-12}$	$^{+47}_{-25}$	$^{+67}_{-37}$
$\sin(2\beta_s)$	$0.0363\,^{+0.0025}_{-0.0025}$	$^{+0.0054}_{-0.0068}$	$^{+0.0082}_{-0.0084}$
β_s (deg)	$1.039\,^{+0.073}_{-0.071}$	$^{+0.155}_{-0.194}$	$^{+0.235}_{-0.239}$
$\sin\theta_{12}$	$0.22625\,^{+0.00098}_{-0.00102}$	$^{+0.00197}_{-0.00203}$	$^{+0.00297}_{-0.00304}$
$\sin\theta_{13}$ $[10^{-3}]$	$3.904\,^{+0.098}_{-0.098}$	$^{+0.247}_{-0.195}$	$^{+0.481}_{-0.295}$
$\sin\theta_{23}$ $[10^{-3}]$	$42.23\,^{+0.43}_{-0.93}$	$^{+0.87}_{-1.77}$	$^{+1.30}_{-2.26}$
R_u	$0.398\,^{+0.011}_{-0.011}$	$^{+0.026}_{-0.021}$	$^{+0.049}_{-0.031}$
R_t	$0.863\,^{+0.047}_{-0.041}$	$^{+0.109}_{-0.107}$	$^{+0.157}_{-0.139}$
Δm_d (ps^{-1}) (meas. not in fit)	$0.400\,^{+0.167}_{-0.079}$	$^{+0.447}_{-0.128}$	$^{+0.722}_{-0.164}$
Δm_s (ps^{-1})	$18.3\,^{+6.5}_{-1.5}$	$^{+11.4}_{-2.7}$	$^{+15.2}_{-3.6}$
Δm_s (ps^{-1}) (meas. not in fit)	$20.9\,^{+4.5}_{-4.2}$	$^{+9.2}_{-6.5}$	$^{+12.8}_{-8.5}$
ϵ_K $[10^{-3}]$ (meas. not in fit)	$2.78\,^{+0.41}_{-1.13}$	$^{+0.83}_{-1.52}$	$^{+1.21}_{-1.71}$
f_{B_d} (MeV) (lattice value not in fit)	$183\,^{+25}_{-12}$	$^{+44}_{-22}$	$^{+61}_{-32}$
B_K (lattice value not in fit)	$0.83\,^{+0.13}_{-0.20}$	$^{+0.42}_{-0.27}$	$^{+0.61}_{-0.32}$
m_c (GeV/c^2) (meas. not in fit)	$1.55\,^{+0.21}_{-1.07}$	$^{+0.54}_{-1.07}$	$^{+0.74}_{-1.07}$
m_t (GeV/c^2) (meas. not in fit)	$160\,^{+50}_{-27}$	$^{+103}_{-44}$	$^{+136}_{-56}$

Table 2: *Numerical results of the global CKM fit (I).*

Observable	central $\pm$ CL $\equiv 1\sigma$	$\pm$ CL $\equiv 2\sigma$	$\pm$ CL $\equiv 3\sigma$
$\mathcal{B}(K^+ \to \pi^+ \nu\overline{\nu})$ $[10^{-11}]$	$7.27^{+1.57}_{-0.76}$	$^{+2.42}_{-1.58}$	$^{+3.03}_{-1.89}$
$\mathcal{B}(K^0_{\rm L} \to \pi^0 \nu\overline{\nu})$ $[10^{-11}]$	$2.73^{+0.41}_{-0.41}$	$^{+0.88}_{-0.94}$	$^{+1.27}_{-1.10}$
$\mathcal{B}(B^+ \to \tau^+ \nu_\mu)$ $[10^{-5}]$	$10.4^{+1.6}_{-1.7}$	$^{+5.4}_{-3.1}$	$^{+9.4}_{-4.2}$
$\mathcal{B}(B^+ \to \mu^+ \nu_\mu)$ $[10^{-7}]$	$4.49^{+0.69}_{-0.71}$	$^{+1.88}_{-1.29}$	$^{+3.25}_{-1.74}$
$\lvert V_{ud}\rvert$	$0.97406^{+0.00023}_{-0.00023}$	$^{+0.00047}_{-0.00046}$	$^{+0.00070}_{-0.00070}$
$\lvert V_{us}\rvert$	$0.22625^{+0.00098}_{-0.00102}$	$^{+0.00198}_{-0.00203}$	$^{+0.00297}_{-0.00303}$
$\lvert V_{ub}\rvert$ $[10^{-3}]$	$3.899^{+0.102}_{-0.095}$	$^{+0.251}_{-0.191}$	$^{+0.486}_{-0.291}$
$\lvert V_{ub}\rvert$ $[10^{-3}]$ (meas. not in fit)	$3.56^{+0.25}_{-0.22}$	$^{+0.47}_{-0.41}$	$^{+0.72}_{-0.41}$
$\lvert V_{cd}\rvert$	$0.22611^{+0.00100}_{-0.00100}$	$^{+0.00200}_{-0.00200}$	$^{+0.00299}_{-0.00301}$
$\lvert V_{cs}\rvert$	$0.97319^{+0.00023}_{-0.00024}$	$^{+0.00046}_{-0.00047}$	$^{+0.00069}_{-0.00070}$
$\lvert V_{cb}\rvert$ $[10^{-3}]$	$42.24^{+0.43}_{-0.93}$	$^{+0.86}_{-1.77}$	$^{+1.29}_{-2.26}$
$\lvert V_{cb}\rvert$ $[10^{-3}]$ (meas. not in fit)	$44.9^{+1.3}_{-2.1}$	$^{+3.4}_{-4.4}$	$^{+5.2}_{-6.5}$
$\lvert V_{td}\rvert$ $[10^{-3}]$	$8.24^{+0.46}_{-0.41}$	$^{+1.05}_{-1.07}$	$^{+1.46}_{-1.33}$
$\lvert V_{ts}\rvert$ $[10^{-3}]$	$41.61^{+0.43}_{-0.90}$	$^{+0.85}_{-1.73}$	$^{+1.28}_{-2.22}$
$\lvert V_{tb}\rvert$	$0.999100^{+0.000039}_{-0.000019}$	$^{+0.000073}_{-0.000037}$	$^{+0.000093}_{-0.000056}$
$\lvert V_{ud}V^*_{ub}\rvert$ $[10^{-3}]$	$3.801^{+0.097}_{-0.094}$	$^{+0.242}_{-0.189}$	$^{+0.471}_{-0.286}$
$\arg\left[V_{ud}V^*_{ub}\right]$ (deg)	$58.7^{+6.7}_{-6.0}$	$^{+15.6}_{-15.3}$	$^{+22.4}_{-18.7}$
$\lvert V_{cd}V^*_{cb}\rvert$ $[10^{-3}]$	$9.55^{+0.11}_{-0.21}$	$^{+0.21}_{-0.41}$	$^{+0.32}_{-0.53}$
$\arg\left[-V_{cd}V^*_{cb}\right]$ (deg)	$0.0347^{+0.0024}_{-0.0024}$	$^{+0.0050}_{-0.0064}$	$^{+0.0071}_{-0.0077}$
$\lvert V_{td}V^*_{tb}\rvert$ $[10^{-3}]$	$8.24^{+0.46}_{-0.42}$	$^{+1.04}_{-1.08}$	$^{+1.45}_{-1.34}$
$\arg\left[V_{td}V^*_{tb}\right]$ (deg)	$-23.18^{+0.76}_{-0.74}$	$^{+2.11}_{-1.71}$	$^{+2.99}_{-2.89}$
$\lvert V_{td}/V_{ts}\rvert$	$0.1982^{+0.0113}_{-0.0098}$	$^{+0.0261}_{-0.0256}$	$^{+0.0377}_{-0.0331}$
$\arg\left[-V_{ts}V^*_{tb}\right]$ (deg)	$1.038^{+0.072}_{-0.071}$	$^{+0.072}_{-0.071}$	$^{+0.072}_{-0.071}$
$\mathrm{Re}\lambda_c$	$-0.22006^{+0.00093}_{-0.00091}$	$^{+0.00186}_{-0.00182}$	$^{+0.00279}_{-0.00274}$
$\mathrm{Im}\lambda_c$ $[10^{-4}]$	$-1.406^{+0.097}_{-0.097}$	$^{+0.257}_{-0.201}$	$^{+0.309}_{-0.285}$
$\mathrm{Re}\lambda_t$ $[10^{-4}]$	$-3.13^{+0.20}_{-0.17}$	$^{+0.47}_{-0.40}$	$^{+0.58}_{-0.56}$
$\mathrm{Im}\lambda_t$ $[10^{-4}]$	$1.407^{+0.096}_{-0.098}$	$^{+0.200}_{-0.258}$	$^{+0.284}_{-0.311}$

Table 3: *Numerical results of the global CKM fit (II).*