M. Bonesini:

$B_s^0$ PRODUCTION AND DECAY AT LEP AND CDF
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Abstract

Recent LEP and CDF data on $B_s^0$ production and decay are described. The world average for $m_{B_s}$ is $(5368.1 \pm 3.8)$ MeV/c$^2$, to be compared with theoretical predictions in the range 5345 – 5388 MeV/c$^2$. The $B_s^0$ production rate is $f(b \to B_s^0) = (12.2 \pm 3.0)$%, in agreement with expectations. The world average for the $B_s^0$ lifetime is $(1.56 \pm 0.14)$ ps, giving $\tau(B_s^0)/\tau(B_s^0) = (1.04 \pm 0.11)$ to be compared with a theoretical expectation of $(1.00 \pm 0.01)$.

* Based on a review talk given at ICHEP 94, Glasgow
1. Introduction

While at $b$-factors, at the $T(4S)$ threshold, only $B^0_d$ and $B^\pm$ mesons can be produced, about 12% of the $b$ hadrons produced at LEP are $B^0_d$ mesons, carrying both beauty and strangeness ($B^0_d = (\bar{b}s)$).

1.1. Early indirect evidence for $B^0_d$ production

The existence of the $B^0_d$ meson was indicated by the comparison of the rates of same sign dileptons at the $T(4S)$ and at high energy colliders and from data at the $T(5S)$ obtained from CUSB at CESR.

The production of same sign dileptons was larger at $e^+e^-$ and $p\bar{p}$ colliders than at the $T(4S)$ threshold [1] and this could be explained by the production, at a rate of around 12%, of strange $B^0_d$ mesons, which undergo complete mixing.

Moreover, the CUSB collaboration [2], using a bismuth germanate (BGO) electromagnetic calorimeter inserted in the CUSB-I NaI-Pb-glass array, has studied the inclusive photon spectrum from $2.9 \times 10^4 \ T(5S)$ decays. A broad structure around 50 MeV was clearly seen, in particular for electron-tagged events. This confirmed the association of these photons with $B$ mesons, undergoing a semileptonic decay. The channels $B^+\bar{B}^-$, $B^+\bar{B}^-$, $B\bar{B}^0$, $B\bar{B}^0$, and $B^+\bar{B}^0$ could contribute to the observed photon signal, via $B^+\rightarrow B_d\gamma$. Two solutions were found for $\Delta(M) = M(B_d) - M(B_s)$ and the fraction $f = N(B_d)/N(B)$ of strange to nonstrange $B$'s produced at the $T(5S)$:

$$\Delta(M) = 82.5 \pm 2.5 \text{ MeV}/c^2 \quad f = 0.36 \pm 0.12$$

$$\Delta(M) = 121 \pm 9 \text{ MeV}/c^2 \quad f = 0.24 \pm 0.02$$

giving $M(B_d) - M(B_s)$ between 80 and 130 MeV/$c^2$ and the fraction of strange $B$ mesons, at the $T(5S)$, to be between 12% and 48%, at the 1σ extremes.

1.2. Evidence for $B^0_d$ production at LEP

Preliminary evidence for $B^0_d$ production was obtained at LEP from the partial reconstruction of its semileptonic decays via a study of opposite sign $D^\pm_\pi$ combinations in the same hemisphere [3]. The relevant diagram is shown in fig. 1. Although the $B^0_d$ meson is not fully reconstructed, requiring a lepton transverse momentum $p_T \geq 1.2$ GeV/c the backgrounds are suppressed at a level lower than 10%. Background processes are due to semileptonic B decay ($B \rightarrow (D^+_\pi K^-)l^-\bar{\nu}_l$ via an intermediate $D^{**}$) or B decay into two charmed mesons ($B \rightarrow D^+D^-$). Looking at $D^+_\pi K^-$ events DELPHI had the first evidence at LEP, soon confirmed by ALEPH and OPAL, of $B^0_d$ production. Using two different decay modes ($D^+_s \rightarrow \phi\pi^+$, $\phi \rightarrow K^+K^-$ and $D^+_s \rightarrow K^{*0}K^+$, $K^{*0} \rightarrow K^-\pi^+$) the signal found by DELPHI is shown in fig. 2, for $p_T \geq 1.2$ GeV/c. In addition to the first evidence of $B^0_d$ production at LEP, ($D_s$-$l$) correlations have been used to study $B^0_d$ lifetimes and production rates.

To increase statistics, samples with smaller purity in $B^0_d$ (inclusive $D_s$ events and $(\phi-l)$ events) have also been used. Since the presence of a $D_s$ meson indicates an enriched $B^0_d$ sample, the first consist of events containing a $D_s$ meson decaying to $\phi\pi$ or $K^{*0}K^-$. Inclusive $D_s$ meson production has been studied by DELPHI [4] and OPAL Collaborations to measure $B^0_d$ production and lifetime. Subtracting the $D_s$ events

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† In all this paper the symbol for a particle is taken to include the corresponding antiparticle, unless explicitly stated otherwise.
due to the fragmentation of primary $c$ quarks and from $B^+, B^0$ decays, the excess can be attributed to $B^0 \rightarrow D^- \pi^0$ decays. The second sample contains events with a high $p_T$ lepton accompanied by a $\phi$ meson in the same jet. The idea of using $\phi - l$ correlations, pioneered by DELPHI [4], is based on the fact that $D_\pi$ meson production in a $B^0$ meson decay is an order of magnitude larger than in non-strange B decays and that $\phi$ are preferentially produced in $D_\pi$ (than in $D^0$ or $D^+$) decays. Asking $p_T^l \geq 1$ GeV/c, a rather pure sample of $B^0 \rightarrow \phi \pi^0$ events can be isolated. Direct evidence for $B^0_d$ production and a precise measurement of its mass have been obtained later, both at LEP and Tevatron, from fully reconstructed charged mode decays [5].

1.3. Exclusive $B^0_d$ reconstruction

The $B^0_d$ decay modes, useful for exclusive reconstruction, include

1. $B^0_d \rightarrow J/\psi(\psi') \phi$
2. $B^0_d \rightarrow D^{*-} (D^{-}) \pi^+(\pi^0; \rho^+)$
3. $B^0_d \rightarrow K^- \overline{D}^0 \pi^+(\pi^0; \rho^+)$

where the $J/\psi$ or $\psi'$ are tagged via leptonic decay modes and the “D’s” through decays with an intermediate $\phi$, $K$ or $K^*$. The main experimental problem is the search for a few $B^0_d$ candidates, distributed over many different decay modes, in the presence of potentially high sources of background. Backgrounds are due to track combinatorics (combinatorial, negligible in channels with a $\phi$ due to its narrowness), or $\pi/K$ misidentification (reflections). For example, $B^0_d \rightarrow D^+ \pi^-$ could fake a $B^0 \rightarrow D^{*+} \pi^-$, when the $\pi^+$ from $D^+$ decay is misinterpreted as a kaon. The reflection background (from $B^0_d$ or $\Lambda_b$) is broad ($\sim 50$ MeV/c$^2$ for $B^0_d$ and $\sim 150$ MeV/c$^2$ for $\Lambda_b$) and peaks around 5.36-5.40 GeV/c$^2$.

All LEP experiments have searched for $B^0_d$ fully reconstructed states in the channels (1) to (3), while CDF has searched $B^0_d$ candidates only in channel (1). The experimental requirements, mainly due to the need to have a tight control over backgrounds, are:

- a good tracking resolution ($\delta p/p \sim 0.001 \times p$), to have precise mass reconstruction
- good vertex reconstruction capabilities, to exploit the multivertex topologies of the $B^0_d$ decay chains
- good particle identification capabilities (PID), to discriminate efficiently between energetic $\pi$ and $K$.

On the top of this there is obviously the requirement to choose physical channels with less background (e.g. involving a $\phi$), when possible.

2. The $B^0$ mass determination

2.1. The LEP experiments

All LEP experiments, measuring the $B^0$ mass, fulfill the previous requirements, in particular on particle identification through the energy loss of charged particles (dE/dx) and in DELPHI also using the Barrel Rich [6]. As an example in OPAL the PID is obtained through the measurement of dE/dx in the jet chamber (150 samplings) with a $\pi/K$ separation at 2$\sigma$'s for $2 \leq p \leq 16$ GeV/c, see fig. 3. In DELPHI the PID is obtained from the measurement of dE/dx in the TPC (192 samplings) with a $\pi/K$ separation at 1.5 $\sigma$'s for $4 \leq p \leq 25$ GeV/c (average rejection factor 5) and from the Barrel Rich (average rejection factor 12-15).

OPAL and ALEPH have analysed samples from the 90+91+92 data taking (about $1.2 \times 10^6$ hadronic Z), while DELPHI has analyzed the 92 data sample only (about $0.8 \times 10^6$ hadronic Z).

2.1.1. OPAL searched for $B^0$ candidates in the channels: (1) $D^- (\rightarrow \phi \pi^-; \rightarrow K^{*0} K^-) \pi^+$ and (2) $J/\psi \pi$. The mass plot for the exclusively reconstructed $B^0_d$ candidates is shown in fig. 5. Six candidates were found in the mass window 5.1-5.5 GeV/c$^2$ in channel (1), giving a mass of $5370 \pm 40$ MeV/c$^2$. From the single candidate in the channel (2): one unambiguous $J/\psi \rightarrow e^+e^-$ candidate (found in the 1990-1991 data sample and shown in fig. 4), the $B^0$ mass was determined as $m_{B^0} = 5359 \pm 19 \pm 7$ MeV/c$^2$. The probability that this event comes from a $B^0_d$ reflection ($B^0_d \rightarrow J/\psi K^+ \pi^-$, where a $\pi$ is misidentified as a $K$) is negligible. Systematic errors take into account track parameters and their covariance after kinematic reft (19 MeV), mass scale errors (5 MeV) and additional systematics on momentum measurement (4 MeV).
are the mass scale (1.1 MeV) and the alignment of the tracking system (0.9 MeV). Fig. 7 shows a fisheye $r - \phi$ view of the $B_s^0 \rightarrow \psi'\phi$ candidate, which due to its very small error dominates the LEP average. For this event the expected combinatorial background is less than 0.006 equivalent events at 95% CL and the expected backgrounds from $B_d^0$ or $A_0$ decays are less than 0.0003 or 0.00008 equivalent events. As expected for a process of hadronization of a b quark into a $B_d^0$ meson, the most energetic particle in the same hemisphere is a kaon. A $K_s^0$ with measured mass of $0.486 \pm 0.008$ GeV/c$^2$, momentum of $1.63$ GeV/c and decay length of $7.39 \pm 0.48$ cm was found.

![Figure 4. OPAL: Display of the $B_s^0 \rightarrow J/\psi(\rightarrow e^+e^-)\phi$ candidate in the transverse plane.](image)

![Figure 5. $B_s^0$ invariant mass distribution in OPAL. The fit includes Gaussian terms for the different sources of $B_s^0$ signal and a parametrization of the combinatorial background.](image)

![Figure 6. ALEPH: a fisheye $r - \phi$ view of the $B_s \rightarrow \psi'\phi$ event](image)

2.1.3. **DELPHI** searched for $B_s^0$ candidates in final states formed by two kaons and either two or four lighter particles. The charged K identification performed by the combined use of the RICH and the dE/dx measurements allowed a clean reconstruction of $B_s^0$ states. The DELPHI analysis provided three $B_s^0$ candidates: one $D^-_s(\rightarrow K^-\pi)\rho_1$, one $D^-_s(\rightarrow \phi\pi^-)\pi^+$ and one $J/\psi\phi$, whose main characteristics are shown in table 1. To take properly into account the sources of biases due to reflections (0.20 equivalent events), the combinatorial background (0.30 equivalent events) and the $D^-_s \rightarrow D_s\gamma$ decay, where the photon is not detected, a global

<table>
<thead>
<tr>
<th>mode</th>
<th>$B_s^0$ mass (MeV/c$^2$)</th>
<th>Reflected mass (MeV/c$^2$)</th>
<th>Energy (GeV)</th>
<th>Decay (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s(\phi\pi)\pi$</td>
<td>5325 ± 32</td>
<td>5200</td>
<td>27.1</td>
<td>2.3</td>
</tr>
<tr>
<td>$D_s(\phi\pi)\rho_1$</td>
<td>5345 ± 32</td>
<td>5130</td>
<td>26.7</td>
<td>1.4</td>
</tr>
<tr>
<td>$J/\psi\phi$</td>
<td>5389 ± 16</td>
<td>5275</td>
<td>36.9</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Table 1. DELPHI: $B_s^0$ fully reconstructed candidates
likelihood fit was performed. The resulting likelihood distribution is shown in fig. 7 also, as a function of the $B^0$ mass. The fit result $m_{B^0} = (5374 \pm 16)$ MeV/c$^2$ takes into account statistical errors and the previous systematics. An additional systematic coming from the absolute mass scale calibration is estimated around 2 MeV.

![Diagram](image)

Figure 7. DELPHI: (a) The three $B^0$ candidate masses and errors; (b) the global likelihood distribution obtained from the fit with the resulting $B^0$ mass and the 68% confidence interval.

<table>
<thead>
<tr>
<th>meson</th>
<th>Number</th>
<th>$B$ mass (MeV/c$^2$)</th>
<th>Width (MeV/c$^2$)</th>
<th>Background (per 5 MeV/c$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+$</td>
<td>$140 \pm 15$</td>
<td>$5279.6 \pm 1.7$</td>
<td>$15.2 \pm 1.8$</td>
<td>$3.2 \pm 0.3$</td>
</tr>
<tr>
<td>$B^0$</td>
<td>$57 \pm 10$</td>
<td>$5279.9 \pm 2.5$</td>
<td>$13.6 \pm 2.2$</td>
<td>$1.7 \pm 0.2$</td>
</tr>
<tr>
<td>$B^0$</td>
<td>$33 \pm 7$</td>
<td>$5367.7 \pm 2.4$</td>
<td>$10.5 \pm 1.9$</td>
<td>$1.1 \pm 0.1$</td>
</tr>
</tbody>
</table>

Table 2. CDF results on $B$ meson reconstruction for the 1992-1993 data sample

2.2. The search at Tevatron: CDF

In the 1988-89 Tevatron run, CDF showed the capability to trigger and reconstruct $B \to J/\psi(\to \mu^+\mu^-)X$ decays in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The further addition of a Silicon Vertex Detector (SVX) and the increase in dimuon acceptance has given to CDF the possibility to make high-statistics $B$ physics studies, such as mass or lifetimes measurements. $B^0$ candidates are searched for in the channel $J/\psi(\to \mu^+\mu^-)\phi$, where having no PID each track is considered as a $\pi$ or a kaon if $p_T \geq 2$ GeV/c. $\phi$ candidates are formed from pairs of tracks assigned to kaon mass, with combined mass consistent with the nominal $\phi$ mass value. The invariant mass of the four-track system is calculated subject to the constraint that they originate from a common decay vertex and the total momentum points back to the beam position. In addition the condition $p_T(B) \geq 6$ GeV/c and a positive flight are required. Preliminary results on the reconstruction of $B^+$, $B^0$ and $B^0$ mesons are shown in table 2. In the full 1992-1993 data sample (run 1A: 19.3 pb$^{-1}$) 33 $\pm 7$ $B^0$ candidates were reconstructed. From a binned likelihood fit to the mass spectra a preliminary mass value of $5367.7 \pm 2.4 \pm 4.8$ MeV/c$^2$ was obtained. The mass plot is shown in fig. 8.

Systematic errors include the $p_T$ scale (1.1 MeV), uncertainties in tracking errors (1.0 MeV), stability of selection criteria (2.8 MeV), fitting procedure (1.2 MeV) and variation in the reconstructed $J/\psi$ mass (3.2 MeV).

![Diagram](image)

Figure 8. CDF: (a) $J/\psi\phi$ invariant mass plot; (b) $\phi$ signal.

2.3. World average for the $B^0$ mass value

The data on $B^0$ mass reconstruction, coming from LEP exclusive fully reconstructed events and from the CDF fit to the $(J/\psi)\phi$ mass plot, are shown in figure 9. The world average for the $B^0$ mass is $5368.1 \pm 3.8$ MeV/c$^2$, being dominated by the CDF measurement and the LEP $\psi'\phi$ ALEPH candidate. This must be compared with theoretical predictions in the range $5345-5388$ MeV/c$^2$ [7]. From the effective theory for heavy quarks (HQET) a prediction of 5379 MeV/c$^2$ was given in [10], using the experimental values for $M_{B_s}$, $M_{B^*}$, $M_D$, $M_{D^*}$, $M_{D_s}$, $M_{D_{s1}}$. So the measurement of $B_s$ mass, together with those of $\Lambda_b$, $\Xi_b$, $B^+_s$ and $\Sigma_b$ masses, can provide an important test of the theory and of the correctness of the basic assumptions of hadron dynamics.
3. $B^0$ production rates and decays

Theoretical predictions for exclusive two-body decays of $B^0$ to final states containing only stable charged particles (e.g. $B^0 \rightarrow D^+\pi^-$, $B^0 \rightarrow \phi\pi$, ...) sum up to about $10^{-3}$ [9]. $B^0$ decay rates have been mainly studied at LEP. The seen fully reconstructed $B^0$ decay modes are:

- $D_sX$
- $D^-\pi^+$
- $J/\psi(1S)\phi$
- $\psi(2S)\phi$

The statistics in all channels is very poor, going from the single $\psi(2S)\phi$ candidate seen by ALEPH, to the around thirty $J/\psi\phi$ candidates seen by CDF+OPAL+DELPHI. Some results, coming from the $B^+_s \rightarrow D^-\pi^+\nu X$ semileptonic decay, on production branching fractions are quoted in table 3.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Data</th>
<th>Branching ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>90-91</td>
<td>$(5.6 \pm 1.5 \pm 0.9) \times 10^{-4}$</td>
</tr>
<tr>
<td>DELPHI</td>
<td>90-91</td>
<td>$(5.4 \pm 2.4 \pm 0.9) \times 10^{-4}$</td>
</tr>
<tr>
<td>OPAL</td>
<td>90-91</td>
<td>$(3.9 \pm 1.1 \pm 0.8) \times 10^{-4}$</td>
</tr>
<tr>
<td>LEP AVERAGE</td>
<td></td>
<td>$(4.7 \pm 1.0) \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Table 3. $f(b \rightarrow B^0_s) \times Br(B^0_s \rightarrow D^-\pi^+\nu X) \times Br(D^-\pi^+\rightarrow \phi\pi)$

From these, the $B^0_s$ meson production rate ($f_s \equiv f(b \rightarrow B^0_s)$) can be evaluated. Using $Br(D^-\pi^+\rightarrow \phi\pi) = (3.5 \pm 0.4)\%$ and assuming $Br(B^0_s \rightarrow D^-\pi^+\nu X) = 11\%$ [8], one obtains $(12.2 \pm 2.6 \pm 1.4)\%$, where the second error is given by the poor knowledge of the $D_s \rightarrow \phi\pi$ branching ratio. This result must be compared with an expected rate of about $12\%$ [11]. $f_s$ can be derived also from the measurement of the average mixing parameter $\bar{\chi} = f_s \cdot \chi_4 + f_4 \cdot \chi_4$ at LEP and the measurement of $\chi_4$ from the $\Upsilon(4S)$, assuming $\chi_4 \simeq 0.5$ as predicted from the Standard Model and a $b$-baryon fraction of $0.10 \pm 0.04$. This gives $f_s = 0.10 \pm 0.03$.

4. The $B^0_s$ Lifetime

In the spectator model picture [12], the $b$ quark decay is treated by analogy with the $\mu$ decay and for all the $B$ hadrons the lifetime is the same as the free $b$ quark, since light quarks play only a passive role in the decay mechanism. However, as seen in the charm sector, non-spectator effects such as annihilation diagrams, exchange diagrams or interference diagrams cause the lifetime of the various hadrons to be different. Theoretical expectations in the framework of HQET give (to a few percent accuracy) for the $b$ sector $\tau_{B^+}/\tau_{B^0} = 1.01 \pm 0.01$ and a definite hierarchy of lifetimes $\tau(B^+)/\tau(B^0) = 1.05$, $\tau(\Lambda_b^+)/\tau(B^0) \approx 0.9$ [13].

For neutral $B$-mesons, simple picture is complicated by the effects due to particle-antiparticle mixing, which appear as a lifetime difference between the mass eigenstates. The effect can be relevant for the $B^0_s$ states and could be seen as a lifetime difference in $B^0_s$ decays to a CP-eigenstate, such as $J/\psi\phi$, respect to semileptonic decays [13].

A compilation of individual $b$-hadron lifetimes is shown in figure 10 [14], [17].
proposed, the purity (defined as the ratio of $B_s^0$ over all the $B$ mesons contained in the sample) goes from 55% to 70% ($D_s X; D_s h$ tag) to ~ 90% ($D_s - l$ correlation tag).

The LEP collaborations (DELPHI, ALEPH, OPAL) have recently reported results from the 91+92+93 data sample (about $1.8 \times 10^6$ hadronic Z) and CDF from the 92-93 Tevatron collider run. ALEPH, DELPHI, OPAL [15] and CDF [16] use $(D_s - l)$ correlations (see figure 1) to tag samples of $B_s$ mesons to measure its lifetime, through the semi leptonic decay chains:

$$B_s \rightarrow D_s^+ (\rightarrow K^{+0}(\rightarrow K^+\pi^-)K^-)l^+\nu X$$
$$B_s \rightarrow D_s^- (\rightarrow \phi\pi^-)l^+\nu X$$

After having reconstructed a $D_s$ meson, an association with a "right sign" lepton (e.g. $D_s^+ l^- \text{ or } D_s^- l^+$) is looked for. Simple kinematic cuts, such as a minimum $p_T$ on the associated lepton, are used to reduce backgrounds, due to $B_{u,d} \rightarrow D_s^+ \overline{D}(\rightarrow l\nu X)X$ and $B_{u,d} \rightarrow D_s^- K^{+}\nu X$. The proper-time of $B_s^0$ (OPAL, ALEPH and CDF) $\tau = t_B$ or the sum of the proper times of $B_s$ and $D_s$ (DELPHI) $\tau = t_B + t_D$ is determined as: $\tau = \frac{L}{\beta c} = L \times \frac{M(B_s)}{M(B_s)}$, using an estimate of the boost $\beta$ and measuring the decay length $L$ of $B_s$ or $B_s + D_s$.

A maximum likelihood method is then used to fit the proper-time distribution, taking into account signal and background components. The likelihood function $L$ is defined as:

$$L = \alpha \times P(t) + (1 - \alpha) \times P_{comb}(t)$$

where $\alpha$ is the relative proportion of signal and background, as determined from the $D_s \rightarrow KK\pi$ invariant mass plot and $P(t)$. $P_{comb}(t)$ are the normalized proper-time probability distributions for signal and background. For DELPHI, where a signal of $37 \pm 8$ events was observed, the proper-time distribution is shown in figure 11. The dominant systematic errors are connected with the estimation of background levels, boost estimate and fit procedure. This measure is still dominated by statistical errors. The results of the $B_s^0$ lifetime measurement with the $(D_s - l)$ correlation method are shown in figure 12. Similar methods to measure $B_s^0$ lifetime are based on $D_s -$hadron correlations (ALEPH) and $D_s -$ $X$ events (DELPHI).

In the first method a $D_s^\pm$ is reconstructed in the $K^+K$ or $\phi\pi$ mode and an opposite sign hadron $h^\mp$ of high momentum is looked for. In the second method the inclusive channel $D_s \rightarrow \phi\pi$ is searched for. Both methods have larger systematics ($\sim 15\%$), due mainly to uncertainty on the background composition and boost estimates, compared to those based on the $(D_s - l)$ correlations ($\sim 5\%$) and comparable statistical errors.

CDF uses also fully reconstructed $B_s \rightarrow J/\psi(\rightarrow \mu^+\mu^-)\phi(\rightarrow K^+K^-)$ events [16] to determine the $B_s$ lifetime as: $\tau_{B_s} = 1.74_{-0.08}^{+0.90} \pm 0.07$ ps. The four candidate tracks ($\mu^+, \mu^-, K^+, K^-$) are constrained to a common vertex and the fit probability is required to be greater than 2%. Additional requirements, to select good tracks in the microvertex detector (SVX), give a
sample of 11 events with an expected signal of 9.5 ± 3.1.

The most recent data on $B_S^0$ lifetime, coming from LEP and CDF, are shown in figure 12, giving a world average of: $1.56 ± 0.14$ ps, still dominated by statistical errors. From the world average of $B_S^0$ lifetimes (1.614 ± 0.078) ps [17], we have: \( \tau(B_S^0) / \tau(B_D^0) = (1.04 ± 0.11) \), to be compared to a theoretical expectation of (1.00 ± 0.01).

The future precision of the lifetime ratios for b-hadron species will be at the level of 5% at best, with the expected data sample from CDF and LEP experiments by the end of 95. Clearly, to have stringent tests of the theory (at the 1% level) it will be necessary to wait for the next generation of colliders. Meanwhile, evidence of the anticipated lifetime hierarchy in the b sector is emerging (see figure 10). From present data the probability that all lifetimes of weakly decaying b-hadrons are the same is less than 1%.

5. Conclusions

The world average for $m_B$ is (5368.1 ± 3.8) MeV/c², to be compared with theoretical predictions in the range 5345 – 5388 MeV/c². The good precision of the experimental value is a challenge to theoretical predictions. Clearly more unambiguous candidates of the type $\psi \phi$, $\psi' \phi$ at LEP are needed to reduce the errors. Some decay channels of $B_S^0$ have been seen, mainly at LEP. The accuracy on the $B_S^0$ meson production rate ($f_s = 12.2 ± 3.0\%$) is still limited.

The world average for the $B_S^0$ lifetime is (1.56 ± 0.14) ps, giving $\tau(B_S^0) / \tau(B_D^0) = (1.04 ± 0.11)$ to be compared with a theoretical expectation of (1.00 ± 0.01). This measurement is still dominated by statistical errors and although it agrees with theory, it is not precise enough to test it.

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