1 Introduction

In the last decade, new weakly decaying B-hadrons have been observed ($B^0_s$, $B_c$, $\Lambda_b$, $\Xi_b$) and their production and decay properties have been intensively studied. In this context CDF (operating at TeVatron), ALEPH, DELPHI, L3, OPAL (operating at LEP) and SLD (operating at SLC) experiments have played a central role. This has been made possible owing to the excellent performance both of the machines and of the detectors. Above all, these measurements would have not been possible without the development of Silicon detectors.

2 B hadron lifetimes

The measurement of the lifetimes of the different B hadrons is an important test of the B decay dynamics. The main improvements, since last year, have been obtained in the determination of $B^0_d$ and $B^+$ lifetimes. The results are given in Table 1. In future no improvements are really expected before the start of the new phase at TeVatron. Few conclusions can be drawn. The charged B-mesons live longer than the neutrals. This effect is now established at 3.5 $\sigma$. The lifetimes of the two neutral B mesons ($B^0_d$, $B^0_s$) are equal within 1$\sigma$. To observe any possible (and unexpected difference) new data are needed. The $b$-baryon lifetime problem still exists (since 3-4 years). $b$-baryons live shorter than $b$-mesons, as expected, but the magnitude of the effect is now more than 3 $\sigma$ away from the lower edge of the predictions. This should push for a better understanding of the theory independently of a possible improvement of the experimental accuracy.

3 Lifetime Difference: $\Delta\Gamma_s$

The ratio between the differences of the widths and of the masses of the $B^0_s$, $\bar{B}^0_s$ system mass eigenstates is (naively): $\Delta\Gamma_s/\Delta m_s \sim 3/2\pi(m_b/m_t)^2$. If $\Delta m_s$ is too large (and so, difficult to measure), $\Delta\Gamma_s$ can eventually gives access to it. Unfortunately the theoretical error attached to the evaluation of $\Delta\Gamma_s$ is still quite large, of the order of 50%. Recent theoretical calculations predict $\Delta\Gamma_s/\Gamma_s$ in the range (5-10) $\%$.

From the experimental point of view, the combination of LEP and CDF results gives (assuming $\tau(B^0_s) = \tau(B^0)$):

$$\Delta\Gamma_s/\Gamma_s = 0.16^{+0.16}_{-0.13} < 0.31 \text{ at 95\% C.L.}$$

4 $B^0 - \bar{B}^0$ mixing : $\Delta m_d, \Delta m_s$

In the Standard Model, $B^0_q - \bar{B}^0_q$ ($q = d, s$) mixing can be expressed by the following formula:

$$\Delta m_q = G_\nu^2/6\pi^2m_W^2\eta_cS(m_\tau^2/m_W^2)|V_{tq}|^2$$

$$m_{Bq}f_{Bq}^2B_{Bq}$$

(1)

where $S(m_\tau^2/m_W^2)$ is the Inami-Lim function, $m_t$ is the $t$ top mass and $\eta_c$ is a QCD correction factor obtained at NLO order in perturbative QCD. The measurement of $\Delta m_d, (\Delta m_s)$ gives access to $V_{td}, (V_{ts})$ CKM matrix elements and thus to the $\overline{\theta}$ and $\overline{\eta}$. 

A review of the results on $B^0$, $\bar{B}^0$ mixing and $b$-lifetimes obtained by CDF, LEP and SLD collaborations is presented with special emphasis on $B^0_s$, $\bar{B}^0_s$ mixing.
Table 1. Lifetime ratios results

| Lifetime ratios | Osaka 2000 | Tampere 1999 | Theory  |
|-----------------|------------|--------------|---------|
| $\tau(B^-)/\tau(B^0)$ | 1.070 ± 0.020 | 1.065 ± 0.023 | 1.0 - 1.1 |
| $\tau(B_s^+)/\tau(B^0)$ | 0.945 ± 0.039 | 0.937 ± 0.040 | 0.99 - 1.01 |
| $\tau(b - bary)/\tau(B^0)$ | 0.780 ± 0.035 | 0.773 ± 0.036 | 0.9 - 1.0 |

parameters of the Wolfenstein parametrization. We can write:

$$\Delta m_d \sim A^2 \lambda^2 [(1 - \bar{\rho})^2 + \bar{\eta}^2] f_{B_d}^2 f_{B_d}$$
$$\Delta m_s \sim A^2 \lambda^4 f_{B_s}^2 f_{B_s}$$

\(\rightarrow \Delta m_s \sim 1/\lambda^2 \Delta m_d \sim 20 \Delta m_d\) \hspace{1cm} (2)

$$\Delta m_d/\Delta m_s \sim \lambda^2 /\xi^2 [(1 - \bar{\rho})^2 + \bar{\eta}^2]$$

with \(\xi = f_{B_d} / f_{B_d} \)

The interest of measuring both \(\Delta m_d\) and \(\Delta m_s\) comes from the fact that the ratio \(\xi\) is better determined from theory than the individual quantities entering into its expression.

The analyses presented here measure \(\Delta m_q\) by looking at the time dependence behaviour of the oscillations:

$$P(B_q \rightarrow B_q^{(-)}) = \frac{1}{2\pi} e^{t/\tau} (1(\pm)\cos \Delta m_q t)$$ \hspace{1cm} (3)

4.1 \(\Delta m_d\) results

The time variation of the \(B_d\) oscillation has been observed for the first time at LEP. In the last years the precision has impressively improved down to 3 % giving:

\(\Delta m_d = 0.486 \pm 0.015 \text{ ps}^{-1}\) \hspace{1cm} \text{LEP/SLD/CDF}

which is an average of 26 measurements!

The recent CLEO \(\chi_d\) measurement is in agreement with this value giving the final result of:

\(\Delta m_d = 0.487 \pm 0.014 \text{ ps}^{-1}\). Improvements on this result are expected in the coming years from B-factories.

4.2 \(\Delta m_s\) results

Since \(B_s\) mesons are expected to oscillate 20 times faster than \(B_d\), it is fundamental to have the best possible resolution on the proper time reconstruction. For details on the analyses see the contributions of P. Coyle and T. Usher in these proceedings. No experiment has observed an oscillation signal. A procedure has been set to combine the different analyses and to get a limit or eventually to quantify the evidence for a "combined" signal. This is done in the framework of the amplitude method which consists in modifying the last part of eq.(3) using: \(1 \pm A \cos \Delta m_q t\). At any given value of \(\Delta m_s\), \(A\) and \(\sigma_A\) are measured. \(A = 1\) and not compatible with \(A = 0\) indicates an oscillation signal at the corresponding value of \(\Delta m_s\). The values of \(\Delta m_s\) excluded at 95 % C. L. are those satisfying \(A(\Delta m_s) + 1.645\sigma_A(\Delta m_s) < 1\). It is also possible to define the sensitivity as the value of \(\Delta m_s\) corresponding to 1.645 \(\sigma_A(\Delta m_s) = 1\). The main actors in this work are LEP and SLD collaborations.

Figure 1 shows the evolution of the combined sensitivity which has dramatically improved during the years. Figure 2 gives the combined plot of the amplitude values as a function of \(\Delta m_s\). The results are:

\(\Delta m_s > 14.9 \text{ ps}^{-1}\) at 95 % C. L sensitivity at 17.9 ps\(^{-1}\).

A “signal” bump is visible at around \(\Delta m_s = 17.7 \text{ ps}^{-1}\) with a significance at 2.5 \(\sigma\) level. The probability of a background fluctuation greater of equal to the one observed, and at any \(\Delta m_s\) value, has been evaluated to be about 2.5 %. This result is still expected to improve during next months by continuing the progress in LEP/SLD analyses.

The impact of this result on the determination of the unitarity triangle parameters.

\(\bar{\rho}\) and \(\bar{\eta}\) are related to the original \(\rho\) and \(\eta\) parameters \(\bar{\rho} = \rho/(1 - \lambda^2/2), \bar{\eta} = \eta/(1 - \lambda^2/2)\).
is shown in Figure 3. Using the constraint coming from the measurements of $V_{ub}$, $\Delta m_d$, $|\epsilon_K|$ and $\Delta m_s$ we obtain:

\[
\begin{align*}
\bar{\rho} &= 0.206 \pm 0.043; \bar{\eta} = 0.339 \pm 0.044 \\
\sin 2\beta &= 0.723 \pm 0.069; \sin 2\alpha = -0.28 \pm 0.27 \\
\text{and } \gamma &= (58.5 \pm 6.9)^\circ
\end{align*}
\]

Conclusions

The different B-lifetimes have been measured at the few percent level ($\sim 1.5 \%$ for $B^+$ and $B^0_d$ and $\sim 4\%$ for $B^0_s$ and $\Lambda^0_b$). A clear experimental hierarchy has been established. The frequency of the $B^0_d$ meson oscillation ($\Delta m_d$) has been measured with a $3 \%$ precision. As far as the $B_s$ oscillation is concerned the combined sensitivity is now at $17.9 \text{ps}^{-1}$ and a possible signal with a $2.5 \sigma$ significance at about $\Delta m_s = 17.7 \text{ps}^{-1}$ has been observed. This result is still expected to be improved during the coming months. Let’s wait a bit for claiming the observation of $B^0_s - \bar{B}^0_s$ oscillations!

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