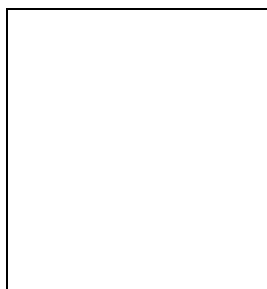


# SEMILEPTONIC B DECAYS AT THE B FACTORIES

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Recent results on inclusive and exclusive semileptonic  $B$  decays from  $B$  Factories are presented. The status and perspectives of the determination of the CKM matrix elements  $V_{ub}$  and  $V_{cb}$  with semileptonic  $B$  decays is discussed.

## 1 Introduction

Semileptonic  $B$  decays provide direct access to the CKM matrix elements  $V_{ub}$  and  $V_{cb}$ , whose ratio gives a measurement of the side of the Unitarity Triangle opposite the angle  $\beta$ .

The underlying theory of semileptonic  $B$  decays is at an advanced stage. The weak currents factorize in leptonic and hadronic parts which do not interact between each other. Moreover, the  $b$  quark mass is considerably larger than the scale  $\Lambda_{QCD}$  of hadronic physics. Therefore, a systematic expansion in  $\Lambda_{QCD}/m_b$  and  $\alpha_s$  can be performed, contributions from perturbative and non-perturbative physics can be separated, and measurements of semileptonic  $B$  decays enable precise determinations of  $V_{cb}$  and  $V_{ub}$ .

Semileptonic  $B$  decays also probe the structure of  $B$  mesons, in analogy with neutrino deep inelastic scattering. Inclusive decays are sensitive to quantities such as the mass and momentum distribution of the  $b$  quark inside the  $B$  meson, whereas exclusive decays measure form factors for specific final states. As a consequence, dominant theoretical uncertainties which enter in the determination of  $V_{ub}$  and  $V_{cb}$  can be experimentally assessed and minimized.

Due to large data sets,  $B$  Factories are now performing precision measurements on high purity samples, such as events where one  $B$  from the  $\Upsilon(4S)$  decay is fully or partially reconstructed, and the semileptonic decay of the other  $B$  is studied. As a consequence, partial rates

for  $\bar{B} \rightarrow X_u \ell \bar{\nu}$  transitions can be measured in regions of the phase space, previously considered inaccessible, where theoretical uncertainties are reduced.

A comprehensive review of  $V_{cb}$  and  $V_{ub}$  measurements is beyond the scope of this paper. In the following, after discussing the general framework of each measurement technique, we will present and discuss only the most recent determinations of  $V_{cb}$  and  $V_{ub}$  with inclusive (Sections 2 and 3) and exclusive (Sections 4 and 5) semileptonic  $B$  decays. The current status and outlook are summarized in Section 6.

## 2 Inclusive Semileptonic Decays with Charm

The rate for  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  decays is related to the free quark rate by Operator Product Expansion (OPE) techniques<sup>1</sup>. The resulting *Heavy Quarks Expansion* is double in powers of  $\alpha_s$  and  $1/m_b$ , and can be written schematically as<sup>2</sup>

$$\Gamma_{sl} = \frac{G_F m_b^5}{192 \pi^3} |V_{cb}|^2 (1 + A_{EW}) A_{pert}(\alpha_s) A_{non-pert}(1/m_b, 1/m_c, a_i) \quad (1)$$

where  $A_{EW}$  and  $A_{pert}$  represent electroweak and QCD perturbative corrections respectively. The non-perturbative QCD part  $A_{non-pert}$  is expanded in terms of the heavy quark masses ( $m_b$ ,  $m_c$ ), with  $a_i$  as coefficients. The latter are matrix elements of operators, such as the kinetic energy and the chromomagnetic moment, which describe in principle universal properties of  $B$  mesons. In practice, the  $a_i$  parameters depend on the renormalization scale, on the chosen renormalization scheme, and their number is a function of the order of the  $1/m_b$  expansion; four of them appear at order  $m_b^{-3}$ .

The Heavy Quark Expansion also predicts the moments of observables in  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  decays such as the lepton energy  $E_\ell$  and the invariant mass of the hadronic final state  $m_X$ , in regions of phase space, as a function of the  $a_i$  parameters,  $m_b$ ,  $m_c$ , and  $V_{cb}$ . Therefore, experimental determinations of these moments in different portions of the phase space allow a simultaneous measurement of the heavy quark parameters and masses, as well as  $V_{cb}$ . Such studies have been performed at the  $B$  Factories<sup>3,4,5</sup>, CDF<sup>6</sup> and Delphi<sup>7</sup>. The resulting moments of the energy spectrum (0th-3rd) and of the squared hadronic mass spectrum (0th-2nd) have comparable statistical and systematic uncertainties.

Radiative  $b \rightarrow s\gamma$  decays can also be used to determine the heavy quark parameters, since the energy spectrum of the photon, monoenergetic at the parton level, is smeared at the hadron level, by an amount which depends on the structure of the  $B$  meson. The same techniques used in semileptonic decays can be applied in this case as well. Moments can be computed and compared to experimental determinations<sup>8,9,10,11</sup>. The main limitation of these measurements is due to background subtraction, which is dominant at low ( $E_\gamma < 1.9\text{GeV}$ ) energies.

The experimental determinations of the  $b \rightarrow \mu \nu$  and  $b \rightarrow s\gamma$  moments can be combined, by using the kinetic mass scheme, in a global fit to heavy quark parameters<sup>12</sup>, which gives uncertainties of about 2% on  $|V_{cb}|$ , 1% on  $m_b$  and 10% on  $\mu_\pi^2$ , the matrix element of the kinetic energy operator:

$$\begin{aligned} |V_{cb}| &= (41.96 \pm 0.23 \pm 0.35 \pm 0.59) \cdot 10^{-3} \\ m_b &= (4.59 \pm 0.04) \text{GeV} & \mu_\pi^2 &= (0.40 \pm 0.04) \text{GeV}^2 & \rho &= -0.26 \end{aligned} \quad (2)$$

Since  $m_b$  and  $\mu_\pi^2$  contribute the dominant systematic uncertainty in the inclusive determination of  $V_{ub}$ , their precise measurement is crucial.

## 3 Inclusive Charmless Semileptonic Decays

In principle,  $|V_{ub}|$  is related to the rate of inclusive charmless semileptonic decays by an expression equivalent to Eq. 1, which contains matrix elements of operators related to the ones entering

in the  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  decay. If the full  $\bar{B} \rightarrow X_u \ell \bar{\nu}$  decay rate were experimentally accessible, the resulting theory uncertainty would be of the order of 5%<sup>13</sup>. In practice the accessible rate is much reduced and the theoretical uncertainty increases considerably, since the overwhelming background (a factor 50) from  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  decays must be suppressed by stringent kinematic requirements. These cuts are all based on the  $u$  quark being much lighter than the  $c$  quark. As a consequence, the distributions of  $E_\ell$  and  $q^2$ , the squared invariant mass of the lepton pair, extends to higher values for signal, whereas the  $m_X$  spectrum is concentrated at lower values. It is therefore possible to select regions of the phase space where the signal over background ratio is adequate. However, the resulting acceptances tend to be small (6%, 20%, up to 70% for typical requirements on  $E_\ell$ ,  $q^2$  and  $m_X$ , respectively) and, if cuts are not carefully chosen, poorly known, since OPE breaks down and a shape function is needed to resum non-perturbative physics to all orders. This shape function depends on  $m_b$  and heavy quark parameters. Therefore, it is possible to determine its basic features from other processes, like  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  and  $b \rightarrow s \gamma$  decays<sup>a</sup>. Indeed, most of the theoretical uncertainty in inclusive  $V_{ub}$  determinations is due to our imperfect knowledge of the shape function,  $m_b$  and the heavy quark parameters. Minimizing these uncertainties by maximizing the acceptance, *e.g.* by relaxing the cut on  $E_\ell$ , is possible only if background knowledge is good. Otherwise, one can choose regions, *e.g.* at low  $m_X$  and high  $q^2$ , where shape function effects are expected to be small and OPE works well.

Several theory calculations<sup>14,15,16,17</sup> can be used to get acceptances in restricted regions of phase space.  $|V_{ub}|$  is determined from the measurement of  $\Delta\mathcal{B}(\bar{B} \rightarrow X_u \ell \bar{\nu})$ , the charmless semileptonic partial branching fraction in the phase space region  $\Delta\Phi$  defined by kinematic cuts, and  $\zeta(\Delta\Phi)$ , the rate (in  $|V_{ub}|^2 \text{ ps}^{-1}$ ) for the same phase space region predicted by theory:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{B} \rightarrow X_u \ell \bar{\nu})}{\tau_b \cdot \zeta(\Delta\Phi)}} \quad (3)$$

where  $\tau_b$  is the  $B$  meson lifetime. Measuring partial branching fractions allows to use and compare several models, and to update previous determinations as theory uncertainties and calculations improve.

### 3.1 Measurements near the Endpoint of the Lepton Energy Spectrum

Historically, the observation of events where the energy of the lepton exceeded the endpoint expected for  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  decays ( $E_\ell > 2.3 \text{ GeV}$ ) provided the first evidence for charmless semileptonic decays. As background knowledge improved, it has been possible<sup>19,20,21</sup> to relax the requirement on  $E_\ell$  down to 2.0 GeV, or even 1.9 GeV (Belle), thereby increasing the acceptance and decreasing theory uncertainty. The typical signal-to-background ratio in these studies is about 1:10. Figure 1, left, shows the distribution of the electron momentum near the kinematic endpoint, after subtraction of backgrounds and corrections for efficiency and radiative effects, obtained by Babar on a sample of 88 million  $B\bar{B}$  events. The resulting determination of  $|V_{ub}|$ , adjusted by HFAG<sup>26</sup> (see Section 3.3), is shown in Table 1 together with measurements from other experiments. The uncertainty on  $V_{ub}$  from endpoint measurements is at the 10% level, dominated by uncertainties on the shape function parameters, mostly a 40 MeV uncertainty on  $m_b$ .

### 3.2 Hadronic $B$ tags

Other discriminating variables such as  $m_X$  and  $q^2$  can be reconstructed experimentally by determining unambiguously which hadrons originate from the semileptonic decay of a  $B$  meson.

<sup>a</sup>Some care must be taken when relating the heavy quark parameters determined in different processes, since the theoretical calculations are performed in different normalization schemes, and the order of the heavy quark expansion is not necessarily the same.

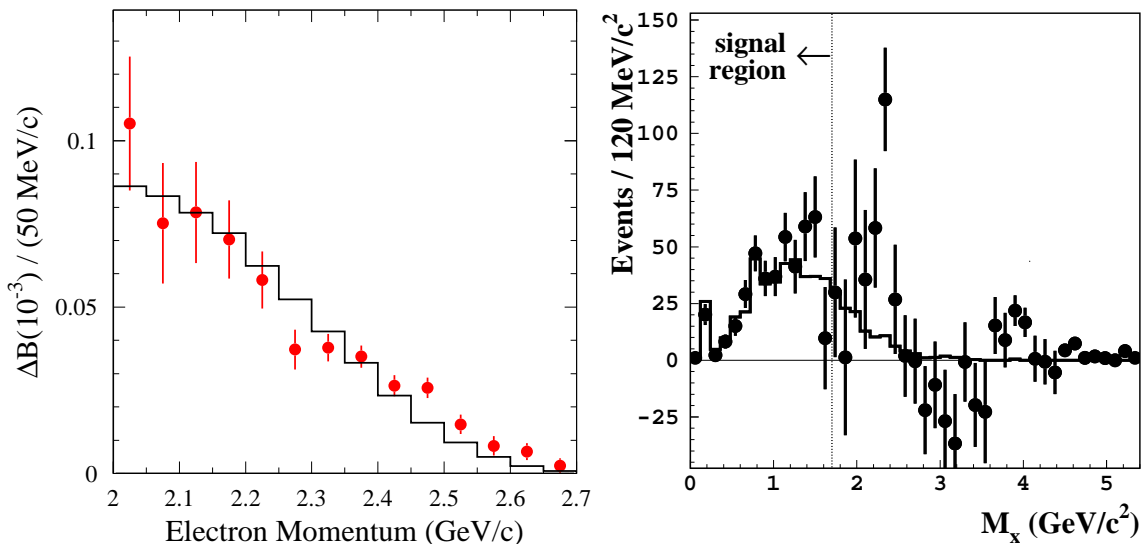


Figure 1: Left: Electron energy spectrum near the endpoint, obtained by Babar on a sample of  $88 \times 10^6$   $B\bar{B}$  events. Data points, after background subtraction and correction for efficiency, bremsstrahlung and final state radiation, are compared to the Monte Carlo simulation (histogram). Right: Distribution of  $m_X$ , obtained by Belle on a sample of  $253 \times 10^6$   $B\bar{B}$  events. A  $B$  meson is reconstructed in a fully hadronic final state and a semileptonic decay of the second  $B$  is identified. Points represent data, after subtracting  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  and other backgrounds, the histogram is the fitted  $\bar{B} \rightarrow X_u \ell \bar{\nu}$  contribution.

This difficult task for experiments running at the  $\Upsilon(4S)$  peak can be solved by explicitly reconstructing the decay of a  $B$  meson in a fully hadronic final state, and studying the recoiling  $B$ , whose momentum and flavour are consequently known. If the recoiling  $B$  decays semileptonically, the only missing particle in the event is the neutrino, which can be reconstructed by using missing mass arguments. The experimental resolution on the discriminating variables can be increased by using a kinematic fit. This technique, pioneered by Babar<sup>27</sup>, provides signal over background ratios of about 1 or more, at the expense of a very small ( $\mathcal{O}(10^{-3})$ ) efficiency due to the full hadronic reconstruction. As datasets increase, inclusive measurements with hadronic  $B$  tags are expected to give the most precise determinations of  $|V_{ub}|$ . Figure 1, right, shows the  $m_X$  spectrum after background subtraction, resulting from an analysis by Belle<sup>25</sup>. The resulting  $V_{ub}$  measurement, adjusted by HFAG, is shown in Table 1, together with results from Babar. Results from the two experiments are comparable, with uncertainties at the 10% level, dominated by theory.

Shape function effects, which give the dominant contribution to the uncertainty in inclusive  $V_{ub}$  determinations, can be reduced by using theoretical calculations which relate the rate  $\Delta\Gamma(\bar{B} \rightarrow X_u \ell \bar{\nu})$  to the photon energy spectrum in  $b \rightarrow s\gamma$  decays. For instance, one can schematically write<sup>28,29</sup>

$$\Delta\Gamma(\bar{B} \rightarrow X_u \ell \bar{\nu}) = \frac{|V_{ub}|^2}{|V_{ts}|^2} \int W(E_\gamma) \frac{d\Gamma(b \rightarrow s\gamma)}{dE_\gamma} dE_\gamma, \quad (4)$$

where the integration is performed in an appropriate phase space region and the weight function  $W(E_\gamma)$  is computed by theory with moderate uncertainty. The dependence on the shape function is therefore folded in the experimental measurement. A new Babar measurement<sup>30</sup>, which uses this approach and calculations by Low, Leibovich and Rothstein<sup>29</sup>, has been released just before this Conference. It is based on an analysis of the recoil of fully reconstructed  $B$  mesons on 88 million  $B\bar{B}$  events. Figure 2 shows the spectrum of the hadronic invariant mass, before (left) and after (right) background subtraction. The partial rate  $\Delta\Gamma(\bar{B} \rightarrow X_u \ell \bar{\nu})$  is determined by

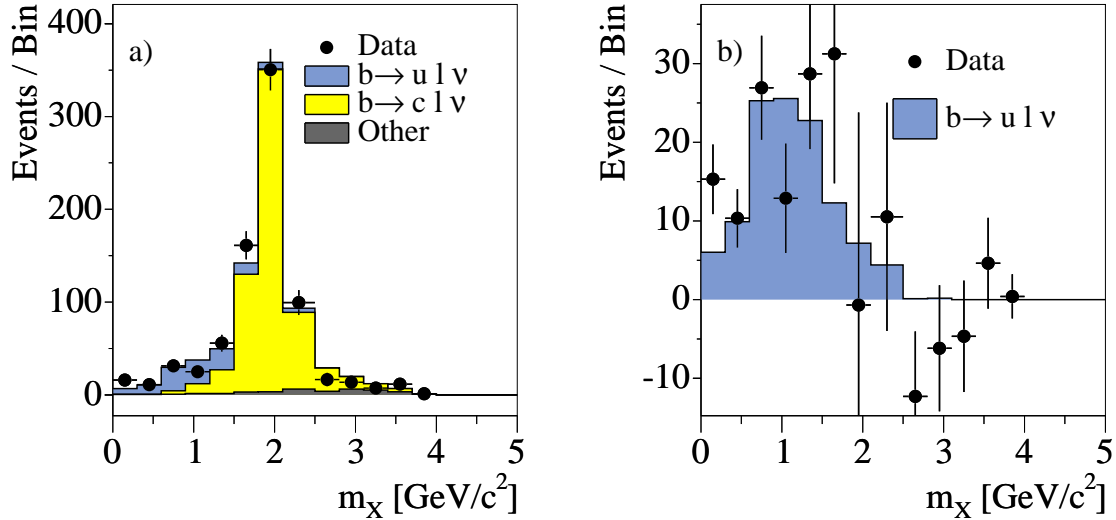


Figure 2: Distributions of  $m_X$  before (left) and after (right) subtraction of  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  and other backgrounds, obtained by Babar on a sample of  $88 \times 10^6$   $B\bar{B}$  events. Semileptonic decays are identified in the recoil of a fully reconstructed hadronic  $B$  decay. Points are data, histograms represent signal and background contributions. The  $m_X$  spectrum after background subtraction is used to compute partial branching fractions as a function of the  $m_X$  cut, which are then combined with suitable integrations of the photon energy spectrum in  $b \rightarrow s\gamma$  decays to obtain  $V_{ub}$ .

counting events below a cut on  $m_X$ , and  $V_{ub}$  is extracted by using the photon energy spectrum in  $b \rightarrow s\gamma$  decays as measured by Babar<sup>10</sup>. Theory uncertainties increase as the  $m_X$  cut is decreased, since a region dominated by non-perturbative effects is selected. Experimental errors increase at higher  $m_X$  cuts due to background subtraction. The resulting optimal working point corresponds to  $m_X < 1.67$  GeV, which gives a measurement of  $|V_{ub}|$  (see Table 1) compatible with other determinations and 12% uncertainty. As expected, the impact of shape function parameters is small in this approach. The theory error results from neglecting high order terms in the  $1/m_b$  expansion. A  $V_{ub}$  measurement over the full  $m_X$  spectrum is also shown in Table 1; as expected, the theory error decreases since the full phase space is used, but the statistical error increases.

### 3.3 Inclusive $V_{ub}$ : Summary and Outlook

Table 1 shows a summary of inclusive  $V_{ub}$  measurements, together with the latest average from HFAG<sup>26</sup>. All measurements have been adjusted by HFAG so that the same theory framework<sup>16</sup> and shape function parameters and uncertainties (Eq. 2) are used. The total uncertainty on  $V_{ub}$  from inclusive measurements is 7.4%, dominated by theory. The uncertainty from limited knowledge of the shape function is about 4%. Experiments can help by determining shape function parameters with better accuracy, but it will be hard to go down 30 MeV on  $m_b$ . Other theoretical uncertainties, due to neglecting higher order terms and weak annihilation effects, contribute 5% to the uncertainty on  $V_{ub}$ . While the latter can be studied experimentally, the former will be difficult to improve. Other theory approaches, such as the Dressed Gluon Exponentiation by Andersen and Gardi<sup>17</sup>, are also promising and worth to investigate.

Table 1: Experimental measurements of partial branching fractions  $\Delta\mathcal{B}$  for inclusive  $\bar{B} \rightarrow X_u \ell \bar{\nu}$  decays and  $|V_{ub}|$ , adjusted by HFAG as explained in the text.  $f_u$  is the space phase acceptance. The errors on  $V_{ub}$  refer to experimental and theoretical uncertainties, respectively. The  $s_h^{\max}$  variable is described elsewhere<sup>18</sup>. The  $P_+$  variable is defined as  $P_+ = E_X - |\vec{p}_X|$ .

	accepted region	$f_u$	$\Delta\mathcal{B}[10^{-4}]$	$ V_{ub} [10^{-3}]$
*CLEO <sup>19</sup>	$E_e > 2.1$ GeV	0.19	$3.3 \pm 0.2 \pm 0.7$	$4.05 \pm 0.47 \pm 0.36$
*BABAR <sup>20</sup>	$E_e > 2.0$ GeV	0.26	$5.3 \pm 0.3 \pm 0.5$	$4.25 \pm 0.30 \pm 0.31$
*BELLE <sup>21</sup>	$E_e > 1.9$ GeV	0.34	$8.5 \pm 0.4 \pm 1.5$	$4.85 \pm 0.45 \pm 0.31$
*BABAR <sup>22</sup>	$E_e > 2.0$ GeV, $s_h^{\max} < 3.5$ GeV <sup>2</sup>	0.19	$3.5 \pm 0.3 \pm 0.3$	$4.06 \pm 0.27 \pm 0.36$
*BABAR <sup>23</sup>	$m_X < 1.7$ GeV/ $c^2$ , $q^2 > 8$ GeV <sup>2</sup> / $c^2$	0.34	$8.7 \pm 0.9 \pm 0.9$	$4.79 \pm 0.35 \pm 0.33$
*BELLE <sup>24</sup>	$m_X < 1.7$ GeV/ $c^2$ , $q^2 > 8$ GeV <sup>2</sup> / $c^2$	0.34	$7.4 \pm 0.9 \pm 1.3$	$4.41 \pm 0.46 \pm 0.30$
BELLE <sup>25</sup>	$m_X < 1.7$ GeV/ $c^2$ , $q^2 > 8$ GeV <sup>2</sup> / $c^2$	0.34	$8.4 \pm 0.8 \pm 1.0$	$4.68 \pm 0.37 \pm 0.32$
BELLE <sup>25</sup>	$P_+ < 0.66$ GeV	0.57	$11.0 \pm 1.0 \pm 1.6$	$4.14 \pm 0.35 \pm 0.29$
*BELLE <sup>25</sup>	$m_X < 1.7$ GeV/ $c^2$	0.66	$12.4 \pm 1.1 \pm 1.2$	$4.10 \pm 0.27 \pm 0.25$
BABAR <sup>30</sup>	$m_X < 1.67$ GeV & $b \rightarrow s\gamma$			$4.43 \pm 0.45 \pm 0.29$
BABAR <sup>30</sup>	$m_X < 2.5$ GeV & $b \rightarrow s\gamma$			$4.34 \pm 0.76 \pm 0.10$
Average of *	$\chi^2 = 6.3/6$ , CL=0.40			$4.39 \pm 0.19 \pm 0.27$

#### 4 Exclusive SL Decays with Charm

The technique of determining  $V_{cb}$  by using  $B \rightarrow D^* l \nu$  decays is well established. The differential distribution can be written in terms of  $w$ , the  $D^*$  boost in the  $B$  rest frame, as

$$\frac{d\Gamma(B \rightarrow D^* l \nu)}{dw} = \frac{G_F^2 |V_{cb}|^2}{48\pi^3} (\mathcal{F}(w))^2 \mathcal{G}(w) \quad (5)$$

where  $\mathcal{G}(w)$  is a phase space factor and  $\mathcal{F}(w)$  is a form factor which would be 1 at  $w = 1$  in the heavy quark limit. Lattice QCD can be used to compute effects due to finite quark masses, leading to<sup>31</sup>  $\mathcal{F}(1) = 0.919_{-0.035}^{+0.030}$ . The shape of  $\mathcal{F}(w)$  cannot be predicted by theory, and is parameterized in terms of a slope  $\rho^2$  and form factor ratios  $R_1$  and  $R_2$ , (nearly) independent of  $w$ . The helicity amplitudes entering in the  $B \rightarrow D^* l \nu$  decay are also function of the above parameters. These amplitudes, and therefore  $\rho^2$ ,  $R_1$  and  $R_2$ , can be determined by fitting the four-fold differential rate of  $B \rightarrow D^* l \nu$  decays in terms of  $w$  and three angles which describe the decay kinematics. Figure 3 shows the result of the fit to the angular and  $w$  distributions obtained in a recent Babar measurement<sup>32</sup>, where form factors are parameterized by using a prescription due to Caprini, Lellouch and Neubert<sup>33</sup>. The uncertainties on the resulting measurements

$$R_1 = 1.396 \pm 0.060 \pm 0.044, \quad R_2 = 0.885 \pm 0.040 \pm 0.026, \quad \rho^2 = 1.145 \pm 0.059 \pm 0.046,$$

are a factor 5 better than in previous determinations<sup>34</sup>. Consequently, the systematic uncertainty, due to form factor ratios, in the Babar exclusive  $V_{cb}$  determination<sup>35</sup> decreases approximately by the same amount. It is also interesting to note that the re-interpretation of the Babar exclusive  $V_{cb}$  measurement gives

$$|V_{cb}| = (37.6 \pm 0.3_{stat} \pm 1.3_{syst} \pm 1.4_{theory}) \times 10^{-3}, \quad (6)$$

which is about 2 standard deviations away from the published result<sup>35</sup>. Since  $B \rightarrow D^* l \nu$  is a dominant background for charmless semileptonic decays, a reduction of the systematic uncertainty due to the better knowledge of the  $B \rightarrow D^* l \nu$  form factor ratios is also observed in the endpoint measurement<sup>20</sup> of  $V_{ub}$ .

## 5 Exclusive Charmless SL Decays

The differential rates for exclusive charmless semileptonic decays in terms of  $q^2$  is proportional to  $|V_{ub}|^2$  times a form factor which is final state dependent. The absolute values of these form factors are predicted by using several theoretical frameworks (light-cone sum rules, lattice calculations, quark models); their dependence on  $q^2$  can be checked experimentally, thereby allowing to discriminate different theoretical models. In brief, experiments search for semileptonic decays with a light meson ( $\pi, \rho, \eta, \eta', \omega$ ) in events where the other  $B$  is tagged via hadronic or semileptonic decays, or even in untagged events. The latter gives better efficiencies, but also higher backgrounds. No new results were released immediately before this Conference. A summary of determinations of exclusive charmless semileptonic branching fractions and  $V_{ub}$  is given elsewhere<sup>26</sup>. The uncertainty on the average value of  $|V_{ub}|$ , about 14%, is dominated by the normalization of the form factors, which contributes about 10%. The determinations of  $V_{ub}$  with inclusive and exclusive decays are in agreement at the present level of accuracy.

Heavy quark symmetry relates the form factors of  $B \rightarrow \pi l \nu$  and  $D \rightarrow \pi l \nu$  decays. A precise measurement of the latter represents a stringent test which can be used to calibrate theoretical calculations and increase the precision of  $V_{ub}$  determinations from  $B \rightarrow \pi l \nu$  decays. A first step towards this goal is measuring the  $q^2$  dependence of the hadronic form factor in  $D \rightarrow K l \nu$  decays with great accuracy. A preliminary result obtained by Babar is shown for the first time at this Conference. A sample of  $2 \times 10^5$  decays has been analysed, and the  $q^2$  distribution, unfolded of detector effects, has been obtained and fit to two different ansätze (the pole and modified pole mass) for the form factor shape. Measurements of the mass and scale entering in these parameterizations give uncertainties which are at least a factor 2 better than previous determinations.

## 6 Conclusion

The study of semileptonic  $B$  decays is a very active area for both theory and experiment. Substantial progress has been obtained by applying HQE fits to inclusive  $\bar{B} \rightarrow X_c \ell \bar{\nu}$  decays, resulting in precise measurements of  $|V_{cb}|$  (2%),  $m_b$  (1%) and heavy quark parameters relevant also to charmless decays. Increased precision (7%) has been obtained in inclusive  $V_{ub}$  determinations, by improving the existing techniques, using a more comprehensive theoretical treatment, and improving the determination of the  $b$  quark mass.

New precision measurement of form factors in exclusive  $B \rightarrow D^* l \nu$  decays allows to reduce systematic uncertainties in the determination of  $V_{cb}$  with exclusive decays and  $V_{ub}$  with inclusive

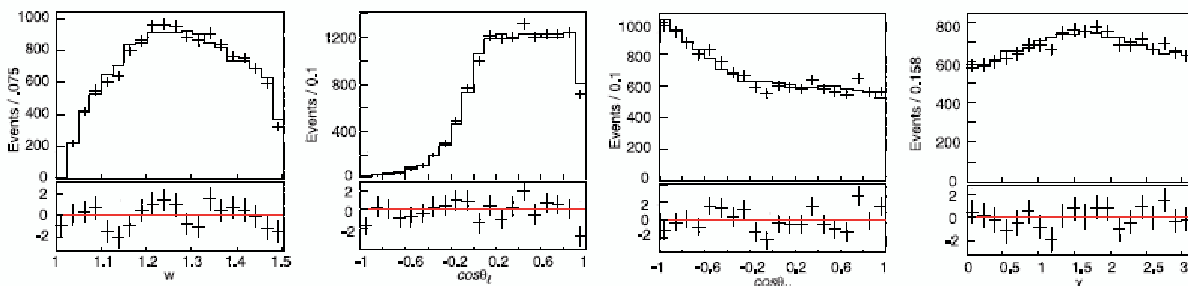


Figure 3: Background-subtracted data (points) overlaid on Monte Carlo (histograms) for the distributions of the four kinematic variables relevant in the  $B \rightarrow D^* l \nu$  decay, as measured in the Babar form factor analysis on a sample of  $86 \times 10^6$   $B\bar{B}$  events. Simulated events have been reweighted according to the best fit of the form factors. The bottom panel of each figure shows the pull (difference over error) plot. The line at zero is shown for comparison purposes only.

decays. Studies of exclusive charmless decays will improve as datasets increase. However, reducing the theoretical uncertainties to a level comparable with the statistical error and the inclusive determinations is challenging. In this respect, measurements of related processes such as semileptonic decays of charm mesons will increase confidence in theoretical calculations and uncertainties.

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