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

NODE=S052

OMITTED FROM SUMMARY TABLE

See the related review(s):

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

V_{cb} MEASUREMENTS

NODE=S052220

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

NODE=S052220

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 $B^0 \to D^{*-} \ell^+ \nu$)

NODE=S052CB1
NODE=S052CB1

3.522±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. → UNCHECKED ←

3.62 ±0.05 OUR AVERAGE Error includes scale factor of 1.6. See the ideogram below.

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
3.66 ±0.05	[1] PRIM	24	BELL	$e^+ e^- \to \Upsilon(4S)$
3.676±0.028±0.086	[2] ADACHI	23J	BEL2	$e^+ e^- \to \Upsilon(4S)$
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. • • •				
3.64 ±0.09	[10] PRIM	23	BELL	$e^+ e^- \to \Upsilon(4S)$, Repl. by PRIM 24
3.483±0.015±0.056	[3] WAHEED	19	BELL	Repl. by WAHEED 21
3.46 ±0.02 ±0.10	[11] DUNGEL	10	BELL	Rep. by WAHEED 19
3.59 ±0.06 ±0.14	[12] AUBERT	08AT	BABR	Repl. by AUBERT 09A
3.44 ±0.03 ±0.11	[13] AUBERT	08R	BABR	Repl. by AUBERT 09A
3.55 ±0.03 ±0.16	[14] AUBERT	05E	BABR	Repl. by AUBERT 08R
3.77 ±0.11 ±0.19	[15] ABDALLAH	04D	DLPH	$e^+ e^- \to Z^0$
3.54 ±0.19 ±0.18	[16] ABE	02F	BELL	Repl. by DUNGEL 10
4.31 ±0.13 ±0.18	[17] 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	[18] ABREU	96P	DLPH	Repl. by ABREU 01H
3.51 ±0.19 ±0.20	[19] BARISH	95	CLE2	Repl. by ADAM 03
3.14 ±0.23 ±0.25	BUSKULIC	95N	ALEP	Repl. by BUSKULIC 97

OCCUR=2

[1] PRIM 24 value established from a complete set of angular coefficients for exclusive $B \to \overline{D}^* \ell^+ \nu_\ell$ decays with hadronic tag-side reconstruction. The $|V_{cb}| \times F(1)$ is derived from the extracted the BGL and CNL form factor parameters: $|V_{cb}|_{\rm BGL}$ = (40.7 ± 0.7) × 10^{-3} with the zero-recoil lattice QCD point $F(1)$ = 0.900 ± 0.009 and $|V_{cb}|_{\rm CNL}$ = (40.3 ± 0.6) × 10^{-3}. NODE=S052CB1;LINKAGE=H

[2] ADACHI 23J result comes 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 $|V_{cb}|_{\rm CNL} = (40.57 \pm 0.31 \pm 0.95 \pm 0.58) \times 10^{-3}$ where the last uncertainty is due to the prediction of $F(1)$. Also reports a measurement of $|V_{cb}|_{\rm BGL} = (40.13 \pm 0.27 \pm 0.93 \pm 0.58) \times 10^{-3}$ using BGL form factors parametrization. NODE=S052CB1;LINKAGE=G

[3] WAHEED 21 uses fully reconstructed $D^{*-} \ell^+ \nu$ events ($\ell = e$ or μ) and $\eta_{EW} = 1.0066$. NODE=S052CB1;LINKAGE=E

[4] Obtained from a global fit to $B \rightarrow D^{(*)} \ell \nu_\ell$ events, with reconstructed $D^0 \ell$ and $D^+ \ell$ final states and $\rho^2 = 1.22 \pm 0.02 \pm 0.07$. NODE=S052CB1;LINKAGE=BE

[5] Measurement using fully reconstructed D^* sample with a $\rho^2 = 1.32 \pm 0.15 \pm 0.33$. NODE=S052CB1;LINKAGE=AB

[6] Average of the $B^0 \rightarrow D^*(2010)^- \ell^+ \nu$ and $B^+ \rightarrow \overline{D}^*(2007)) \ell^+ \nu$ modes with $\rho^2 = 1.61 \pm 0.09 \pm 0.21$ and $f_{+-} = 0.521 \pm 0.012$. NODE=S052CB1;LINKAGE=BR

[7] ABREU 01H measured using about 5000 partial reconstructed D^* sample with a ρ^2=$1.34 \pm 0.14^{+0.24}_{-0.22}$. NODE=S052CB1;LINKAGE=BU

[8] ABBIENDI 00Q: measured using both inclusively and exclusively reconstructed $D^{*\pm}$ samples with a ρ^2=$1.21 \pm 0.12 \pm 0.20$. The statistical and systematic correlations between $\left|V_{cb}\right| \times F(1)$ and ρ^2 are 0.90 and 0.54 respectively. NODE=S052CB1;LINKAGE=A

[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. NODE=S052CB1;LINKAGE=B

[10] Measured from differential shapes of exclusive $B \rightarrow D^* \ell^- \nu_\ell$ decays with hadronic tag-side reconstruction and extracting the CNL and BGL form factor parameters. PRIM 23 finds $|\mathrm{V}_{cb}|_{\mathrm{CNL}} = (40.2 \pm 0.9) \times 10^{-3}$ with the zero-recoil lattice QCD point $F(1) = 0.906 \pm 0.013$. PRIM 23 provides also a measurement of $|\mathrm{V}_{cb}|_{\mathrm{BGL}} = (40.7 \pm 1.0) \times 10^{-3}$. NODE=S052CB1;LINKAGE=F

[11] Uses fully reconstructed $D^{*-} \ell^+ \nu$ events ($\ell = e$ or μ). NODE=S052CB1;LINKAGE=DU

[12] Measured using the dependence of $B^- \rightarrow D^{*0} e^- \overline{\nu}_e$ decay differential rate and the form factor description by CAPRINI 98 with $\rho^2 = 1.16 \pm 0.06 \pm 0.08$. NODE=S052CB1;LINKAGE=ER

[13] 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 $R_2(1) = 0.827 \pm 0.038 \pm 0.022$. NODE=S052CB1;LINKAGE=UB

[14] Measurement using fully reconstructed D^* sample with a $\rho^2 = 1.29 \pm 0.03 \pm 0.27$. NODE=S052CB1;LINKAGE=AU

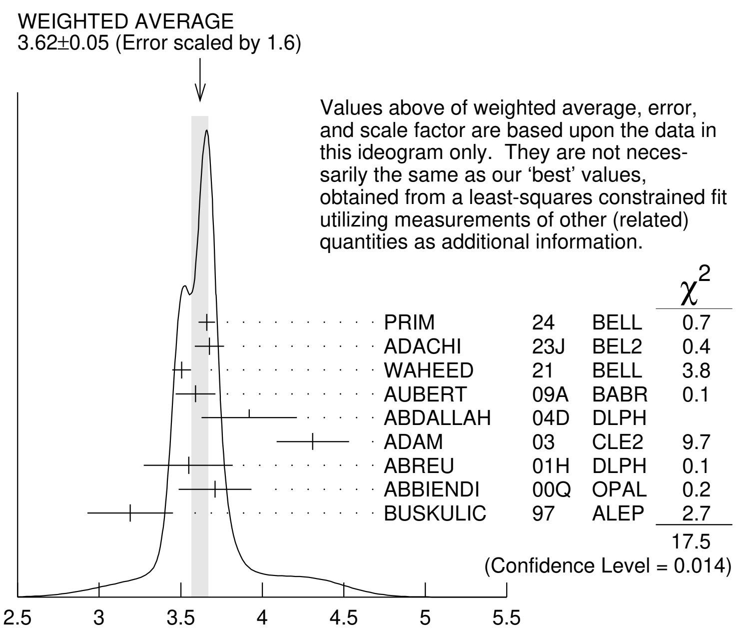
[15] Combines with previous partial reconstructed D^* measurement with a $\rho^2 = 1.39 \pm 0.10 \pm 0.33$. NODE=S052CB1;LINKAGE=AD

[16] Measured using exclusive $B^0 \rightarrow D^*(892)^- e^+ \nu$ decays with ρ^2= $1.35 \pm 0.17 \pm 0.19$ and a correlation of 0.91. NODE=S052CB1;LINKAGE=CF

[17] BRIERE 02 result is based on the same analysis and data sample reported in ADAM 03. NODE=S052CB1;LINKAGE=DM

[18] ABREU 96P: measured using both inclusively and exclusively reconstructed $D^{*\pm}$ samples. NODE=S052CB1;LINKAGE=C

[19] BARISH 95: measured using both exclusive reconstructed $B^0 \rightarrow D^{*-} \ell^+ \nu$ and $B^+ \rightarrow D^{*0} \ell^+ \nu$ 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. NODE=S052CB1;LINKAGE=D



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

$\left|V_{cb}\right| \times G(1)$ (from $B \rightarrow D^- \ell^+ \nu$) NODE=S052CB2

NODE=S052CB2

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. → UNCHECKED ←

4.15 ±0.07 OUR AVERAGE NEW

[$(4.17 \pm 0.08) \times 10^{-2}$ OUR 2025 AVERAGE]

4.06 ± 0.14	[1] ADACHI	25Y	BELL	$e^+e^- \rightarrow \Upsilon(4S)$
4.109 ± 0.116	[2] LEES	24	BABR	$e^+e^- \rightarrow \Upsilon(4S)$
4.229 ± 0.137	[3] GLATTAUER	16	BELL	$e^+e^- \rightarrow \Upsilon(4S)$
$4.23 \pm 0.19 \pm 0.14$	[4] AUBERT	10	BABR	$e^+e^- \rightarrow \Upsilon(4S)$
$4.31 \pm 0.08 \pm 0.23$	[5] AUBERT	09A	BABR	$e^+e^- \rightarrow \Upsilon(4S)$
$4.16 \pm 0.47 \pm 0.37$	[6] BARTELT	99	CLE2	$e^+e^- \rightarrow \Upsilon(4S)$
$2.78 \pm 0.68 \pm 0.65$	[7] BUSKULIC	97	ALEP	$e^+e^- \rightarrow Z$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$4.11 \pm 0.44 \pm 0.52$	[8] ABE	02E	BELL	Repl. by GLATTAUER 16
$3.37 \pm 0.44 \,^{+0.72}_{-0.49}$	[9] ATHANAS	97	CLE2	Repl. by BARTELT 99

[1] The listed value, obtained by averaging B^0 and B^+ results, is based on CLN form factor model. ADACHI 25Y also lists $|V_{cb}| = (39.2 \pm 0.9) \times 10^{-3}$ based on BCL form factor model, which results in more precise than the value based on CLN. NODE=S052CB2;LINKAGE=D

[2] Obtained from a 2D fit to the combined $B \rightarrow \overline{D}\ell^+\nu_\ell$ sample with a model-independent parametrization according to Boyd-Grinstein-Lebed (BGL), in which a hadronic decay of the second B meson is fully reconstructed. NODE=S052CB2;LINKAGE=C

[3] Obtained from a fit to the combined partially reconstructed $B \rightarrow \overline{D}\ell\nu_\ell$ sample while tagged by the other fully reconstructed B meson in the event. Also reports fitted $\rho^2 = 1.09 \pm 0.05$. NODE=S052CB2;LINKAGE=A

[4] Obtained from a fit to the combined $B \rightarrow \overline{D}\ell^+\nu_\ell$ sample in which a hadronic decay of the second B meson is fully reconstructed and $\rho^2 = 1.20 \pm 0.09 \pm 0.04$. NODE=S052CB2;LINKAGE=AU

[5] Obtained from a global fit to $B \rightarrow D^{(*)}\ell\nu_\ell$ events, with reconstructed $D^0\ell$ and $D^+\ell$ final states and $\rho^2 = 1.20 \pm 0.04 \pm 0.07$. NODE=S052CB2;LINKAGE=BE

[6] BARTELT 99: measured using both exclusive reconstructed $B^0 \rightarrow D^-\ell^+\nu$ and $B^+ \rightarrow D^0\ell^+\nu$ samples. NODE=S052CB2;LINKAGE=F

[7] 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. NODE=S052CB2;LINKAGE=B

[8] Using the missing energy and momentum to extract kinematic information about the undetected neutrino in the $B^0 \rightarrow D^-\ell^+\nu$ decay. NODE=S052CB2;LINKAGE=CE

[9] ATHANAS 97: measured using both exclusive reconstructed $B^0 \rightarrow D^-\ell^+\nu$ and $B^+ \rightarrow D^0\ell^+\nu$ 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. NODE=S052CB2;LINKAGE=E

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

NODE=S052A00
NODE=S052A00

VALUE (units 10^{-3})	*DOCUMENT ID*		*TECN*	*COMMENT*
$41.4 \pm 0.6 \pm 0.9 \pm 1.2$	[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. NODE=S052A00;LINKAGE=A

V_{ub} MEASUREMENTS

NODE=S052230

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

NODE=S052230

The CKM matrix element $|V_{ub}|$ can be determined by studying the rate of the charmless semileptonic decay $b \rightarrow u\ell\nu$. 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

NODE=S052

ADACHI	25Y	PR D112 112009	I. Adachi *et al.*	(BELLE II Collab.)	REFID=63689
LEES	24	PR D110 032018	J.P. Lees *et al.*	(BABAR Collab.)	REFID=62937
PRIM	24	PRL 133 131801	M.T. Prim *et al.*	(BELLE Collab.)	REFID=63050
ADACHI	23J	PR D108 092013	I. Adachi *et al.*	(BELLE II Collab.)	REFID=62502
PRIM	23	PR D108 012002	M.T. Prim *et al.*	(BELLE Collab.)	REFID=62303
WAHEED	21	PR D103 079901	E. Waheed *et al.*	(BELLE Collab.)	REFID=61232
AAIJ	20E	PR D101 072004	R. Aaij *et al.*	(LHCb Collab.)	REFID=60289
WAHEED	19	PR D100 052007	E. Waheed *et al.*	(BELLE Collab.)	REFID=59994
GLATTAUER	16	PR D93 032006	R. Glattauer *et al.*	(BELLE Collab.)	REFID=57132
AUBERT	10	PRL 104 011802	B. Aubert *et al.*	(BABAR Collab.)	REFID=53189
DUNGEL	10	PR D82 112007	W. Dungel *et al.*	(BELLE Collab.)	REFID=53579
AUBERT	09A	PR D79 012002	B. Aubert *et al.*	(BABAR Collab.)	REFID=52640
AUBERT	08AT	PRL 100 231803	B. Aubert *et al.*	(BABAR Collab.)	REFID=52368
AUBERT	08R	PR D77 032002	B. Aubert *et al.*	(BABAR Collab.)	REFID=52226
AUBERT	05E	PR D71 051502	B. Aubert *et al.*	(BABAR Collab.)	REFID=50510

ABDALLAH	04D	EPJ C33 213	J. Abdallah *et al.*	(DELPHI Collab.)	REFID=49916
ADAM	03	PR D67 032001	N.E. Adam *et al.*	(CLEO Collab.)	REFID=49204
ABE	02E	PL B526 258	K. Abe *et al.*	(BELLE Collab.)	REFID=48601
ABE	02F	PL B526 247	K. Abe *et al.*	(BELLE Collab.)	REFID=48602
BRIERE	02	PRL 89 081803	R. Briere *et al.*	(CLEO Collab.)	REFID=48758
ABREU	01H	PL B510 55	P. Abreu *et al.*	(DELPHI Collab.)	REFID=48075
ABBIENDI	00Q	PL B482 15	G. Abbiendi *et al.*	(OPAL Collab.)	REFID=47640
BARTELT	99	PRL 82 3746	J. Bartelt *et al.*	(CLEO Collab.)	REFID=47004
CAPRINI	98	NP B530 153	I. Caprini, L. Lellouch, M. Neubert	(BCIP, CERN)	REFID=52699
ACKERSTAFF	97G	PL B395 128	K. Ackerstaff *et al.*	(OPAL Collab.)	REFID=45260
ATHANAS	97	PRL 79 2208	M. Athanas *et al.*	(CLEO Collab.)	REFID=45598
BUSKULIC	97	PL B395 373	D. Buskulic *et al.*	(ALEPH Collab.)	REFID=45291
ABREU	96P	ZPHY C71 539	P. Abreu *et al.*	(DELPHI Collab.)	REFID=44932
BARISH	95	PR D51 1014	B.C. Barish *et al.*	(CLEO Collab.)	REFID=44139
BUSKULIC	95N	PL B359 236	D. Buskulic *et al.*	(ALEPH Collab.)	REFID=44475