G. Capon:

B PHYSICS AT LEP

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ABSTRACT

Recent results obtained at Lep by the Aleph, Delphi, L3 and Opal collaborations on B-lifetime, B\bar{B}mixing, D\* fragmentation function and on the inclusive decay Z^0 -> J/\Psi + X, are presented. New world averages for the B-lifetime and the mixing parameter \chi_B are obtained from these measurements.

1. - INTRODUCTION

This report illustrates recent Lep results on:

- B-lifetime;
- B\bar{B}-mixing;
- D\* fragmentation function;
- inclusive decays Z^0 -> J/\Psi + X.

In the B lifetime and B\bar{B} mixing analysis the Z^0 -> b\bar{b} events are selected among the other hadronic decays according to the standard b-tagging technique by requiring a high p, high p_t lepton in the event. The p_t is computed with respect to the b-hadron direction, which in the experimental practice is approximated by the jet axis (in the following analysis the lepton is excluded in the computation of the jet axis; then the p_t values are on average about 1.5 -2 times larger than in the case where the lepton is included).

In the experiment, charged tracks identified as a leptons may be:
1) prompt leptons coming from primary b, primary c or secondary c decay (cascade decay: b -> c -> lνX). In the primary b decays are also included the b -> τ -> lνX decays. Beyond b->c-> lνX the cascade decay includes also the decay chain b -> cW with W -> c -> lνX. (the two modes have relative fractions approximately = 91 % and 9 %).

2) non prompt (or decay) leptons, that is true lepton tracks but not originating from heavy quarks semileptonic decays. These include essentially photon conversions into e+e- pairs, Dalitz pairs and π,κ decay in flight into muons.

3) misidentified hadrons: these are generally due to π+γ overlap in the calorimeters for electrons and to π/κ/p punchthrough for muons.

Some common systematic uncertainties affect the lifetime and mixing measurements.

The first one is due to the imprecise knowledge of the heavy quark fragmentation functions. In general one assumes the Peterson form for the fragmentation function:

\[ d_q(z) = \frac{1}{z} \left( 1 - \frac{1}{z} - \frac{\varepsilon_q}{1-z} \right)^2 \quad q = \text{quark flavour} = c,b \]

where \( z = (E + p_t)_{\text{hadron}}/(E+p_t)_{\text{quark}} \) and \( \varepsilon_q \) is a phenomenological parameter, expected to be inversely proportional to \( M_q^2 \).

Often, instead of \( z \), the variable \( x = E_t/E_{\text{beam}} \) is used. However \( x \) is affected by initial state radiation and gluon emission so that \( <x> \) values obtained at different c.m. energies are not directly comparable.

A second systematic uncertainty comes from the knowledge of the semileptonic branching ratios which are presently measured with a precision around 10 %. Moreover one should remind that the measurements refer to heavy quark mixtures which may be different in different experiments: at Y(4S) \( B_s^0 \) and \( \Lambda_b \) are under production threshold, while the \( c\bar{c}/b\bar{b} \) relative rates are different in the continuum (Pep, Petra, Tristan) and at the \( Z^0 \) resonance.

2. - MEASUREMENT OF THE B LIFETIME

The measurement of the B lifetime \( \tau_B \) yields a constraint on the K.M. matrix elements \( V_{cb} \) and \( V_{ub} \). In fact the B meson semileptonic width \( \Gamma_{SL} \) can be expressed as:

\[ \Gamma_{SL} = \frac{BR(B \rightarrow l\nu X)}{\tau_B} = \frac{G_F^2M_B}{192\pi^3}(0.48|V_{cb}|^2+0.86|V_{ub}|^2) \]

where the numerical factors incorporate QCD and phase space corrections\(^{(1)}\).

At Lep only the inclusive lifetime, that is the average of the various b-hadrons (\( B^+, B_d^0, B_s^0, \Lambda_b \)) lifetimes, is measured up to now.

The lifetime measurement is based on the lepton impact parameter distribution. The analysis proceeds as follows:
hadronic decays of the $Z^0$ are selected according to the standard criteria.
2) to have a high purity $b$-sample a high $p, p_t$ lepton is required in the event.
3) the impact parameter $\delta$ of the lepton track with respect to the $e^+e^-$ interaction point (I.P.) is measured in the $r-\phi$ plane (where the spatial resolution is better and the beam spread along the $z$ axis is influent).
4) the $b$-hadron direction is assumed to be given by the axis of the jet containing the lepton. Then a positive (negative) sign is given to the impact parameter $\delta$ if the decay appears to happen downstream (upstream) with respect to the I.P.

Because of the finite $B$ lifetime the $\delta$ distribution has its average shifted toward a positive value of about 150 $\mu$m. It should be noted that $<\delta>$ is very slowly dependent on the $b$-hadron momentum $p_B$ at the high $p_B$ values reached at Lep. Therefore the uncertainties on the $b$-hadron fragmentation function do not affect seriously the lifetime measurement.

For the definition of the interaction point Aleph and L3 use the beam spot while Delphi uses the event primary vertex reconstructed by the minivertex detector.

To obtain the $\tau_B$ value the observed $\delta$ distribution is fitted with the $b \to l\nu X$ decay signal contribution plus the other contributions ($b\to c\to l$, $c\to l$, misidentif. hadrons and decay leptons). This implies the MC simulation of the true $\delta$ distribution for the $b$ and $c$ quarks and then its smearing according the experimental resolution on $\delta$ (which may be obtained directly from the data). The misidentification background may be evaluated from the data looking at tracks passing the $p, p_t$ cuts but not identified as leptons. The decay background is estimated via MC.

The $\delta$ distributions are plotted in Figs. 1, 2 for the Aleph, L3 experiments where the signal and the different background contributions as determined by the fit are also shown. The values of $\tau_B$ from the fit are shown in Table I together with the lepton statistics, the cuts (in Gev/c) used in the analysis and the corresponding $b$ purities.

<table>
<thead>
<tr>
<th></th>
<th>$p$</th>
<th>$p_t$ cuts</th>
<th>e + $\mu$</th>
<th>b-&gt;l purity</th>
<th>$&lt;\delta&gt;$ ($\mu$m)</th>
<th>$\tau_B$ (psec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aleph</td>
<td>5</td>
<td>2</td>
<td>1215+1758</td>
<td>66%</td>
<td>142 $\pm$ 7</td>
<td>1.29 $\pm$ 0.06 $\pm$ 0.10</td>
</tr>
<tr>
<td>Delphi</td>
<td>3</td>
<td>1</td>
<td>759</td>
<td>48%</td>
<td>161 $\pm$ 15</td>
<td>1.30 $\pm$ 0.12 $\pm$ 0.11</td>
</tr>
<tr>
<td>L3</td>
<td>4</td>
<td>1 (1.5)</td>
<td>673+712</td>
<td>83%</td>
<td>176 $\pm$ 8</td>
<td>1.31 $\pm$ 0.06 $\pm$ 0.08</td>
</tr>
</tbody>
</table>

The three values of $\tau_B$ from Aleph$^{(2)}$, Delphi$^{(3)}$ and L3$^{(4)}$ are almost too consistent among them and a little bit away from the 1990 PDG value of 1.18 $\pm$ 0.11 psec. By adding in quadrature the statistical and systematic error for the Lep results and then taking the weighted average between the Lep values and the PDG value, one obtains:

$$\tau_B = 1.27 \pm 0.06 \text{ psec (present world average)}$$
3. BB MIXING

A neutral $B^0_d$ ($B^0_s$) meson can oscillate into a $\bar{B}^0_d$ ($\bar{B}^0_s$) meson because of the $\Delta B=2$ transition represented by the box diagrams:

![Box Diagrams](image)

The mixing probability $\chi$ is given by:

$$\chi = \text{Prob} \left( B^0 \rightarrow \bar{B}^0 \right) = \frac{1}{2} \frac{(\Delta M/\Gamma)^2 + (\Delta \Gamma/2\Gamma)^2}{1 + (\Delta M/\Gamma)^2},$$

where $\Delta M$, $\Delta \Gamma$, $\Gamma$ are respectively the mass difference, the total width difference and the average total width for the two mass eigenstates. (For the $B$ mesons the term $\Delta \Gamma/\Gamma$ is negligible).

At Lep the weighted average $\chi_B$ of the $\chi$ values for $B^0_d$ and $B^0_s$ is measured:

$$\chi_B = f_d \cdot BR_d \cdot \chi_d/<BR> + f_s \cdot BR_s \cdot \chi_s/<BR>$$

where $f_d$, $f_s$ and $BR_d$, $BR_s$ are respectively the production fractions and the semileptonic branching ratios of the $B^0_d$, $B^0_s$ mesons, and $<BR>$ is the average semileptonic branching ratio of all produced $b$-states. Generally one neglects the possible differences between $BR_d$, $BR_s$ and $<BR>$ and uses $\chi_B = f_d \cdot \chi_d + f_s \cdot \chi_s$. For the production fractions it is customary to use $f_d = f_u = 0.375 \pm 0.05$ and $f_s = 0.15 \pm 0.05$.

For a pure $b\bar{b}$ sample $\chi_B$ can be determined from the dilepton events in which both $b$ quarks decay semileptonically, by looking at the rate of same sign and opposite sign dileptons:

$$l^+l^+/l= (l^+l^+ + l^+\bar{l})/(l^+l^+ + l^+\bar{l} + l^+l^- + l^-l^-) = 2\chi_B (1-\chi_B)$$

In real life the dilepton sample is contaminated by primary and secondary $c$ decays and by misid/decay background. In this case the above formula is corrected as:

$$l^+l^+/l= 2\chi_B (1-\chi_B)(f_{PB-PB} + f_{SC-SC}) +$$

$$(0.91(\chi_B^2 + (1-\chi_B)^2) + 0.09*2\chi_B (1-\chi_B))f_{PB-SC} + \alpha f_{BACKG}$$

where the $f$'s represent the fractions of the various dilepton configurations.
PB-PB : (b -> l)(b -> l)  
SC-SC : (b->c->l)(b->c->l)
PB-SC : (b -> l)(b -> c -> l)  
PC-PC : (c->l)(c->l)
BACKG : (good or backg. lepton) (backg. lepton)

and $\alpha$ is the charge asymmetry of the background. In the absence of charge correlations $\alpha$ is expected to be 0.5. In fact some correlations exist ($\alpha = 0.417 \pm 0.010$ in the Aleph analysis).

Hadronic $Z^0$ decays are selected and among these only those having two identified leptons are kept. A cut on $p$ and $p_t$ is imposed to increase the $b$ purity of the dilepton sample. Moreover an opening angle between the two leptons greater than $60^0$-$90^0$ is required in order to select leptons belonging to two opposite jets.

Essentially two different procedures have been followed in the mixing analysis:

1) select a very good purity sample with high $p$, $p_t$ cuts and obtain $\chi_B$ using the above formula from the observed numbers of same sign and opposite sign dileptons (the various dilepton fractions are obtained from MC).

2) use somewhat lower $p$, $p_t$ cuts (this yields a larger dilepton sample) and then determine $\chi_B$ from a maximum likelihood fit to the data. This method aims to exploit the full physical content of the dilepton sample and yields a smaller statistical error. The official values of Aleph and L3 are obtained by this method while the former one is presented as an analysis check. $p_t$.

The details of the fit procedure are illustrated in the original papers$^{(5,6)}$. L3 fits the dilepton data in the 4-dimensional space $p_1$, $p_{1t}$, $p_2$, $p_{2t}$. Aleph fits the data in the Prob$_1$, Prob$_2$ plane where Prob($p$, $p_t$) is the probability for a lepton of given $p$, $p_t$ to originate from a primary $b$ quark decay. This probability has been parametrized from a comparative analysis of one lepton data and MC.

The results of the Aleph and L3 analysis are presented in Table II, the $\chi_B$ values obtained by the two experiments are compatible within the still large statistical errors.

Recently the UA1 collaboration has published an updated measurement$^{(7)}$:

$$\chi_B = 0.148 \pm 0.029 \text{ (stat)} \pm 0.017 \text{ (syst)} \quad \text{(UA1)}$$

If statistical and systematic errors are added in quadrature the average of the three experiments is:

$$\chi_B = 0.146 \pm 0.020 \quad \text{(Aleph - L3 - UA1)}$$

This result is shown in Fig. 3 where using the above quoted values for $f_d$ and $f_s$ it is plotted as a band in the $\chi_d$-$\chi_s$ plane (the band width contains also the effect of the assumed errors on $f_d$ and $f_s$). In the same figure is also reported the Cleo/Argus result$^{(8,9)}$ for $\chi_d$. The results tend to confirm the expectation of full mixing ($\chi_s = 0.5$) for the $B_s^0$ meson.
TABLE II - Results of the mixing analysis (values of L3 in () refer to muons).

<table>
<thead>
<tr>
<th>ALEPH</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>high purity sample</td>
</tr>
<tr>
<td>lepton cuts (p p_t in Gev/c)</td>
<td>p&gt;5 p_t &gt;1</td>
</tr>
<tr>
<td></td>
<td>Prob&gt;0.1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>b-&gt;l purity</td>
<td>64 %</td>
</tr>
<tr>
<td>all dilepton</td>
<td>440</td>
</tr>
<tr>
<td>same sign dilept</td>
<td>146</td>
</tr>
<tr>
<td>&quot;MC (x_B=0)&quot;</td>
<td>106</td>
</tr>
<tr>
<td>$10^3x_B$</td>
<td>120 ± 30</td>
</tr>
</tbody>
</table>

An alternative analysis to obtain the mixing parameter $x_B$ has been developed by Aleph. This analysis uses the one lepton events which have a larger statistics (about a factor ten, depending on the chosen cuts) than the dilepton events.

The charge of the jet opposite to the lepton is estimated according to the empirical formula:

$$Q_{jet} = \frac{\sum Q_i \left| p_{li}\right|^k}{\sum \left| p_{li}\right|^k}$$

where $Q_i$ is the charge and $p_{li}$ is the longitudinal momentum (with respect to the thrust axis) of track $i$, while the exponent $k$ is a parameter whose optimum value lies between 0.5 and 1.0.

If $Q_{jet}$ would be a perfect estimator of the primary quark charge, mixing would be signalled by the presence of events having $Q_{lepton}$ and $Q_{jet}$ of the same sign. In practice the distribution of $Q_{jet}$ is smeared and diluted, i.e. $\langle Q_{jet}\rangle$ is smaller than $\langle Q_{quark}\rangle$, because of the fragmentation process.

Aleph has extracted the value of $x_B$ from a fit to the observed distribution of the product $Q_{lepton}Q_{jet}$ (see Fig. 4):

$$x_B = 0.100 \pm 0.020 \pm \frac{0.014}{0.016}$$

Notice that the statistical error given by this method is in fact slightly smaller than the one from the dilepton sample.
4. D* FRAGMENTATION FUNCTION

The D* fragmentation function has been studied by Aleph\(^{(10)}\) and Opal\(^{(11)}\) by looking at the decay chain \(D^* \rightarrow D^0 \pi^+\), with \(D^0 \rightarrow \kappa \pi^+\) (+ charge conjugate).

The selection is made easier by the fact that the D* decay has a very low Q value (only 6 Mev) which makes the signal to appear at the edge of the phase space distribution.

A cut is imposed on \(M(\kappa\pi) - M_{D^0}\) and on \(M(\kappa\pi) - M(\kappa\pi) - \Delta M\) where \(\Delta M = 145\) Mev is the \(D^*-D^0\) mass difference. For \(\kappa/\pi\) discrimination Opal uses the \(dE/dx\) information in a fraction of the data. The combinatorial background is reduced by requiring \(|\cos \theta^*_\kappa| < 0.8\) (\(\theta^*_\kappa\) is the \(\kappa\) emission angle in the \(D^0\) rest frame with respect to the \(D^0\) line of flight). Moreover the analysis is done only in the \(x (x = E_{D^*}/E_{\text{beam}})\) region \(x > 0.2 - 0.25\). In the signal region Aleph
(Opal) has 360 (115) events; the \(M(\kappa\pi\pi)-M(\kappa\pi)\) distribution is shown in Fig. 5.

The \(x\) distribution is the sum of 3 contributions: energetic \(D^*\) coming from primary c-quark decays, softer \(D^*\) coming from primary b-quark decays and fake \(D^*\) due to combinatorial background. It can be written as:

\[
dN/dx = BR((Z^0 \rightarrow c\bar{c}) \cdot BR(c \rightarrow D^*) \cdot BR(D^* \rightarrow \kappa\pi\pi) \cdot \epsilon(x) \cdot d_c(x) +  \\
+ BR((Z^0 \rightarrow b\bar{b}) \cdot BR(b \rightarrow D^*) \cdot BR(D^* \rightarrow \kappa\pi\pi) \cdot \epsilon(x) \cdot d_b(x) + f_{\text{backg}}(x)
\]

where the various branching ratios have been explicited and \(\epsilon(x)\) is the detector acceptance for a \(D^*\) with energy fraction \(x\). \(d_c(x), d_b(x)\) are the fragmentation functions for \(D^*\) originating respectively from primary c and primary b quarks. In the analysis the b contribution is fixed (all parameters are taken from data) while for the c contribution \(\epsilon_c\) and a second parameter related to the branching ratios are fitted. The fit assumptions and results are shown in Table III. The two \(<x_{D^*}>\) values are in good agreement, but lower than the Pep/Petra values \((<x_{D^*}> = 0.59 \pm 0.02)\) as expected from QCD scaling violations.

<table>
<thead>
<tr>
<th>TABLE III - Fit to the x distribution for the D*</th>
</tr>
</thead>
<tbody>
<tr>
<td>input: ((b \rightarrow D^<em>)/(c \rightarrow D^</em>) = 0.95 \pm 0.1)</td>
</tr>
<tr>
<td>((Z^0 \rightarrow c\bar{c})) and ((Z^0 \rightarrow b\bar{b})) from standard model</td>
</tr>
<tr>
<td>fit: (\epsilon_c = (48 \pm 18/13 \pm 7) \times 10^{-3})</td>
</tr>
<tr>
<td>(&lt;x_{D^*} &gt;= 0.504 \pm 0.013 \pm 0.017 \pm 0.008)</td>
</tr>
<tr>
<td>((c \rightarrow D^<em>)/(D^</em> \rightarrow \kappa\pi\pi) = (6.8 \pm 0.4 \pm 0.6) \times 10^{-3})</td>
</tr>
<tr>
<td>Opal</td>
</tr>
<tr>
<td>((b \rightarrow D^<em>)/(D^</em> \rightarrow \kappa\pi\pi) = (5.8 \pm 1.3) \times 10^{-3})</td>
</tr>
<tr>
<td>((Z^0 \rightarrow b\bar{b})/(Z^0 \rightarrow \text{hadr}) = 0.215 \pm 0.018)</td>
</tr>
<tr>
<td>(&lt;x_{D^*} &gt;= 0.52 \pm 0.03 \pm 0.01)</td>
</tr>
<tr>
<td>((Z^0 \rightarrow c\bar{c})/(c \rightarrow D^<em>)/(D^</em> \rightarrow \kappa\pi\pi) = (1.36 \pm 0.23 \pm 0.15) \times 10^{-3})</td>
</tr>
</tbody>
</table>
The $d_c(x)$, $d_b(x)$ distributions together with the fit results are shown in Figs. 6,7. For Opal the second output of the fit is the overall branching ratio $\text{BR}(Z^0 \rightarrow c \bar{c} \rightarrow D^* \rightarrow \kappa \pi \pi)$. Using from other measurements $\text{BR}(c \rightarrow D^* \rightarrow \kappa \pi \pi) = (7.3 \pm 0.6) \times 10^{-3}$ Opal derives then the partial width of the $Z^0$ into $c \bar{c}$ quarks : $\Gamma(Z^0 \rightarrow c \bar{c}) = 323 \pm 61 \pm 35 \text{ Mev}$ in agreement with the standard model prediction of 296 $\pm 4 \text{ Mev}$.

5. THE INCLUSIVE DECAY $Z^0 \rightarrow J/\Psi + X$

Opal$^{(12)}$ has looked for the $J/\Psi \rightarrow \mu^+ \mu^-$ decay in the distribution of the $\mu^+ \mu^-$ invariant mass. With a cutoff on muon momentum as low as 2.4 Gev one obtains the $M(\mu^+ \mu^-)$ distribution shown in Fig. 8 where is evident a signal containing 25-30 $J/\Psi$ events. After background subtraction and efficiency corrections Opal gets an inclusive branching ratio: $\text{BR}(Z^0 \rightarrow J/\Psi + X) = (5.2 \pm 1.1 \pm 0.6 \pm 0.7) \times 10^{-3}$ where the last error reflects the error on $\text{BR}(J/\Psi \rightarrow \mu^+ \mu^-)$. The above value can be compared with an expected value of $(3.4 \pm 0.5) \times 10^{-3}$ which can be inferred using $\text{BR}(Z^0 \rightarrow \bar{b}b) = 0.151$ (standard model) and the Cleo/Argus measurements$^{(13)}$ $\text{BR}(B \rightarrow J/\Psi + X) = 1.12 \pm 0.18\%$ (assuming that all $b$-hadrons have the same branching ratio into $J/\Psi + X$).

The $x$ distribution of the produced $J/\Psi$ does not show an excess of low $x$ events as would be expected by $J/\Psi$ production due to gluon splitting in the parton shower fragmentation process.

REFERENCES

3) Delphi Collab., contribution by C. Troncon to this Conference.
4) L3 Collab., contribution by G. Rahal-Callot to this Conference.
7) UA1 Collab., C. Albajar et al., CERN-PPE/91-55 (1991).(*)

(*) Note added in proof: the CDF collaboration has presented at the subsequent Moriond week (17-24 March) a preliminary measurement $\chi_B = 0.176 \pm 0.028 \pm 0.041$. 
FIG. 1 - Distribution of the lepton impact parameter. The full curves represent the fit to the various lepton sources. (Aleph)

FIG. 2 - Distribution of the lepton impact parameter. The full curves represent the fit to the various lepton sources. (L3)

FIG. 3 - Plot of the average value of $\chi_B$ in the $\chi_d$, $\chi_s$ plane. The measured value of $\chi_d$ by Cleo and Argus is also shown.

FIG. 4 - Distribution of $Q_{\text{jet}} \cdot Q_{\text{lepton}}$. The histograms represent the fit values for the various lepton sources. (Aleph).
**FIG. 5** - Distribution of $M(\kappa\pi\pi) - M(\kappa\pi)$. The $\kappa\pi$ mass is selected between 1835-1895 Mev. The curve is a fit to the data.

**FIG. 6** - $x$ distribution after background subtraction and acceptance corrections (Aleph).

**FIG. 7** - $x$ distribution after background subtraction and acceptance corrections. (Opal)

**FIG. 8** - $\mu^+\mu^-$ invariant mass. The full curve is a fit, the histogram represents the MC prediction for the background.