V_{cb} and V_{ub} CKM Matrix Elements

OMITTED FROM SUMMARY TABLE

See the related review(s):

Semileptonic B Hadron Decays, Determination of V_{cb} and V_{ub}

V_{cb} MEASUREMENTS

For the discussion of V_{cb} measurements, which is not repeated here, see the review on "Determination of $|V_{cb}|$ and $|V_{ub}|$."

The CKM matrix element $|V_{cb}|$ can be determined by studying the rate of the semileptonic decay $B \to D^{(*)}\ell\nu$ as a function of the recoil kinematics of $D^{(*)}$ mesons. Taking advantage of theoretical constraints on the normalization and a linear ω dependence of the form factors ($F(\omega)$, $G(\omega)$) provided by Heavy Quark Effective Theory (HQET), the $|V_{cb}|\times F(\omega)$ and ρ^2 can be simultaneously extracted from data, where ω is the scalar product of the two-meson four velocities, $F(1)$ is the form factor at zero recoil (ω=1) and ρ^2 is the slope. Using the theoretical input of $F(1)$, a value of $|V_{cb}|$ can be obtained.

$|V_{cb}| \times F(1)$ (from $B^0 \to D^{*-}\ell^+\nu$)

3.534±0.037 OUR EVALUATION (Produced by HFLAV) with ρ^2=1.139 ± 0.020 and a correlation 0.268. The fitted χ^2 is 63.2 for 27 degrees of freedom.

3.60 ±0.06 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram below.

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
3.676±0.028±0.086	[1] ADACHI	23J	BELL	$e^+e^- \to \Upsilon(4S)$
3.64 ±0.09	[2] PRIM	23	BELL	$e^+e^- \to \Upsilon(4S)$
3.506±0.015±0.056	[3] WAHEED	21	BELL	$e^+e^- \to \Upsilon(4S)$
3.59 ±0.02 ±0.12	[4] AUBERT	09A	BABR	$e^+e^- \to \Upsilon(4S)$
3.92 ±0.18 ±0.23	[5] ABDALLAH	04D	DLPH	$e^+e^- \to Z^0$
4.31 ±0.13 ±0.18	[6] ADAM	03	CLE2	$e^+e^- \to \Upsilon(4S)$
3.55 ±0.14 $^{+0.23}_{-0.24}$	[7] ABREU	01H	DLPH	$e^+e^- \to Z$
3.71 ±0.10 ±0.20	[8] ABBIENDI	00Q	OPAL	$e^+e^- \to Z$
3.19 ±0.18 ±0.19	[9] BUSKULIC	97	ALEP	$e^+e^- \to Z$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.483±0.015±0.056	[3] WAHEED	19	BELL	Repl. by WAHEED 21
3.46 ±0.02 ±0.10	[10] DUNGEL	10	BELL	Rep. by WAHEED 19
3.59 ±0.06 ±0.14	[11] AUBERT	08AT	BABR	Repl. by AUBERT 09A
3.44 ±0.03 ±0.11	[12] AUBERT	08R	BABR	Repl. by AUBERT 09A
3.55 ±0.03 ±0.16	[13] AUBERT	05E	BABR	Repl. by AUBERT 08R
3.77 ±0.11 ±0.19	[14] ABDALLAH	04D	DLPH	$e^+e^- \to Z^0$

3.54 ±0.19 ±0.18	[15] ABE	02F	BELL	Repl. by DUNGEL 10
4.31 ±0.13 ±0.18	[16] BRIERE	02	CLE2	$e^+ e^- \to \Upsilon(4S)$
3.28 ±0.19 ±0.22	ACKERSTAFF	97G	OPAL	Repl. by ABBIENDI 00Q
3.50 ±0.19 ±0.23	[17] ABREU	96P	DLPH	Repl. by ABREU 01H
3.51 ±0.19 ±0.20	[18] BARISH	95	CLE2	Repl. by ADAM 03
3.14 ±0.23 ±0.25	BUSKULIC	95N	ALEP	Repl. by BUSKULIC 97

[1] Measured from differential shapes of exclusive $B \to D^* \ell^- \nu_\ell$ ($\ell = e$ or μ) decays. Using CNL form factor parametrization and the zero-recoil lattice QCD point $F(1) = 0.906 \pm 0.013$ ADACHI 23J finds $|V_{cb}|_{CNL} = (40.57 \pm 0.31 \pm 0.95 \pm 0.58) \times 10^{-3}$ where the last uncertainty is due to the prediction of $F(1)$. Also reports a measurement of $|V_{cb}|_{BGL} = (40.13 \pm 0.27 \pm 0.93 \pm 0.58) \times 10^{-3}$ using BGL form factors parametrization.

[2] Measured from differential shapes of exclusive $B \to D^* \ell^- \nu_\ell$ decays with hadronic tag-side reconstruction and extracting the CNL and BGL form factor parameters. PRIM 23 finds $|V_{cb}|_{CNL} = (40.2 \pm 0.9) \times 10^{-3}$ with the zero-recoil lattice QCD point $F(1) = 0.906 \pm 0.013$. PRIM 23 provides also a measurement of $|V_{cb}|_{BGL} = (40.7 \pm 1.0) \times 10^{-3}$.

[3] WAHEED 21 uses fully reconstructed $D^{*-} \ell^+ \nu$ events ($\ell = e$ or μ) and $\eta_{EW} = 1.0066$.

[4] Obtained from a global fit to $B \to D^{(*)} \ell \nu_\ell$ events, with reconstructed $D^0 \ell$ and $D^+ \ell$ final states and $\rho^2 = 1.22 \pm 0.02 \pm 0.07$.

[5] Measurement using fully reconstructed D^* sample with a $\rho^2 = 1.32 \pm 0.15 \pm 0.33$.

[6] Average of the $B^0 \to D^*(2010)^- \ell^+ \nu$ and $B^+ \to \overline{D}^*(2007)) \ell^+ \nu$ modes with $\rho^2 = 1.61 \pm 0.09 \pm 0.21$ and $f_{+-} = 0.521 \pm 0.012$.

[7] ABREU 01H measured using about 5000 partial reconstructed D^* sample with a $\rho^2 = 1.34 \pm 0.14^{+0.24}_{-0.22}$.

[8] ABBIENDI 00Q: measured using both inclusively and exclusively reconstructed $D^{*\pm}$ samples with a $\rho^2 = 1.21 \pm 0.12 \pm 0.20$. The statistical and systematic correlations between $|V_{cb}| \times F(1)$ and ρ^2 are 0.90 and 0.54 respectively.

[9] BUSKULIC 97: measured using exclusively reconstructed $D^{*\pm}$ with a $a^2 = 0.31 \pm 0.17 \pm 0.08$. The statistical correlation is 0.92.

[10] Uses fully reconstructed $D^{*-} \ell^+ \nu$ events ($\ell = e$ or μ).

[11] Measured using the dependence of $B^- \to D^{*0} e^- \overline{\nu}_e$ decay differential rate and the form factor description by CAPRINI 98 with $\rho^2 = 1.16 \pm 0.06 \pm 0.08$.

[12] Measured using fully reconstructed D^* sample and a simultaneous fit to the Caprini-Lellouch-Neubert form factor parameters: $\rho^2 = 1.191 \pm 0.048 \pm 0.028$, $R_1(1) = 1.429 \pm 0.061 \pm 0.044$, and $R_2(1) = 0.827 \pm 0.038 \pm 0.022$.

[13] Measurement using fully reconstructed D^* sample with a $\rho^2 = 1.29 \pm 0.03 \pm 0.27$.

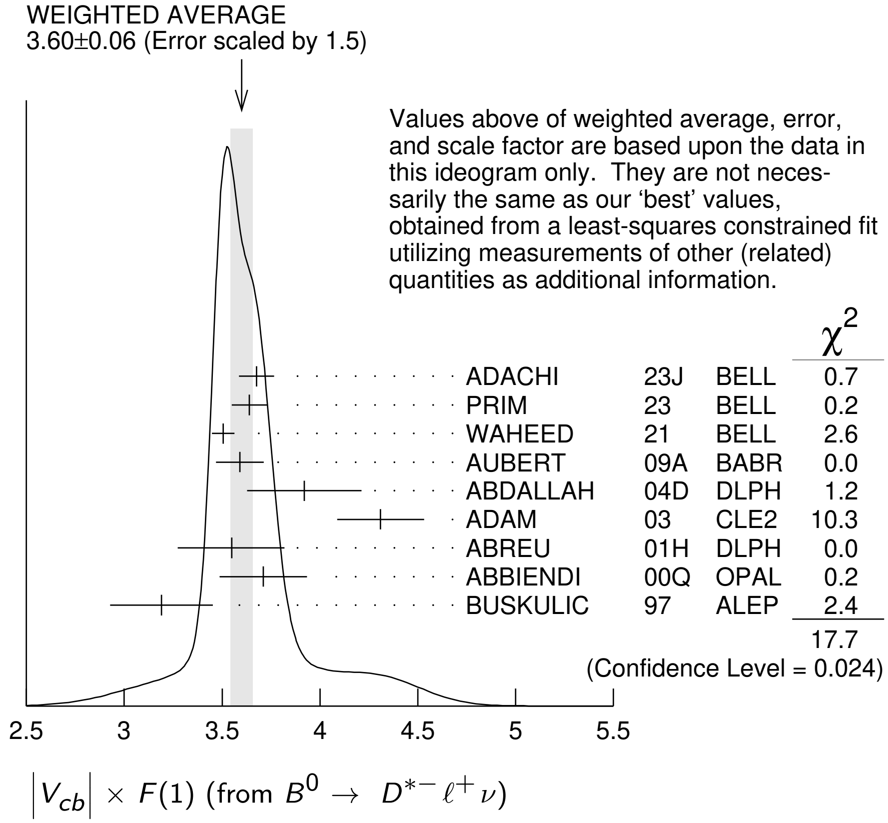
[14] Combines with previous partial reconstructed D^* measurement with a $\rho^2 = 1.39 \pm 0.10 \pm 0.33$.

[15] Measured using exclusive $B^0 \to D^*(892)^- e^+ \nu$ decays with $\rho^2 = 1.35 \pm 0.17 \pm 0.19$ and a correlation of 0.91.

[16] BRIERE 02 result is based on the same analysis and data sample reported in ADAM 03.

[17] ABREU 96P: measured using both inclusively and exclusively reconstructed $D^{*\pm}$ samples.

[18] BARISH 95: measured using both exclusive reconstructed $B^0 \to D^{*-} \ell^+ \nu$ and $B^+ \to D^{*0} \ell^+ \nu$ samples. They report their experiment's uncertainties $\pm 0.0019 \pm 0.0018 \pm 0.0008$, where the first error is statistical, the second is systematic, and the third is the uncertainty in the lifetimes. We combine the last two in quadrature.



$\left|V_{cb}\right| \times G(1)$ (from $B \to D^- \ell^+ \nu$)

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
4.121±0.100 OUR EVALUATION (Produced by HFLAV) with ρ^2=1.128 ± 0.033 and a correlation 0.747. The fitted χ^2 is 4.8 for 8 degrees of freedom.			
4.22 ±0.10 OUR AVERAGE			
4.229±0.137	[1] GLATTAUER	16 BELL	$e^+ e^- \to \Upsilon(4S)$
4.23 ±0.19 ±0.14	[2] AUBERT	10 BABR	$e^+ e^- \to \Upsilon(4S)$
4.31 ±0.08 ±0.23	[3] AUBERT	09A BABR	$e^+ e^- \to \Upsilon(4S)$
4.16 ±0.47 ±0.37	[4] BARTELT	99 CLE2	$e^+ e^- \to \Upsilon(4S)$
2.78 ±0.68 ±0.65	[5] BUSKULIC	97 ALEP	$e^+ e^- \to Z$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
4.11 ±0.44 ±0.52	[6] ABE	02E BELL	Repl. by GLATTAUER 16
3.37 ±0.44 $^{+0.72}_{-0.49}$	[7] ATHANAS	97 CLE2	Repl. by BARTELT 99

[1] Obtained from a fit to the combined partially reconstructed $B \to \overline{D} \ell \nu_\ell$ sample while tagged by the other fully reconstructed B meson in the event. Also reports fitted $\rho^2 = 1.09 \pm 0.05$.

[2] Obtained from a fit to the combined $B \to \overline{D} \ell^+ \nu_\ell$ sample in which a hadronic decay of the second B meson is fully reconstructed and $\rho^2 = 1.20 \pm 0.09 \pm 0.04$.

[3] Obtained from a global fit to $B \to D^{(*)} \ell \nu_\ell$ events, with reconstructed $D^0 \ell$ and $D^+ \ell$ final states and $\rho^2 = 1.20 \pm 0.04 \pm 0.07$.

[4] BARTELT 99: measured using both exclusive reconstructed $B^0 \to D^- \ell^+ \nu$ and $B^+ \to D^0 \ell^+ \nu$ samples.

[5] BUSKULIC 97: measured using exclusively reconstructed $D^{\pm}$ with a $a^2 = -0.05 \pm 0.53 \pm 0.38$. The statistical correlation is 0.99.
[6] Using the missing energy and momentum to extract kinematic information about the undetected neutrino in the $B^0 \to D^- \ell^+ \nu$ decay.
[7] ATHANAS 97: measured using both exclusive reconstructed $B^0 \to D^- \ell^+ \nu$ and $B^+ \to D^0 \ell^+ \nu$ samples with a $\rho^2 = 0.59 \pm 0.22 \pm 0.12^{+0.59}_{-0}$. They report their experiment's uncertainties $\pm 0.0044 \pm 0.0048^{+0.0053}_{-0.0012}$, where the first error is statistical, the second is systematic, and the third is the uncertainty due to the form factor model variations. We combine the last two in quadrature.

$|V_{cb}|$ (from $D_s^{*-} \mu^+ \nu_\mu$)

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
41.4±0.6±0.9±1.2	[1] AAIJ	20E	LHCB	pp at 7, 8 TeV

[1] Measured from an inclusive sample of $D_s^- \mu^+$ candidates using CNL parameterization of the form factor. AAIJ 20E provides also measurement of $|V_{cb}| = (42.3 \pm 0.8 \pm 0.9 \pm 1.2) \times 10^{-3}$ using BGL parameterization of the form factor. The third uncertainty is due to the external inputs used in the measurement.

V_{ub} MEASUREMENTS

For the discussion of V_{ub} measurements, which is not repeated here, see the review on "Determination of $|V_{cb}|$ and $|V_{ub}|$."

The CKM matrix element $|V_{ub}|$ can be determined by studying the rate of the charmless semileptonic decay $b \to u \ell \nu$. The relevant branching ratio measurements based on exclusive and inclusive decays can be found in the B Listings, and are not repeated here.

V_{cb} and V_{ub} CKM Matrix Elements REFERENCES

ADACHI	23J	PR D108 092013	I. Adachi *et al.*	(BELLE II Collab.)
PRIM	23	PR D108 012002	M.T. Prim *et al.*	(BELLE Collab.)
WAHEED	21	PR D103 079901	E. Waheed *et al.*	(BELLE Collab.)
AAIJ	20E	PR D101 072004	R. Aaij *et al.*	(LHCb Collab.)
WAHEED	19	PR D100 052007	E. Waheed *et al.*	(BELLE Collab.)
GLATTAUER	16	PR D93 032006	R. Glattauer *et al.*	(BELLE Collab.)
AUBERT	10	PRL 104 011802	B. Aubert *et al.*	(BABAR Collab.)
DUNGEL	10	PR D82 112007	W. Dungel *et al.*	(BELLE Collab.)
AUBERT	09A	PR D79 012002	B. Aubert *et al.*	(BABAR Collab.)
AUBERT	08AT	PRL 100 231803	B. Aubert *et al.*	(BABAR Collab.)
AUBERT	08R	PR D77 032002	B. Aubert *et al.*	(BABAR Collab.)
AUBERT	05E	PR D71 051502	B. Aubert *et al.*	(BABAR Collab.)
ABDALLAH	04D	EPJ C33 213	J. Abdallah *et al.*	(DELPHI Collab.)
ADAM	03	PR D67 032001	N.E. Adam *et al.*	(CLEO Collab.)
ABE	02E	PL B526 258	K. Abe *et al.*	(BELLE Collab.)
ABE	02F	PL B526 247	K. Abe *et al.*	(BELLE Collab.)
BRIERE	02	PRL 89 081803	R. Briere *et al.*	(CLEO Collab.)
ABREU	01H	PL B510 55	P. Abreu *et al.*	(DELPHI Collab.)
ABBIENDI	00Q	PL B482 15	G. Abbiendi *et al.*	(OPAL Collab.)
BARTELT	99	PRL 82 3746	J. Bartelt *et al.*	(CLEO Collab.)
CAPRINI	98	NP B530 153	I. Caprini, L. Lellouch, M. Neubert	(BCIP, CERN)
ACKERSTAFF	97G	PL B395 128	K. Ackerstaff *et al.*	(OPAL Collab.)
ATHANAS	97	PRL 79 2208	M. Athanas *et al.*	(CLEO Collab.)
BUSKULIC	97	PL B395 373	D. Buskulic *et al.*	(ALEPH Collab.)
ABREU	96P	ZPHY C71 539	P. Abreu *et al.*	(DELPHI Collab.)
BARISH	95	PR D51 1014	B.C. Barish *et al.*	(CLEO Collab.)
BUSKULIC	95N	PL B359 236	D. Buskulic *et al.*	(ALEPH Collab.)