NEW CKM-RELATED STUDIES ON $b$ DECAYS IN THE DELPHI EXPERIMENT AT LEP

Winfried A. Mitaroff

Institute of High Energy Physics, Austrian Academy of Sciences, Vienna
(on behalf of the DELPHI Collaboration)

ABSTRACT

The $e^-e^+$ collider LEP, running at $\sqrt{s} = m(Z^0)$, has been a copious source of $b$-hadrons produced in decays $Z^0 \to b\bar{b}$. We present recent studies using up to $4 \times 10^6$ hadronic $Z^0$ decays acquired by the DELPHI detector between 1992 and 2000. They rely on efficient particle identification, precise track and vertex reconstruction and sophisticated data analysis algorithms.

Presented are: a new measurement of the CKM matrix element $|V_{cb}|$ in the semileptonic exclusive decays $\bar{B}_d^0 \to D^{*+}\ell^-\bar{\nu}_\ell$; a new measurement of the $B^0_d - \bar{B}_d^0$ oscillation frequency $\Delta m_d$; and searches by three methods for $B^0_s - \bar{B}_s^0$ oscillations, yielding new lower limits on $\Delta m_s$.

1 $|V_{cb}|$ from s.l. exclusive decays $\bar{B}_d^0 \to D^{*+}\ell^-\bar{\nu}_\ell$

This analysis is performed on the exclusive channels $\ell^- = e^- \text{ or } \mu^-$, $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ or $K^-\pi^+\pi^-\pi^-$ or $K^-\pi^+(\pi^0)$ \(^1\) by measuring the differential partial width (i.e. decay rate) which is, according to HQET, given by

$$\frac{d\Gamma}{d\omega} = \frac{G_F^2}{48\pi^3} \cdot K(\omega) \cdot F_{D^*}^2(\omega) \cdot |V_{cb}|^2$$

as a function of the $D^*$ boost $\omega$ in the $B^0_d$ rest frame, defined as

$$\omega(q^2) \equiv v_{B^0} \cdot v_{D^*} = \frac{m_{B^0}^2 + m_{D^*}^2 - q^2}{2m_{B^0}m_{D^*}}, \quad q^2 \equiv (p_{B^0} - p_{D^*})^2$$

\(^1\)the charge-conjugate states ($B_d^0 \to D^{*-}\ell^+\nu_\ell$, $D^{*-} \to \bar{D}^0\pi^-$, $\bar{D}^0 \to K^+\pi^-\ldots$) are implicitly considered as well.
Its range is \(1 \leq \omega \lesssim 1.5\), with the lower bound corresponding to \(D^*\) zero recoil. \(\mathcal{K}(\omega)\) is a known kinematic factor, and \(\mathcal{F}_{D^*}(\omega)\) is the hadronic form factor which may be expanded at \(\omega = 1\). \(\mathcal{F}_{D^*}(1) \cdot |V_{cb}|\) and \([d\mathcal{F}_{D^*}/d\omega]_{\omega=1}\) are fitted from data, using eq. (1) convoluted with the experimental resolution as a function of \(q^2\), and extrapolated to \(\omega \to 1\). Since \(\mathcal{K}(1) = 0\), a reasonably constant reconstruction efficiency is required at \(\omega \approx 1\). Separation of different decay mechanisms producing \(D^*\) in the final state (notably for the exclusion of \(D^{**} \to D^*X\) background) is achieved by novel algorithms and is shown in fig. 1a.

Results of the fit, a calculation of \(|V_{cb}|\) using \(\mathcal{F}_{D^*}(1) = 0.91 \pm 0.04\) \(^2\), and the corresponding decay branching fraction are [1]:

\[
\begin{align*}
\mathcal{F}_{D^*}(1) \cdot |V_{cb}| &= (38.0 \pm 1.8 \pm 2.1) \times 10^{-3} \\
|V_{cb}| &= (41.8 \pm 2.0 \pm 2.3 \pm 1.7_{\text{theor}}) \times 10^{-3} \\
\text{BR} (\bar{B}_d^0 \to D^+ \ell^- \bar{\nu}_\ell) &= (5.54 \pm 0.20 \pm 0.41)\%
\end{align*}
\]

Figure 1: (a) \(|V_{cb}|\) analysis: distribution of \(q^2\) for \(D^*\) candidate events (dots) with their fitted contributions (shaded). (b) \(\Delta m_d\) analysis: fraction of like-sign tagged events as a function of the reconstructed proper time (data and fit).

2 Studies of \(B_d^0 - \bar{B}_d^0\) and \(B_s^0 - \bar{B}_s^0\) oscillations

Mixing of \(B_q^0 - \bar{B}_q^0\) \((q = d\) or \(s)\) proceeds via 2\(^{nd}\) order weak transitions (box graphs) which are dominated by \(t\)-quark exchange. The probabilities \(P_{\text{mix}}^{\text{nomix}}\) of a \(B_q^0 (\bar{B}_q^0)\)

\(^2\)in the heavy quark limit, \(\mathcal{F}_{D^*}(1) \to 1\); non-pertubative QCD corrections yield the value cited.
to have, after some time $t$, mixed or not mixed into a $\bar{B}_q^0 (B_q^0)$ state are

$$P_{\text{mix}}^{\text{nomix}} = \frac{1}{2}\tau_q \cdot e^{-\sigma_q^v} \cdot \left[ \cosh \frac{\Delta \Gamma_q}{2} t \mp \cos \Delta m_q t \right]$$

(3)

The SM predicts $\Delta \Gamma_q \ll \Delta m_q$, thus the $\cosh$ term is approximated by 1.

The oscillation frequencies $\Delta m_d$ and $\Delta m_s$ are directly related to $|V_{td}|$ and $|V_{ts}|$, respectively. Their measurements in a time-dependent analysis rely on two basic requirements: precise measurement of the proper decay time of the $B$ meson, achieved by precise track momentum and vertex reconstruction; and efficient tagging of the $B$ meson’s flavour, both at production and decay.

2.1 $\Delta m_d$ from $B_d^0 - \bar{B}_d^0$ oscillations

A high-statistics analysis, based on inclusive secondary vertex reconstruction and fitting $\Delta m_d$ (fig. 1b) as well as an upper limit of $|\Delta \Gamma_d|/\Gamma_d$ [2]:

$$\Delta m_d = 0.531 \pm 0.025 \pm 0.007 \text{ ps}^{-1}$$

$$|\Delta \Gamma_d|/\Gamma_d < 0.18 \text{ at 95\% c.l.}$$

2.2 Search for $B_s^0 - \bar{B}_s^0$ oscillations

(a) An analysis using the same method as that for $\Delta m_d$ (see section 2.1 above) [2]; and two analyses using new sophisticated algorithms, based on (b) inclusive high-$p_t$ leptons or (c) reconstructed $B_s^0 \rightarrow D_s^+ \ell^- \bar{\nu}_\ell X$ events [3] yield:

(a) $\Delta m_s > 5.0 \text{ ps}^{-1}$ (sensitivity = 6.6 ps$^{-1}$) at 95\% c.l.
(b) $\Delta m_s > 8.0 \text{ ps}^{-1}$ (sensitivity = 9.1 ps$^{-1}$) at 95\% c.l.
(c) $\Delta m_s > 4.9 \text{ ps}^{-1}$ (sensitivity = 8.6 ps$^{-1}$) at 95\% c.l.

Acknowledgements

Thanks are due to Franz Mandl (HEPHY Vienna) for his assistance in the poster presentation session at the conference.

References