Experimental status of $B \to D^{(*)} l \nu$

Christoph Schwanda (Vienna)

Joint workshop on $|V_{ub}|$ and $|V_{cb}|$ (Vxb 2009)
October 29-31, 2009, SLAC

$B \rightarrow D^{(*)} l\nu$ width

$$\frac{d\Gamma}{dw}(\overline{B} \rightarrow D^{*}\ell\overline{\nu}_{\ell}) = \frac{G_F^2}{48\pi^3}|V_{cb}|^2 m_{D^*}^3 (w^2-1)^{1/2} P(w) (\mathcal{F}(w))^2$$

$$\frac{d\Gamma}{dw}(\overline{B} \rightarrow D\ell\overline{\nu}_{\ell}) =$$

$$\frac{G_F^2}{48\pi^3}|V_{cb}|^2 (m_B + m_D)^2 m_D^3 (w^2-1)^{3/2} (\mathcal{G}(w))^2$$

form factor

$$w \equiv v \cdot v'$$

- The F(w) and G(w) form factors can be parameterized based on HQET and dispersion relations
  [Caprini et al., Nucl. Phys. B530, 153 (1998)]
- Form factor parameters are ρ^2, R_1, R_2 (ρ^2) for $D^* l\nu$ ($Dl\nu$)
- F(1) and G(1) from lattice QCD

New !

F(1) = 0.921 +/- 0.013 +/- 0.020	C.Bernard et al. [Phys.Rev.D79, 014506 (2009)]
G(1) = 1.074 +/- 0.018 +/- 0.016	M.Okamoto et al. [Nucl.Phys.Proc.Suppl. 140, 461 (2005)]

- Experiments do not "extrapolate the rate to zero recoil (w=1)" but fit the f.f. parameterization over nearly the entire phase
- Thus $|V_{cb}|$ excl. relies not only on lattice QCD but also on the f.f. parameterization

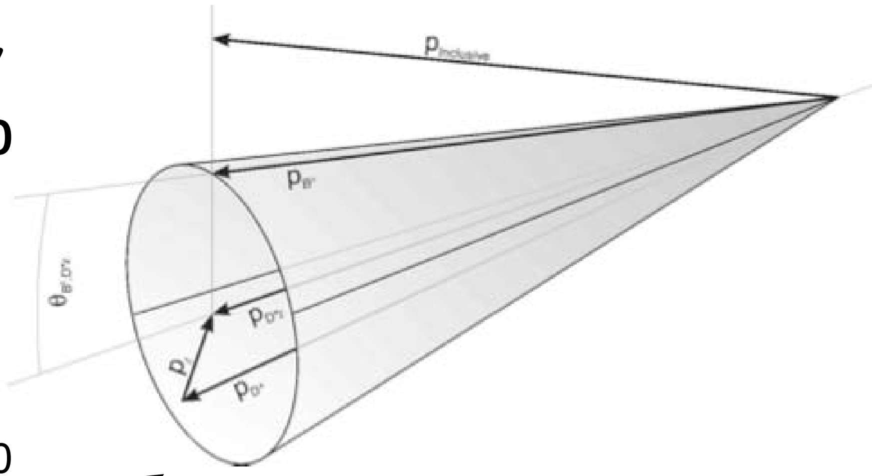
	Experimental observables	Uncertainty on $|V_{cb}|$ excl
$B \to D^* l \nu$	$F(1)|V_{cb}|$, ρ^2, R_1, R_2	Theory dominated (lattice)
$B \to D l \nu$	$G(1)|V_{cb}|$, ρ^2	Experiment dominated (backgrounds)

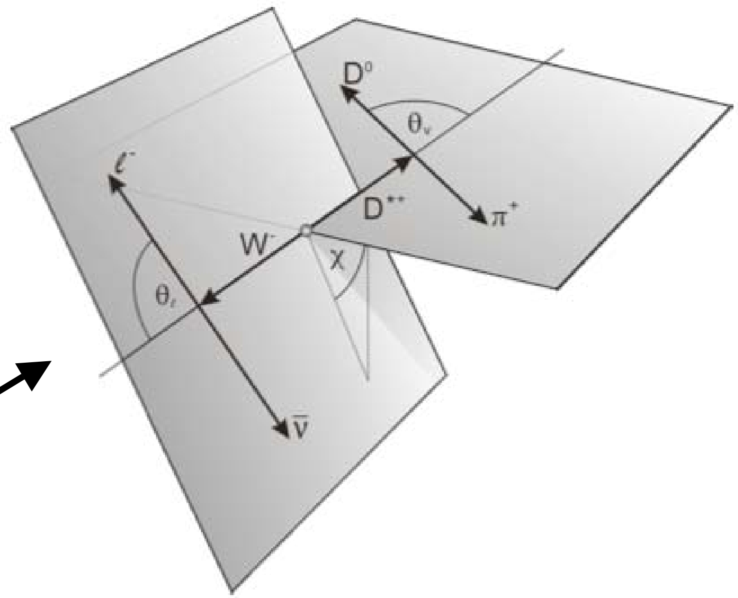
Belle $B \to D^* l \nu$

[arXiv:0810.1657] preliminary

[arXiv:0910.3534] preliminary

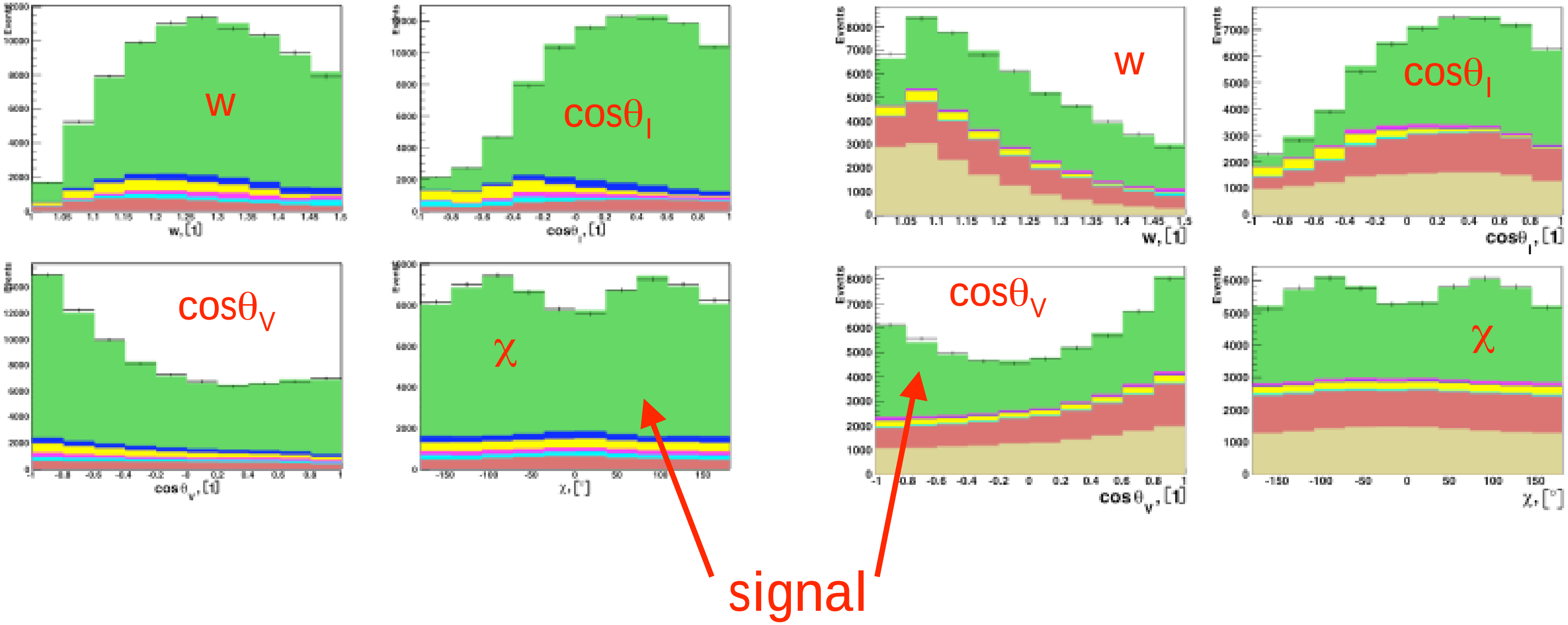
- Untagged analysis of $B^0 \to D^{*-} l^+ \nu$ and $B^+ \to D^{*0} l^+ \nu$ based on 140/fb of Belle Υ(4S) data
- Reconstruct $D^0 \to K^- \pi^+$ and $D^0 \to K^- \pi^+ \pi^+ \pi^-$
- Then $D^{*+} \to D^0 \pi^+_s$ and $D^{*0} \to D^0 \pi^0_s$
- Reconstruct B momentum using kinematics and the remaining particles in the event
- Calculate w=p(B)p(D*)/M(B)M(D*) and three angles that fully describe the decay





- Fit these 4 variables to the differential width
  (binned fit to the projections in w, $\cos\theta_l$, $\cos\theta_V$ and χ)

$B^0 \to D^{*-} l^+ \nu$ $\qquad\qquad$ $B^+ \to D^{*0} l^+ \nu$

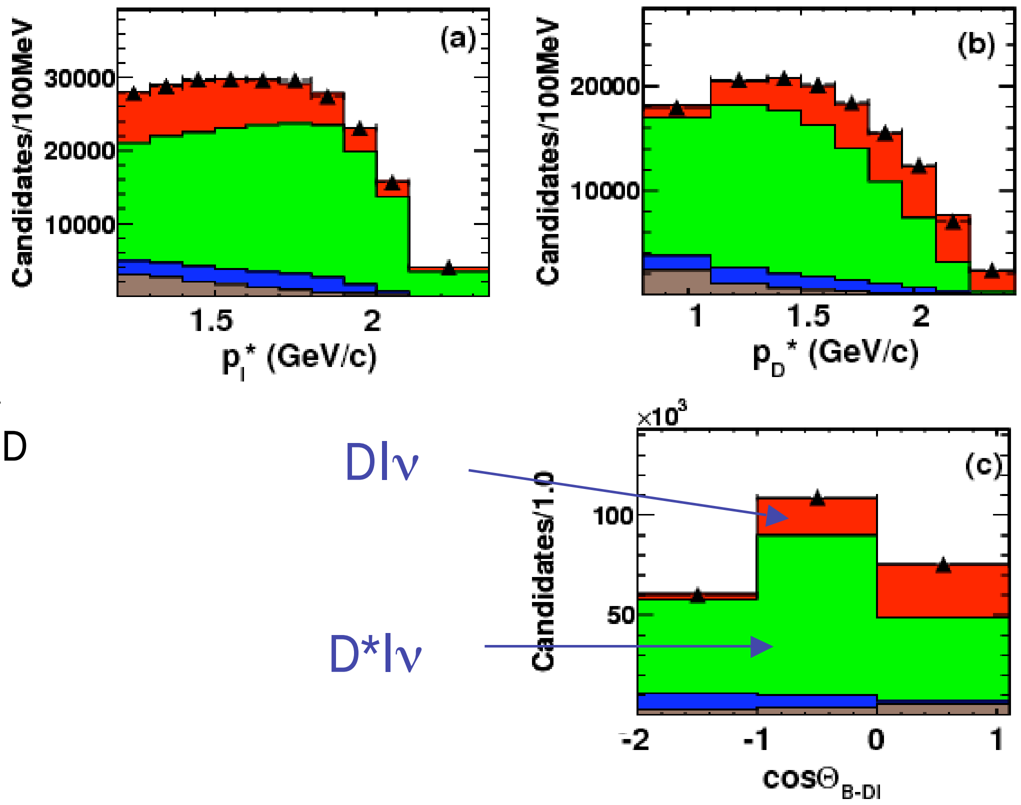


	$B^0 \to D^{*-}\ell\nu$	$B^+ \to \bar{D}^{*0}\ell\nu$
ρ^2	$1.293 \pm 0.045 \pm 0.029$	$1.376 \pm 0.074 \pm 0.056$
$R_1(1)$	$1.495 \pm 0.050 \pm 0.062$	$1.620 \pm 0.091 \pm 0.092$
$R_2(1)$	$0.844 \pm 0.034 \pm 0.019$	$0.805 \pm 0.064 \pm 0.036$
$R_{K3\pi/K\pi}$	2.153 ± 0.011	2.072 ± 0.023
$\mathcal{B}(B \to D^*\ell^+\nu_\ell)$	$(4.42 \pm 0.03 \pm 0.25)\%$	$(4.84 \pm 0.04 \pm 0.56)\%$
$\mathcal{F}(1)\,\lvert V_{cb}\rvert \times 10^3$	$34.4 \pm 0.2 \pm 1.0$	$35.0 \pm 0.4 \pm 2.2$
$\chi^2/\mathrm{n.d.f.}$	$138.8/155$	$187.8/155$
P_{χ^2}	82.0%	3.7%

- Good consistency between isospin states
- Both analyses measure all four observables ($F(1)|V_{cb}|$, ρ^2, R_1, R_2), in contrast to, e.g., the BaBar $B^+ \to D^{*0}e^+\nu$ analysis [PRL 100, 231803]

BaBar $B \to DXl\nu$ global fit

- Reconstruct $D^0 l$ and $D^+ l$ ($l=e,\mu$) combinations in 207/fb of $\Upsilon(4S)$ data
- Fit $F(1)|V_{cb}|$, $G(1)|V_{cb}|$, $\rho^2_{D^*}$ and ρ^2_D using the kinematic variables p^*_l, p^*_D and $\cos\theta_{B\text{-}Dl}$
- No slow pion systematics for $D^*l\nu$



$F(1)|V_{cb}| = (35.9 +/- 0.2 +/- 1.2) \times 10^{-3}$

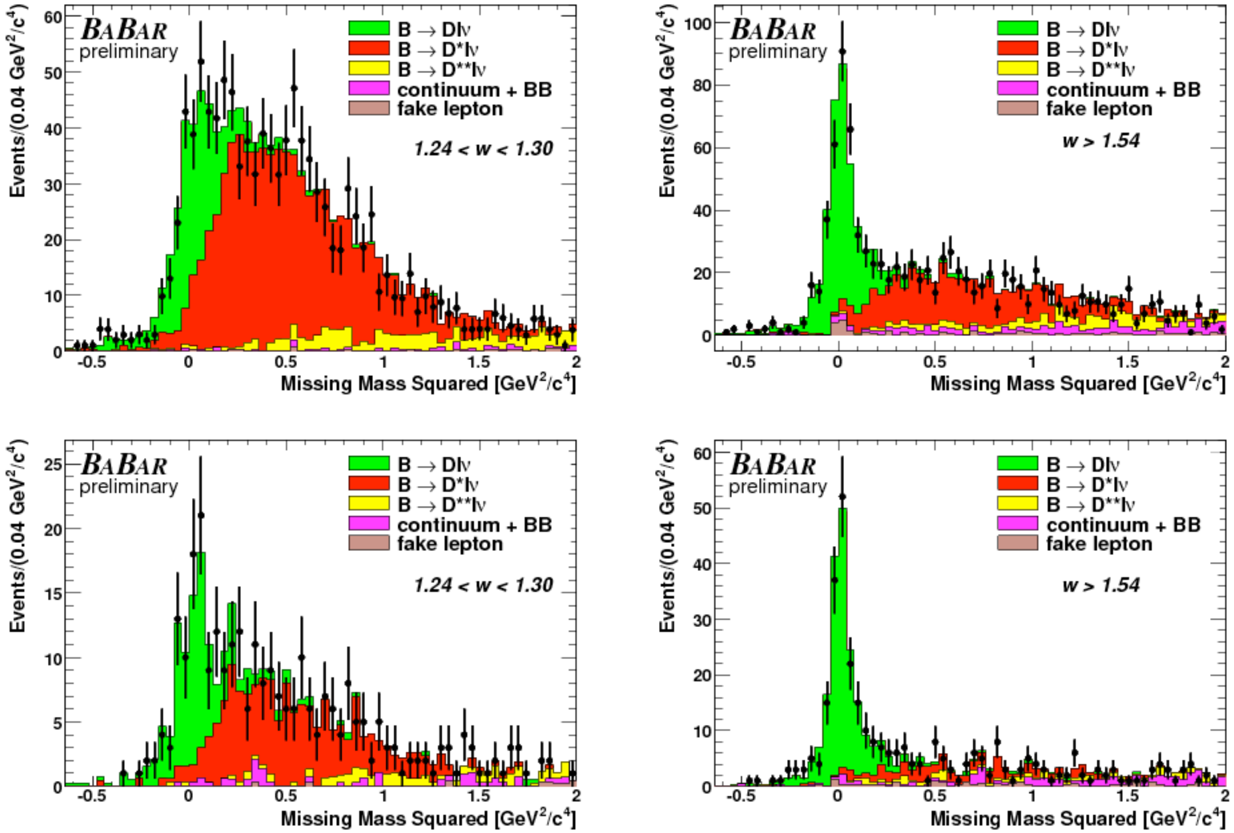
$G(1)|V_{cb}| = (43.1 +/- 0.8 +/- 2.3) \times 10^{-3}$

[arXiv:0904.4063] submitted to PRL

BaBar $B \to Dl\nu$ with hadronic tag

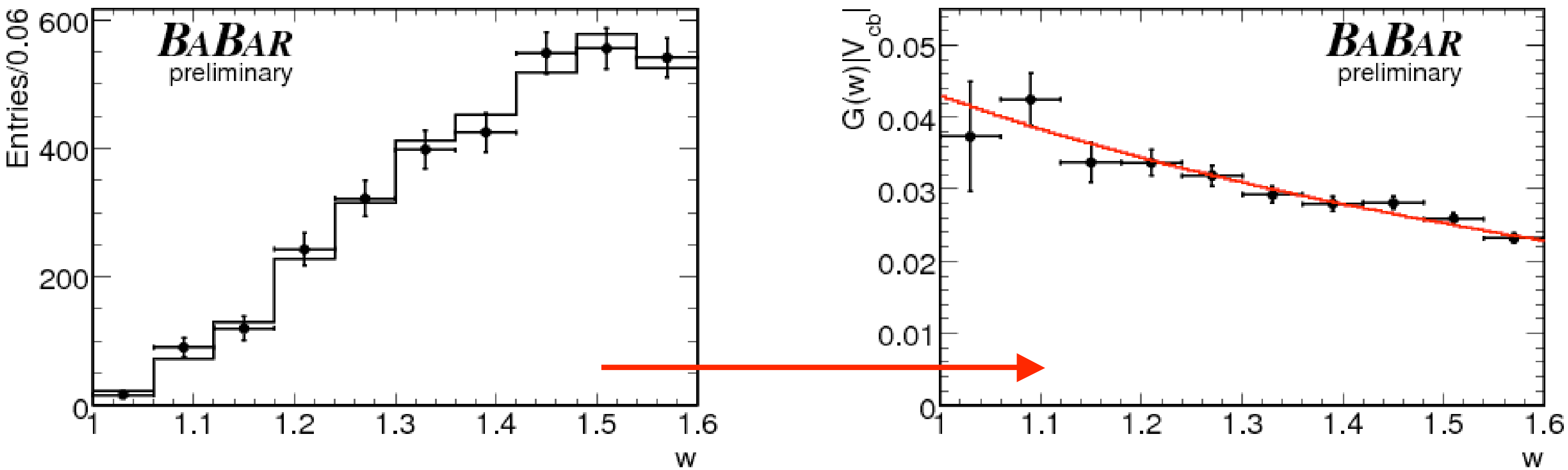
$D^0 l\nu$

$Dl\nu$



- Use 417/fb of Y(4S) data in which the hadronic decay of one B is fully reconstructed
- Reconstruct $B^0 \to D^- l^+ \nu$ and $B^+ \to D^0 l^+ \nu$ on signal side in 10 bins of w and fit $G(1)|V_{cb}|$ and ρ^2

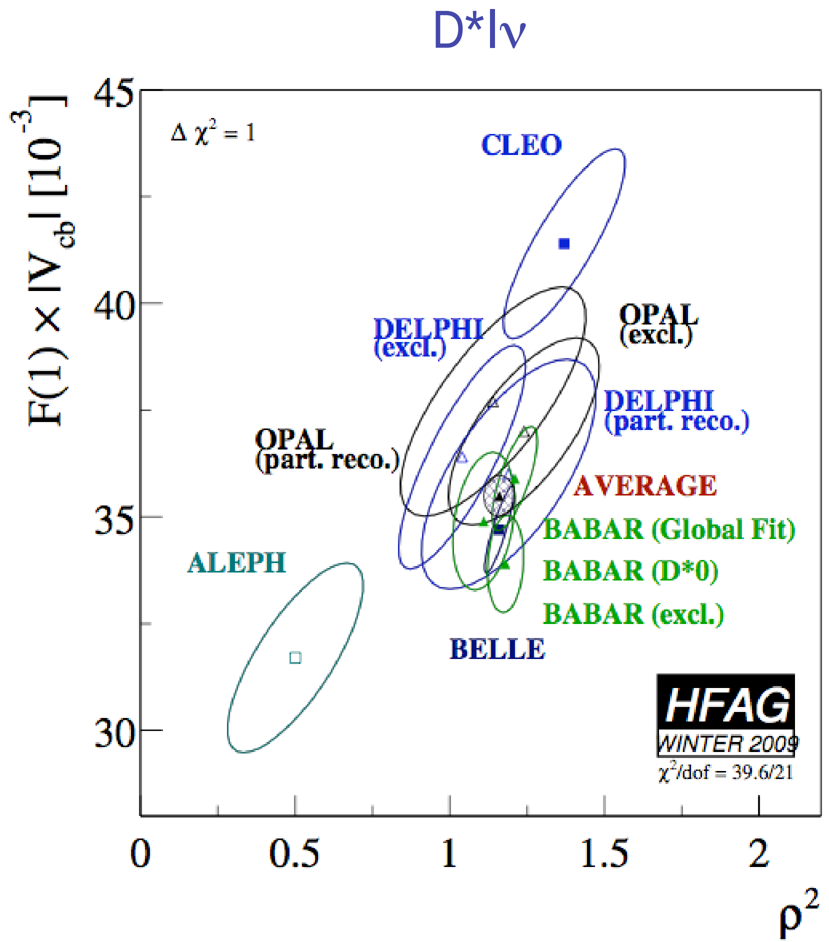
	$B^- \to D^0 \ell^- \bar{\nu}_\ell$	$\overline{B}^0 \to D^+ \ell^- \bar{\nu}_\ell$	$\overline{B} \to D \ell^- \bar{\nu}_\ell$
$\mathcal{G}(1)\vert V_{cb}\vert \cdot 10^3$	$41.7 \pm 2.1 \pm 1.3$	$45.6 \pm 3.3 \pm 1.6$	$43.0 \pm 1.9 \pm 1.4$
ρ^2	$1.14 \pm 0.11 \pm 0.04$	$1.29 \pm 0.14 \pm 0.05$	$1.20 \pm 0.09 \pm 0.04$
ρ_{corr}	0.943	0.950	0.952
χ^2/ndf	3.4/8	5.6/8	9.9/18
Signal Yield	2147 ± 69	1108 ± 45	-
Recon. efficiency	$(1.99 \pm 0.02) \times 10^{-4}$	$(1.09 \pm 0.02) \times 10^{-4}$	-
$\mathcal{B}$	$(2.31 \pm 0.08 \pm 0.09)\%$	$(2.23 \pm 0.11 \pm 0.11)\%$	$(2.17 \pm 0.06 \pm 0.09)\%$

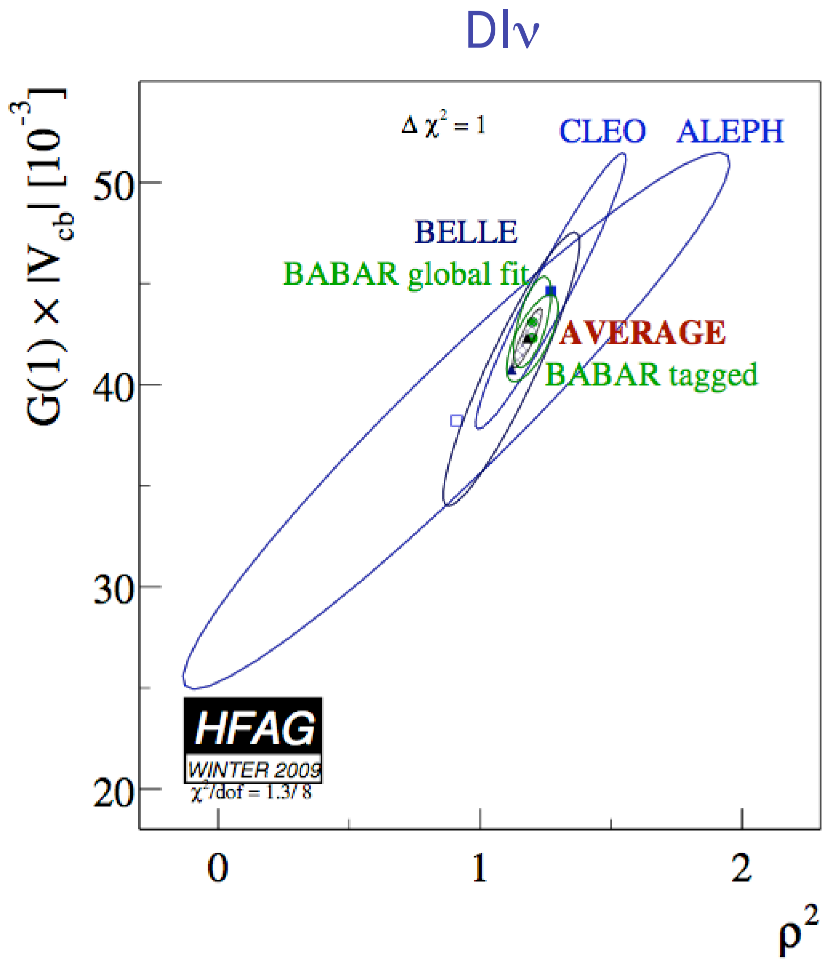


efficiency correction

$G(1)|V_{cb}| = (43.0 +/- 1.9 +/- 1.4) \times 10^{-3}$

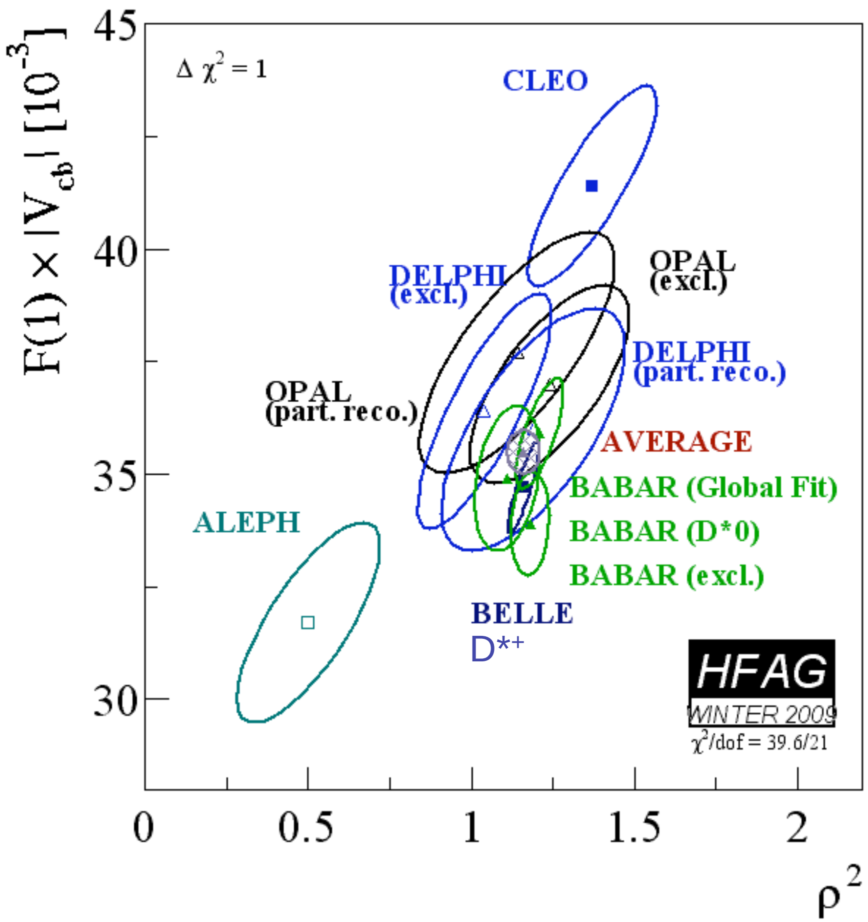
HFAG winter 09 average

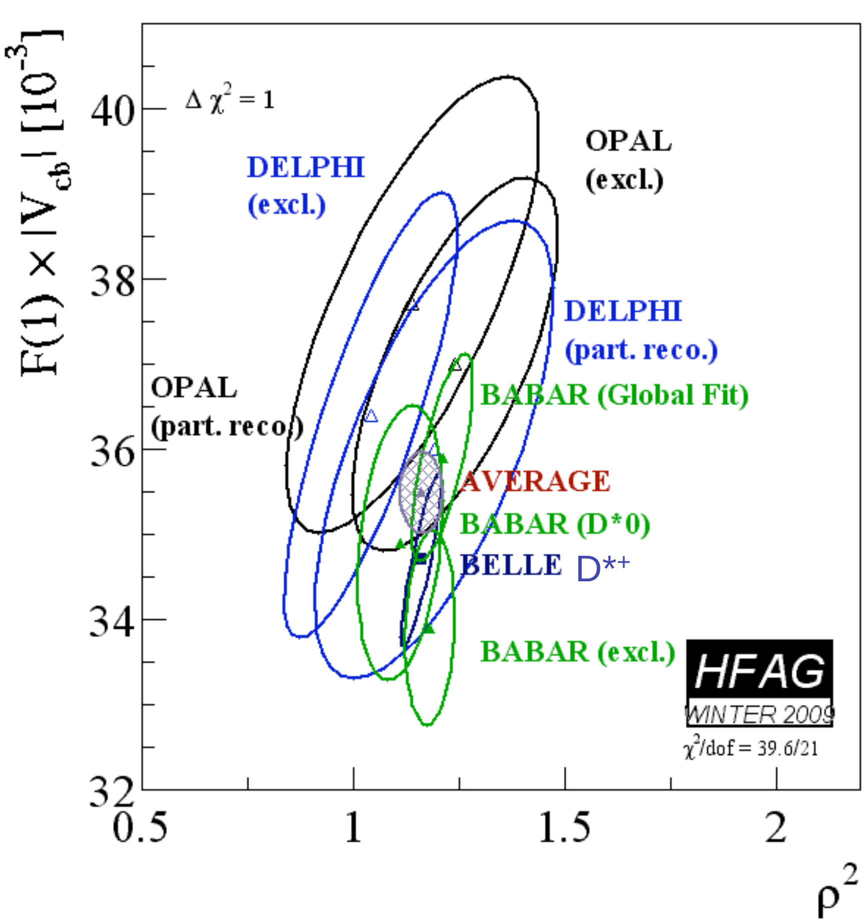




$F(1)|V_{cb}| = (35.49 +/- 0.48) \times 10^{-3}$

$G(1)|V_{cb}| = (42.3 +/- 0.7(stat) +/- 1.3(syst)) \times 10^{-3}$





without new Belle: $F(1)|V_{cb}|=(35.49+/-0.48)x10^{-3}$,

$\chi^2/ndf. = 39.6/21$

with new Belle: $F(1)|V_{cb}|=(35.75+/-0.42)x10^{-3}$,

$\chi^2/ndf. = 56.9/21$

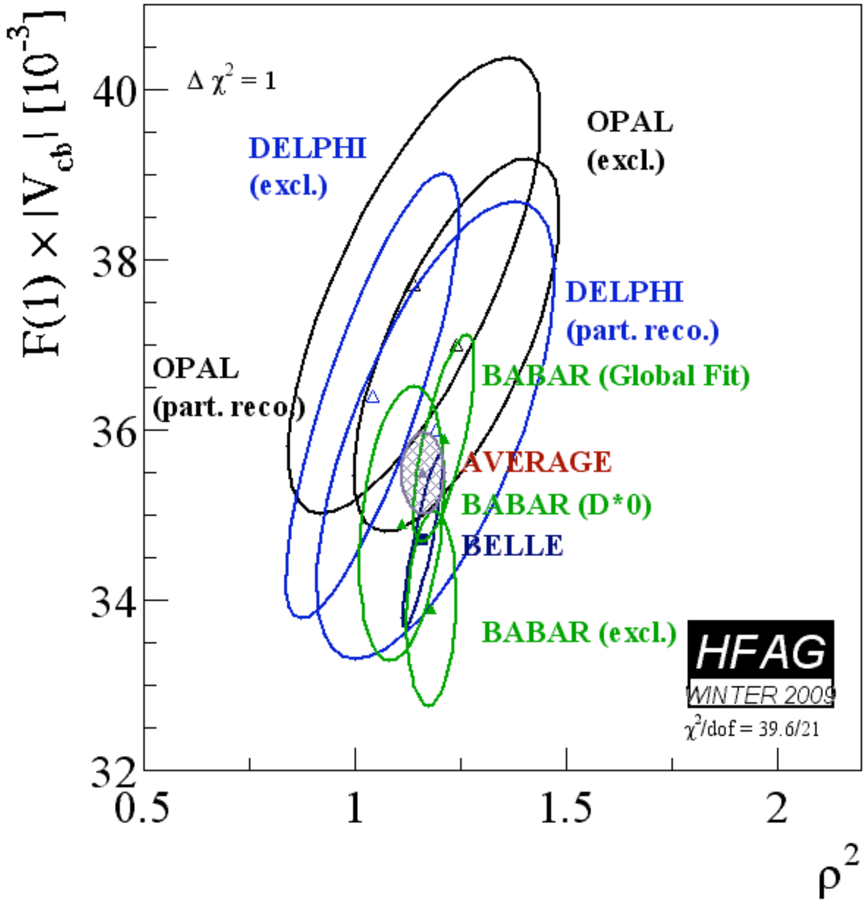
Convenor's questions

- How consistent are existing measurements between experiments, and how well do they respect isospin symmetry?

	$F(1)|V_{cb}|$ (10^{-3})
Belle $B^0 \to D^{*-} l^+ \nu$ [arXiv:0810.1657]	34.4 +/- 0.2 +/- 1.0
Belle $B^+ \to D^{*0} l^+ \nu$ [arXiv:0910.3534]	35.0 +/- 0.4 +/- 2.2
BaBar $B^0 \to D^{*-} l^+ \nu$ [PRD77, 032002]	34.4 +/- 0.3 +/- 1.1
BaBar $B^+ \to D^{*0} e^+ \nu$ [PRL100, 231803]	35.9 +/- 0.6 +/- 1.4

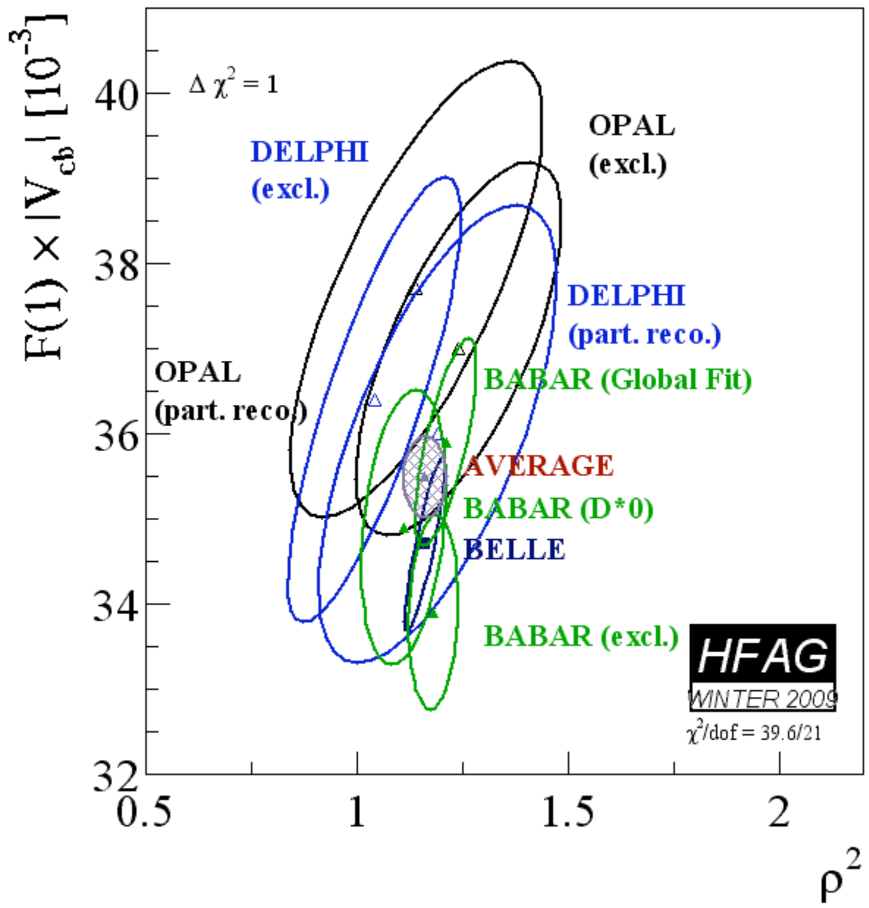
Convenor's questions (2)

- What can be done to determine the sources of the observed discrepancies?



- Discrepancies arise when combining with LEP data
- Slow pion efficiency cannot explain the difference
- Maybe we should check the assumptions in the LEP measurements more carefully?

Is there a systematic difference between 2- and 4-parameter measurements?



BaBar global fit [PRD79, 012002]

Measured	$F(1)\|V_{cb}\|$ (10^{-3})
$F(1)\|V_{cb}\|$, ρ^2	35.9 +/- 0.2 +/- 1.2
$F(1)\|V_{cb}\|$, ρ^2, R_1, R_2	35.6 +/- 0.3 +/- 1.0

- Problem with parameterization?
- Artefact of the averaging procedure?

Convenor's questions (3)

- How much improvement in precision can be expected by 2011 (or similar date)?
- Experiment
  - Belle will reduce slow pion tracking uncertainty by moving to the full data set (710/fb)
  - Belle will also try to catch up by doing a tagged analysis of $B \rightarrow Dl\nu$
- Lattice
  - $\rightarrow$ Ruth' talk

Backup

[arXiv:0810.1657] preliminary

Belle $B^0 \to D^{*-} l^+ \nu$ systematics

	ρ^2	$R_1(1)$	$R_2(1)$	$\mathcal{B}(D^* \ell \nu_\ell)$	$\mathcal{F}(1)\|V_{cb}\|$
D^{**}	0.015	0.038	0.011	0.051	0.25
uncorrelated	0.009	0.028	0.002	0.003	0.04
correlated	0.003	0.003	0.007	0.028	0.14
fake ℓ	0.020	0.037	0.009	0.002	0.04
fake D^*	0.012	0.011	0.009	0.034	0.33
continuum	0.003	0.008	0.000	0.001	0.02
tracking	–	–	–	0.221	0.86
$\mathcal{B}(D^0 \to K^- \pi^+)$ [6]	–	–	–	0.081	0.31
$\mathcal{B}(D^{*+} \to D^0 \pi^+)$ [6]	–	–	–	0.033	0.13
$\tau(B^0)$ [6]	–	–	–	0.026	0.10
$N(B\bar{B})$	–	–	–	0.036	0.14
$f_{+-}/f_{0\bar{0}}$ [6]	0.003	0.011	0.005	0.001	0.04
total	0.029	0.062	0.019	0.251	1.04

[arXiv:0910.3534] preliminary

Belle $B^+ \to D^{*0} l^+ \nu$ systematics

	ρ^2	$R_1(1)$	$R_2(1)$	$\mathcal{F}(1)\|V_{cb}\| \times 10^3$	$\mathcal{B}(B^+ \to \bar{D}^{*0}\ell^+\nu_\ell)$
Value	1.376	1.620	0.805	34.98	4.841
Statistical Error	0.074	0.091	0.064	0.37	0.044
Tracking	-0.027	+0.025	+0.012	-1.97	-0.491
LeptonID	+0.012	+0.024	-0.011	-0.39	-0.096
Norm - Signal Corr.	-0.007	+0.002	+0.007	+0.13	+0.038
Norm - D^{**}	+0.005	-0.023	+0.002	-0.04	-0.041
Norm - Uncorr	+0.014	+0.074	-0.025	-0.28	-0.023
Norm - Fake ℓ	+0.017	+0.028	-0.010	-0.05	-0.024
Norm - Comb D^{*0}	+0.008	+0.014	-0.008	-0.11	-0.028
Norm - Fake D^0	-0.009	-0.014	+0.007	+0.06	+0.020
Norm - Continuum	+0.004	+0.005	-0.001	0.00	-0.003
Shape - Uncorr	+0.014	+0.003	-0.005	+0.10	
Shape - Comb D^{*0}	+0.027	-0.005	-0.008	+0.21	
Shape - Fake D^0	+0.024	+0.003	+0.008	+0.17	
$\mathcal{B}(D^0 \to K\pi)$				-0.32	-0.089
$\mathcal{B}(D^{*0} \to D^0\pi^0)$				-0.82	-0.227
B^+ lifetime				-0.12	-0.033
$N(\Upsilon(4S))$				-0.14	-0.040
f_{+-}/f_{00}	+0.003	+0.006	-0.003	-0.15	-0.043

[PRD 79, 012002 (2009)]

BaBar global fit systematics

item	Electron sample ρ_D^2	$\rho_{D^*}^2$	$\mathcal{B}(D\ell\overline{\nu})$	$\mathcal{B}(D^*\ell\overline{\nu})$	$\mathcal{G}(1)\lvert V_{cb}\rvert$	$\mathcal{F}(1)\lvert V_{cb}\rvert$	Muon sample ρ_D^2	$\rho_{D^*}^2$	$\mathcal{B}(D\ell\overline{\nu})$	$\mathcal{B}(D^*\ell\overline{\nu})$	$\mathcal{G}(1)\lvert V_{cb}\rvert$	$\mathcal{F}(1)\lvert V_{cb}\rvert$
R_1'	0.44	2.74	0.71	−0.38	0.60	0.71	0.50	2.67	0.74	−0.40	0.63	0.70
R_2'	−0.40	1.02	−0.18	0.30	−0.32	0.49	−0.45	0.96	−0.19	0.30	−0.33	0.48
D^{**} slope	−1.42	−2.52	−0.07	−0.09	−0.82	−0.87	−1.42	−2.58	−0.10	−0.10	−0.77	−0.92
D^{**} FF approximation	−0.87	0.33	−0.12	0.19	−0.54	0.20	−0.99	0.59	−0.12	0.21	−0.59	0.30
$\mathcal{B}(B^- \to D^{(*)}\pi\ell\overline{\nu})$	0.28	−0.27	−0.22	−0.80	0.04	−0.49	0.59	−0.32	−0.13	−0.86	0.24	−0.54
$f_{D_2^*/D_1}$	−0.39	0.16	−0.38	0.16	−0.41	0.13	−0.50	0.17	−0.41	0.18	−0.47	0.15
$f_{D_0^* D\pi/D_1 D_2^*}$	−2.30	1.12	−1.53	0.97	−2.07	0.85	−3.13	1.23	−1.53	1.02	−2.41	0.93
$f_{D_1' D^*\pi/D_1 D_2^*}$	1.82	−1.14	1.30	−0.65	1.65	−0.70	2.44	−1.15	1.35	−0.72	1.91	−0.75
$f_{D\pi/D_0^*}$	−0.88	−1.28	0.36	0.17	−0.31	−0.34	−0.83	−1.23	0.31	0.18	−0.27	−0.33
$f_{D^*\pi/D_1'}$	−0.21	−0.05	−0.13	0.21	−0.18	0.09	−0.30	−0.04	−0.15	0.23	−0.23	0.10
NR D^*/D ratio	0.58	−0.16	0.11	−0.09	0.38	−0.04	0.66	−0.16	0.11	−0.09	0.40	−0.03
$\mathcal{B}(B^- \to D^{(*)}\pi\pi\ell\overline{\nu})$	1.19	−1.97	0.25	−1.28	0.78	−1.28	1.98	−1.71	0.40	−1.20	1.20	−1.18
X^*/X and Y^*/Y ratio	0.61	−1.15	0.09	−0.27	0.39	−0.52	0.74	−1.02	0.08	−0.24	0.42	−0.47
X/Y and X^*/Y^* ratio	0.76	−0.83	0.21	−0.65	0.52	−0.60	1.09	−0.76	0.25	−0.63	0.68	−0.57
$D_1 \to D\pi\pi$	2.22	−1.54	0.74	−1.08	1.63	−1.05	2.74	−1.48	0.76	−1.06	1.81	−1.03
$f_{D_2^*}$	−0.14	−0.01	−0.10	0.07	−0.12	0.03	−0.16	−0.01	−0.10	0.07	−0.13	0.03
$\mathcal{B}(D^{*+} \to D^0\pi^+)$	0.73	−0.01	0.43	−0.34	0.62	−0.17	0.80	−0.00	0.41	−0.33	0.61	−0.17
$\mathcal{B}(D^0 \to K^-\pi^+)$	0.69	0.02	−0.21	−1.63	0.29	−0.80	0.92	0.12	−0.27	−1.68	0.35	−0.80
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	−1.46	−0.42	−2.17	0.30	−1.89	0.01	−1.43	−0.42	−2.10	0.28	−1.77	−0.01
τ_{B^-}/τ_{B^0}	0.26	0.16	0.63	0.27	0.46	0.19	0.22	0.16	0.58	0.28	0.41	0.19
f_{+-}/f_{00}	0.88	0.43	0.66	−0.53	0.82	−0.12	0.91	0.48	0.57	−0.52	0.75	−0.10
Number of $B\overline{B}$ events	0.00	−0.00	−1.11	−1.11	−0.55	−0.55	0.00	−0.00	−1.11	−1.11	−0.55	−0.55
Off-peak Luminosity	0.05	0.01	−0.02	−0.00	0.02	0.00	0.07	0.00	−0.02	−0.00	0.02	−0.00
B momentum distrib.	−0.96	0.63	1.29	−0.54	−1.15	0.48	1.30	−0.10	1.27	−0.64	1.31	−0.35
Lepton PID eff	0.52	0.16	1.21	0.82	0.90	0.46	3.30	0.06	5.11	5.83	1.99	2.90
Lepton mis-ID	0.03	0.01	−0.01	−0.01	0.01	−0.00	2.65	0.70	−0.59	−0.50	1.06	−0.01
Kaon PID	0.07	0.80	0.28	0.23	0.18	0.38	1.02	0.71	0.35	0.29	0.70	0.39
Tracking eff	−1.02	−0.43	−3.35	−2.00	−2.25	−1.15	−0.63	−0.28	−3.37	−2.09	−2.02	−1.14
Radiative corrections	−3.13	−1.04	−2.87	−0.74	−3.02	−0.71	−0.76	−0.61	−0.82	−0.25	−0.79	−0.33
Bremsstrahlung	0.07	0.00	−0.13	−0.28	−0.04	−0.14	0.00	0.00	0.00	0.00	0.00	0.00
Vertexing	0.83	−0.64	0.63	0.60	0.78	0.09	1.79	−0.76	0.97	0.54	1.41	0.01
Background total	1.39	1.12	0.64	0.34	1.07	0.51	1.58	1.09	0.67	0.38	1.16	0.49
Total	**6.25**	**5.66**	**6.01**	**4.03**	**5.99**	**3.20**	**8.12**	**5.47**	**7.35**	**7.07**	**6.06**	**4.23**

[arXiv:0904.4063] submitted to PRL

BaBar B → Dlν tagged systematics

	Systematic uncertainty on $\|V_{cb}\|$, ρ^2 and BF								
	$D^0\ell^-\bar{\nu}_\ell$			$D^+\ell^-\bar{\nu}_\ell$			$D\ell^-\bar{\nu}_\ell$		
	$\|V_{cb}\|(\%)$	ρ^2	BF (%)	$\|V_{cb}\|(\%)$	ρ^2	BF (%)	$\|V_{cb}\|(\%)$	ρ^2	BF (%)
Tracking efficiency	0.5	0.008	0.7	1.1	0.003	1.4	0.7	0.004	1.0
Neutral reconstruction	1.0	0.003	1.2	0.8	0.006	0.9	0.9	0.004	1.2
Lepton ID	1.0	0.009	1.0	0.9	0.009	0.8	0.9	0.009	0.9
Final State Radiation	0.1	0.005	0.2	0.1	0.005	0.2	0.1	0.005	0.2
Cascade $\overline{B} \to X \to \ell^-$ decay background	0.6	-	1.2	1.0	-	2.0	0.8	-	1.5
$B^0 - B^\pm$ cross-feed	0.2	0.003	0.2	0.2	0.003	0.2	0.2	0.003	0.2
$\overline{B} \to D^*\ell^-\bar{\nu}_\ell$ form factors	0.6	0.008	0.5	0.2	0.003	0.2	0.4	0.006	0.3
$\overline{B} \to D^{**}\ell^-\bar{\nu}_\ell$ form factors	0.2	0.007	0.2	0.3	0.006	0.2	0.3	0.007	0.1
D branching fractions	1.0	-	2.0	1.4	-	2.7	1.1	-	2.2
$\mathcal{B}(\overline{B} \to D^{**}\ell^-\bar{\nu}_\ell)$	1.2	0.023	0.6	1.0	0.011	0.9	1.1	0.019	0.6
$\mathcal{B}(\overline{B} \to X\ell^-\bar{\nu}_\ell)$	0.9	-	1.9	0.9	-	1.9	0.8	-	1.7
$B_{\rm tag}$ selection	1.1	0.021	0.6	1.8	0.036	0.8	1.5	0.028	0.8
$\overline{B} \to X\ell^-\bar{\nu}_\ell$ fit	0.7	-	1.4	1.1	-	2.2	0.8	-	1.7
$\overline{B} \to D\ell^-\bar{\nu}_\ell$ fit	1.3	0.018	1.1	1.1	0.027	0.6	1.3	0.020	0.8
B meson lifetime	-	-	0.7	-	-	0.6	-	-	0.6
Total systematic error	3.1	0.04	4.1	3.6	0.05	5.0	3.3	0.04	4.3