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

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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 $\bar{B}^0_d \to D^{*+}\ell^-\bar{\nu}_\ell$; a new measurement of the $B^0_d - \bar{B}^0_d$ oscillation frequency $\Delta m_d$; and searches by three methods for $B^0_s - \bar{B}^0_s$ oscillations, yielding new lower limits on $\Delta m_s$.

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

This analysis is performed on the exclusive channels $\ell^- = e^-$ 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

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\omega} = \frac{G_F^2}{48\pi^3} \cdot \mathcal{K}(\omega) \cdot \mathcal{F}^2_{D^*}(\omega) \cdot |V_{cb}|^2 \tag{1}$$

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

$$\omega(q^2) \equiv v_{B^0} \bullet v_{D^*} = \frac{m^2_{B^0} + m^2_{D^*} - q^2}{2\, m_{B^0}\, m_{D^*}}, \qquad q^2 \equiv (p_{B^0} - p_{D^*})^2 \tag{2}$$

[1] the charge-conjugate states ($B^0_d \to D^{*-}\ell^+\nu_\ell$, $D^{*-} \to \bar{D}^0\pi^-$, $\bar{D}^0 \to K^+\pi^- \ldots$) 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 $[\mathrm{d}\mathcal{F}_{D^*}/\mathrm{d}\omega]_{\omega=1}$ 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]:

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

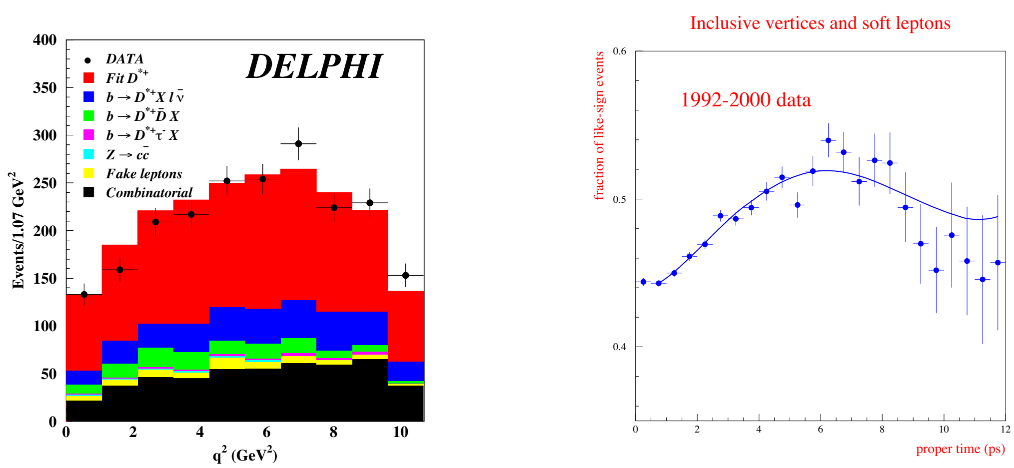


Figure 1: (a) $|V_{cb}|$ *analysis: distribution of* $q^2$ *for* $D^*$ *candidate events (dots) with their fitted contributions (shaded).* (b) $\Delta m_d$ *analysis: fraction of like-sign tagged events as a function of the reconstructed proper time (data and fit).*

## 2 Studies of $B^0_d - \bar{B}^0_d$ and $B^0_s - \bar{B}^0_s$ oscillations

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

[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 $\bar{B}^0_q$ ($B^0_q$) state are

$$\mathcal{P}^{mix}_{nomix} = \frac{1}{2\,\tau_q} \cdot e^{-\frac{t}{\tau_q}} \cdot \left[\cosh \frac{\Delta\Gamma_q}{2}\, t \;\mp\; \cos\Delta m_q\, t\right] \qquad (3)$$

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 $B^0_d - \bar{B}^0_d$ 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]:

$$\begin{aligned} \Delta m_d &= 0.531 \pm 0.025 \pm 0.007\,\mathrm{ps}^{-1} \\ |\Delta\Gamma_d|/\Gamma_d &< 0.18 \text{ at } 95\%\,\text{c.l.} \end{aligned}$$

### 2.2 Search for $B^0_s - \bar{B}^0_s$ 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 $\bar{B}^0_s \to D^+_s \ell^- \bar{\nu}_\ell X$ events [3] yield:

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

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## References

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