Eighteenth Annual SLAC Summer Institute on Particle Physics
Topical Conference

Results from LEP on Heavy Quark Physics

Roberto Tenchini
INFN - Pisa

1. Introduction

The study of hadronic decays of the Z at the LEP e^+e^- collider offers new opportunities for Heavy Quark Physics. For the first time the coupling of c,b quarks to the Z can be precisely measured providing an important test of the Standard Model. In addition fundamental properties of b hadrons, such as B^0-$\overline{B^0}$ mixing and lifetimes, can be measured with large samples of high purity $Z \to b\ \bar{b}$ decays. In this review we will present results from LEP experiments after one year of LEP operation. Most of the results are preliminary and based on integrated luminosities of a few inverse picobarns. Nevertheless they represent an excellent start for Heavy Quark Physics at LEP.

2. Production of *c,b* quarks at the Z pole

In the Standard Model the coupling of the Z to individual quark flavours depends on the weak isospin of the quark. In particular the expected fractions of $c\bar{c}$ and $b\bar{b}$ events in hadronic Z decays are

$$\Gamma_{c\bar{c}} / \Gamma_{\text{had}} = 0.171$$

and

$$\Gamma_{b\bar{b}} / \Gamma_{\text{had}} = 0.217\ .$$

The problem of separating the $c\bar{c}$ and $b\bar{b}$ contributions and to disentangle them from the u,d,s background has been tackled by LEP experiments using different techniques. The traditional heavy flavour tagging by detecting the lepton produced in semileptonic decays has been used by ALEPH to measure the $c\bar{c}$ and $b\bar{b}$ decay fractions and by L3 to measure the $b\bar{b}$ decay fraction. DELPHI and ALEPH have both measured the $c\bar{c}$ fraction by looking for events containing a D^*. Finally the larger sphericity of $b\bar{b}$ events has been used by DELPHI to measure the $b\bar{b}$ decay fraction. We will describe here these results and we will compare the systematics involved in the different analyses.

2.1 Lepton tagging

Because of the hard fragmentation of the c and b quarks and the large masses of c and b hadrons, semileptonic decays of heavy quarks yield leptons of high average momentum p and transverse momentum p_t with respect to jet axis. Algorithms based on lepton tagging rely on good particle identification and good jet reconstruction; the (p,p_t) lepton spectrum is the basic tool to disentangle $b\bar{b}$ from $c\bar{c}$ and from the background. The use of the lepton p_t makes the definition of the jet axis mandatory, as we shall see this is not the same for all the experiments.

2.1.1 ALEPH

The ALEPH lepton tagging analysis has been recently published [1]; here we will describe only its most relevant features. Results are based on a sample of about 25000 hadronic events, inclusive electrons and inclusive muons are both used. Electron identification is performed in two independent ways : by measuring the energy deposition in the electromagnetic calorimeter (ECAL) and the energy loss (dE/dx) in the TPC. As far as the energy deposition in the calorimeter is concerned, first the measured track momentum is compared to the energy deposited in the four towers closest to the extrapolated track (four towers only are used in order to reflect the compactness of the electromagnetic shower), then the longitudinal shower profile is measured and compared to that expected for an electron. The dE/dx measurement is complementary to the calorimetric method since it is most effective at low momentum (below 5 GeV/c) where hadronic showers fake more easily electromagnetic showers. This can be seen in Fig.1 where the value of two estimators based on the two criteria is plotted for a sample of tracks as a function of the track momentum. In the case of electrons both estimators have a gaussian distribution with zero mean and unit variance. The first (R_T, Fig.1a) is related to the energy deposited in the calorimeter towers, while the second (R_I, Fig.1b) is computed from the dE/dx. A further source of contamination of the prompt electron signal is mainly caused by electrons from photon conversions and π^0 decays. A pair rejection algorithm, based on the distance of the track to the interaction point and on the invariant mass calculated pairing the electron candidate with oppositely charged tracks, greatly reduces this kind of background. The efficiency for electron identification and the hadron misidentification probability are entirely determined from data and are given in Ref. [1] as a function of p and p_t. The hadron misidentification probability is extremely low (less than 0.1%) at low momentum, where the u,d,s quark contamination is more important.

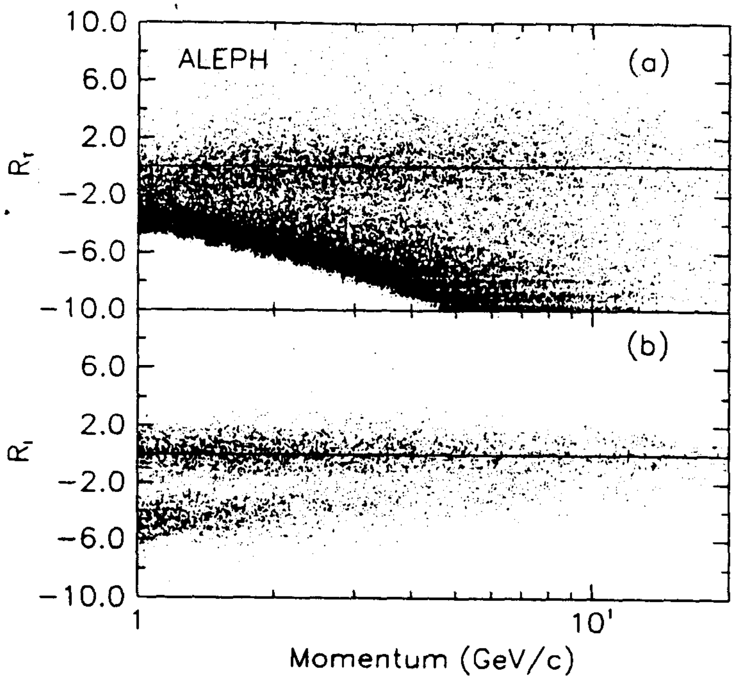

Fig.1

Muons are identified as tracks penetrating through all 23 layers of iron of the ALEPH hadron calorimeter (HCAL). They can be effectively separated from punch-through hadrons thanks to the tracking capabilities of the HCAL. The muon identification efficiency is greater than 80% and the contamination from charged pion and kaon decays and punch-through hadrons is less than 1% (see Ref.[1] for more details).

Jet identification is performed using charged tracks and the scaled-invariant mass clustering algorithm. The transverse momentum of the lepton, p_t, is determined by removing the lepton from its jet, re-evaluating the jet momentum and then calculating the p_t of the lepton with respect to the axis of the new jet momentum. This has been proved to be more effective in separating b quarks from background when charged tracks only are used in the jet definition.

Several sources contribute to the measured lepton sample : prompt leptons from decay of b hadrons (including cascade processes like $b \to cX \to lX'$), prompt leptons from decays of charm hadrons, leptons from decays of light hadrons, electrons from photon conversions and misidentified hadrons. Decays of bottom hadrons dominate the high p_t region defined by ALEPH by the conditions $p_t > 2$ GeV/c and $p > 3$ GeV/c . Most of the contribution from direct charm decay is in the region $p_t < 2$ GeV/c. While the high p_t region is relatively background free, most of the background leptons are in the low p_t range. For this reason, measuring the $c\bar{c}$ fraction requires a good knowledge of the background, something that in ALEPH is achieved for the electron sample by using the two independent identification methods described above. Fig. 2 shows the momentum spectrum for electrons (Fig. 2a) and muons (Fig. 2b) in the range $p_t > 2$ GeV/c. Fig. 3 shows the p_t spectrum for electron, in the range $p > 2$ GeV/c . The Monte Carlo prediction, normalized to the same number of hadronic events, is superimposed and separated into the different sources.

The extraction of the $c\bar{c}$ and $b\bar{b}$ decay fractions requires knowledge of the semileptonic branching ratios of the c and b quarks. The value used by ALEPH for the semileptonic c decays is an average of measurements made at PEP and PETRA (the mixture of D mesons and charm baryons is expected to match that at LEP energies). For semileptonic b decays an average of CLEO and ARGUS results is used. In this case the systematic error is increased to account for the uncertainty in the mixture of b hadrons at different centre of mass energies. The actual values of the used branching ratios as well as the references to the papers can be found in [1].

The fit to the lepton spectra yield the following values for the decay fractions :

$$\Gamma_{c\bar{c}} / \Gamma_{had} = 0.148 \pm 0.044(\text{stat.})^{+0.045}_{-0.038}(\text{syst.})$$

and

$$\Gamma_{b\bar{b}} / \Gamma_{had} = 0.220 \pm 0.016(\text{stat.}) \pm 0.024(\text{syst.})$$

in good agreement with the Standard Model predictions.
In the fit of the (p, p_t) spectrum the average x's of c and b hadrons (x is the fraction of beam momentum carried out by the hadron) are free parameters. The fit gives

$$\langle x_c \rangle = 0.52^{+0.16}_{-0.15} \text{ and } \langle x_b \rangle = 0.67^{+0.04}_{-0.03} .$$

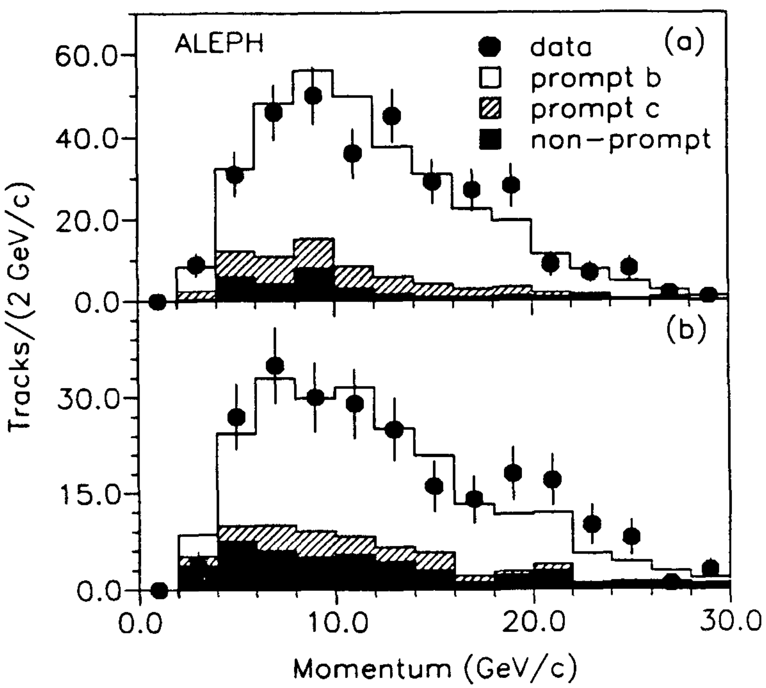
ALEPH
data
prompt b
prompt c
non-prompt
(a)
(b)
Tracks/(2 GeV/c)
Momentum (GeV/c)

Fig.2

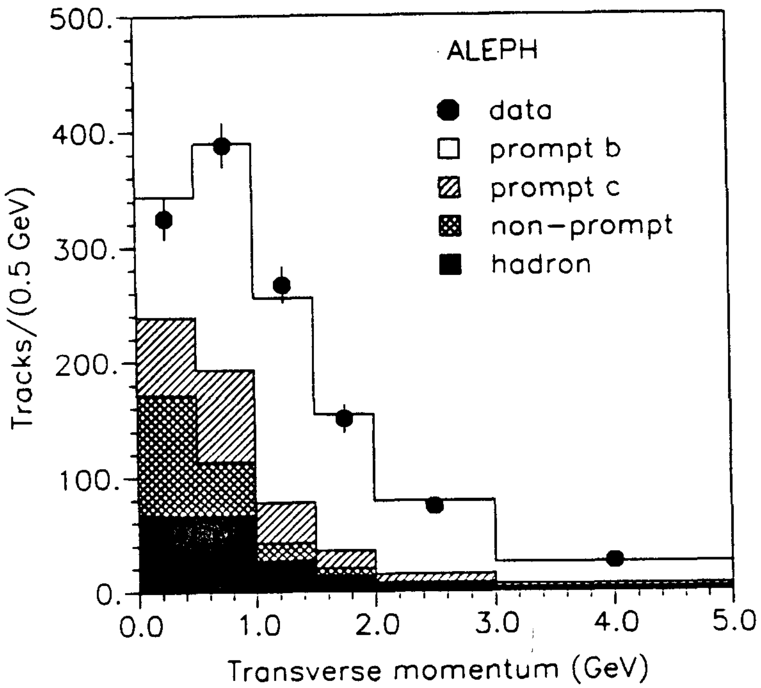
ALEPH
data
prompt b
prompt c
non-prompt
hadron
Tracks/(0.5 GeV)
Transverse momentum (GeV)

Fig.3

2.1.2 L3

The L3 collaboration has measured the decay width of $Z \to b\,\bar{b}$ and the forward backward asymmetry of the produced b quarks using their inclusive muon sample. The analysis we present here follows the lines of Ref. [2], with an increased statistics of 38.000 hadron events. Muons are detected with a muon detector consisting of 3 layers of very precise drift chambers. An average of 6.5 absorption lengths before the chambers makes the punch-through background very low. The contamination from π and K decay in flight is particularly low in the L3 detector because of the short decay path from the interaction point to the front face of the electromagnetic calorimeter. Inclusive muons are selected by requiring at least one track in the muon detector with momentum greater than 4 GeV/c that is consistent with coming from the interaction point . Jets are found using a clustering algorithm which groups the energy deposited in the electromagnetic and hadron calorimeter. In order to have events well contained the Thrust axis of the event has to satisfy the condition $|\cos(\theta_T)| < 0.7$ where θ_T is the angle between the Thrust axis and the beam line. These criteria select 1850 hadron events containing a muon.

A maximum likelihood fit is performed to the muon-momentum (p) and transverse momentum to the nearest jet (p_t) distributions in order to extract the $Z \to b\bar{b}$ component. Fig.4 shows the p_t distribution for the final sample superimposed to the Monte Carlo expectation, the b and $b \to \mu$ components are indicated. The p_t scale is different from that of Fig.3 since here the lepton momentum is used to compute the jet axis. The free parameters of the fit are the $Z \to b\,\bar{b}$ decay width (multiplied by the branching ratio $b \to \mu$) and the average x of b hadrons. After inserting the semi-leptonic branching ratio (L3 takes an average of PEP and PETRA results) the following preliminary results are obtained :

$$\Gamma_{b\bar{b}} = 378\,^{+17}_{-16}\,(\text{stat.}) \pm 36\,(\text{syst.})\ \text{MeV}$$

or, using $\Gamma_{had} = 1733 \pm 44$ MeV from L3

$$\Gamma_{b\bar{b}} / \Gamma_{had} = 0.218 \pm 0.010(\text{stat.}) \pm 0.021(\text{syst.})$$

and

$$\langle x_b \rangle = 0.69 \pm 0.02\ .$$

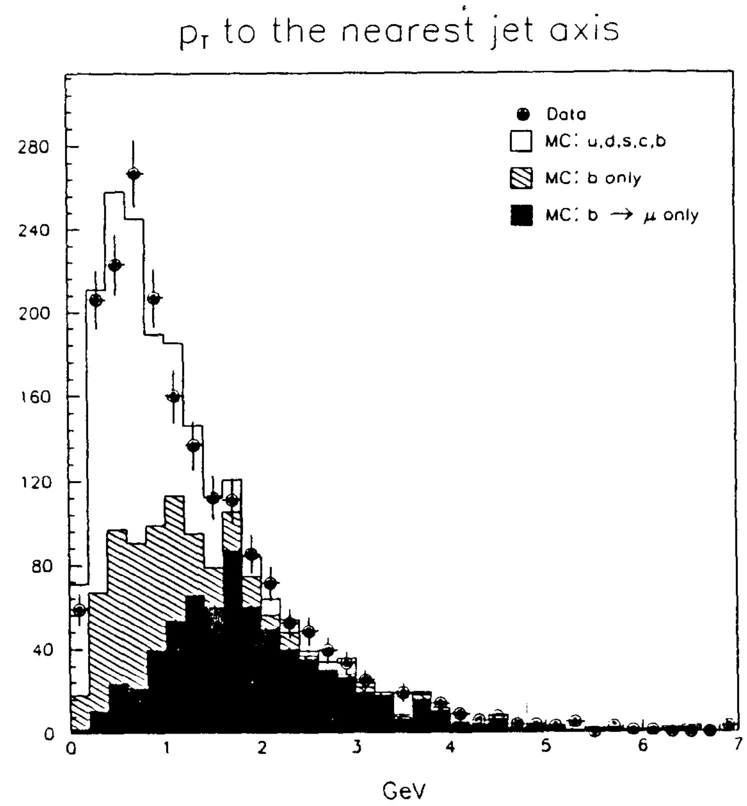

Fig. 4

Using this inclusive muon sample L3 measures the forward backward asymmetry in $Z \rightarrow b\bar{b}$ at the Z pole. The charge of the detected muon is assumed to have the same sign of the original b quark, the two charges are indeed correlated in semi-leptonic decays of b quarks. The Thrust axis is used to define the direction of the quark and the measurement (performed with the condition $|\cos(\theta_T)| < 0.7$) is extrapolated to the full angular range. The preliminary result is

$$A_{b\bar{b}} = 0.145 \pm 0.052 \text{ (stat.)} \ .$$

The result has been corrected for the contamination from background and the cascade process $b \rightarrow cX \rightarrow lX'$, but it is not corrected for B^0-$\overline{B^0}$ oscillations. The Standard Model prediction assuming m_{top}=150 GeV, m_{Higgs}=1000 GeV and applying QED radiative corrections is 0.086 [3]. Since the quark charge is determined by measuring the prompt muon charge B^0-$\overline{B^0}$ mixing has the effect of reducing the magnitude of the asymmetry to about 75% of the original value (the reduction factor is $1\text{-}2\chi$ where χ is the average mixing parameter).

2.1.3 Systematic errors in the lepton tagging analyses

There are basically 3 sources of systematics in the ALEPH and L3 determinations of the partial decay width of $Z \rightarrow b\bar{b}$: uncertainties on the semileptonic branching ratios, uncertainties on the amount of background and lepton identification efficiencies. The fact that $<x_b>$ has been allowed to vary independently in the fit leaves just a weak dependence on the fragmentation hypotheses. Since by far the most important systematic error for this measurement comes from the knowledge of $Br(b \rightarrow l\nu X)$, the average bottom hadron semileptonic branching ratio, both experiments give a measurement of the $b\bar{b}$ fraction times the branching ratio :

$$Br(b \rightarrow l\nu X) \times \Gamma_{b\bar{b}}/\Gamma_{had} = 0.0224 \pm 0.0016\text{(stat.)} \pm 0.0010\text{(syst.)} \quad \text{(ALEPH)}$$

and

$$Br(b \rightarrow l\nu X) \times \Gamma_{b\bar{b}}/\Gamma_{had} = 0.0257 \pm 0.0012\text{(stat.)} \pm 0.0011\text{(syst.)} \quad \text{(L3)} \ .$$

The residual systematic errors come from the extra sources mentioned at the start of this paragraph. It should be pointed out that the value of $Br(b \rightarrow l\nu X)$ used by the two experiments, being obtained from averages of different measurements, it is not the same :

$$Br(b \rightarrow l\nu X) = 0.102 \pm 0.010 \quad \text{(ALEPH [1])}$$

and

$$Br(b \rightarrow l\nu X) = 0.118 \pm 0.011 \quad \text{(L3 [2])} \ .$$

The average of the two determinations of the $b\bar{b}$ fraction times the branching ratio with the errors added in quadrature is

$$Br(b \rightarrow l\nu X) \times \Gamma_{b\bar{b}}/\Gamma_{had} = 0.0243 \pm 0.0012 \ .$$

It is interesting to note that if we assume the Standard Model prediction of 0.217 for the $b\bar{b}$ decay fraction we find $Br(b \rightarrow l\nu X)$=0.112±0.005, with an error that is better than the present world averages of direct measurements.

2.2 D* tagging

The identification of a D^* tags an heavy flavour event. The D^* can either be produced from primary $c\bar{c}$ or as a secondary product from b decay. Typically the search for D^* is done through the channel $D^{*+} \rightarrow D^0\pi^+$ which, being a decay with a Q value of only 5.9 MeV, gives a pion of low momentum and with a transverse momentum that is small with respect to the D^* line of flight. A very effective tagging can be performed by searching for exclusive decay chains like $D^{*+} \rightarrow D^0\pi^+$ with $D^0 \rightarrow K^-\pi^+$, taking advantage of the small Q value that yields a sharp peak in the distribution of the mass difference $\Delta M = M(K^-\pi^+\pi^+) - M(K^-\pi^+)$. The mass difference obtained by ALEPH from 80,000 hadronic Z decays can be seen in Fig.5. However, this method has the disadvantage that branching ratios for exclusive decay chains are low and $c\bar{c}$ events have to be disentagled from secondary charm. An alternative procedure to tag $c\bar{c}$ events using $D^{*+} \rightarrow D^0\pi^+$ has been developed by the HRS and TASSO collaborations [4,5] and very recently applied to $Z \rightarrow c\bar{c}$ by DELPHI and ALEPH. The method relies on the properties of the π^+ produced in the D^{*+} decay that, as we have just mentioned, is low momentum and low p_t with respect to the D^* direction.

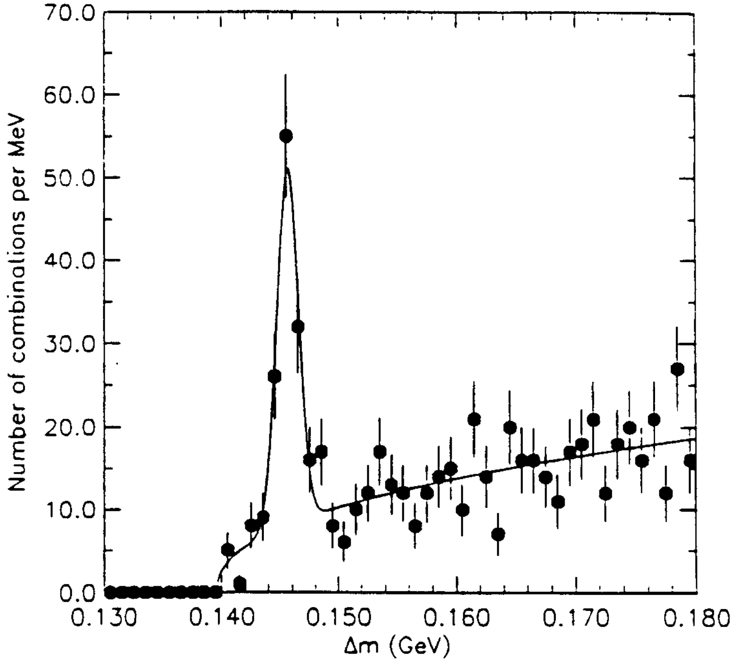

Fig.5

The direction of the D^* is estimated from a jet analysis and it is approximated with the jet direction. Pions from D^* produced in $Z \rightarrow c\bar{c}$ reveal themselves as an accumulation above the continuum background at very low p_t^2 while pions from secondary charm are more smeared out since the jet direction does not approximate so well the direction of the D^*. The peak at very low p_t^2 can be clearly seen in Fig.6a, which was produced with a Monte Carlo simulation of the DELPHI detector for $Z \rightarrow c\bar{c}$. The hatched area represents the $D^{*+} \rightarrow D^0\pi^+$ contribution. The peak is not present in Fig. 6b, which shows the simulation for *udsb* quarks only.

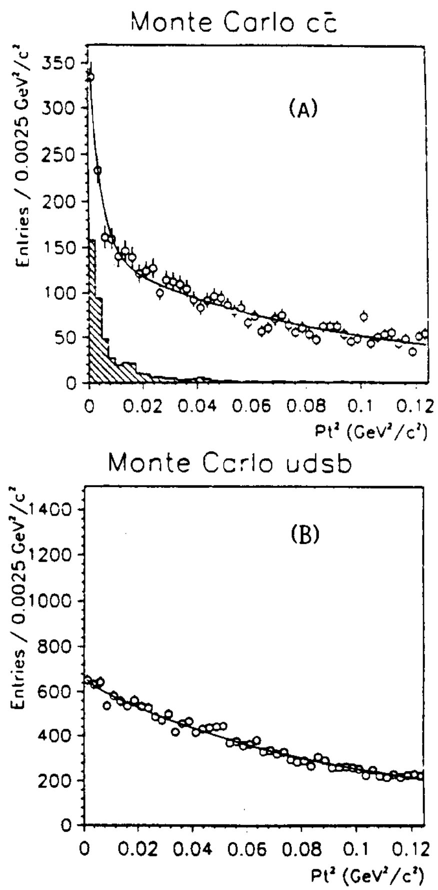

Fig.6

2.2.1 DELPHI

DELPHI has used the p_t^2 distribution for soft pions to measure the partial decay fraction of $Z \rightarrow c\bar{c}$. In order to select hadronic Z decays with a negligible background, events with 5 or more charged tracks and invariant mass of all charged tracks greater of 12 GeV/c^2 are selected. This has the effect of selecting about 36900 hadronic Z decays with an efficiency of 92%. Then soft pions are retained if their momentum is in the range 1.5 to 2.5 GeV/c. The lower momentum cut has the effect of reducing the $b\bar{b}$ background, since D^*'s from bottom hadrons have on average a lower momentum. Jets are reconstructed from charged tracks using the LUCLUS algorithm of the LUND package [6]. Quality checks are performed on the jet containing the soft pion, in particular the sum of the energies of the charged tracks in the jet has to be at least 90% of that of all tracks in the same sphericity hemisphere. For the selected sample of real data Fig. 7a shows the p_t^2 distribution of charged tracks in the momentum interval 1.5 to 2.5 GeV/c : a clear peak is seen. Fig. 7b, made with pions in a different momentum range (3 to 5 GeV/c), shows no peak. The signal in Fig. 7a is fitted with an exponential function,

$$N_s \exp(-p_t^2/B^2)$$

the slope of the exponential is determined from the Monte Carlo simulation of $Z \rightarrow c\bar{c}$ events yielding a decay $D^{*+} \rightarrow D^0\pi^+$. For the background two different functions are used :

$$\frac{a}{1+bp_t^2+cp_t^4}$$

or

$$a'+b'\times\exp(-p_t^2/c'^2) \;;$$

the final result is rather insensitive to the exact choice of this function. The fitted signal and background are superimposed to the experimental data points in Fig.7a, the measured D^* signal is N_s=381±76 .

In order to measure the $Z \rightarrow c\bar{c}$ partial decay width it is necessary to determine the efficiency of this tagging procedure in selecting $c\bar{c}$ events. The efficiency can be expressed as

$$\varepsilon_s = P_1 \times P_2 \times P_3$$

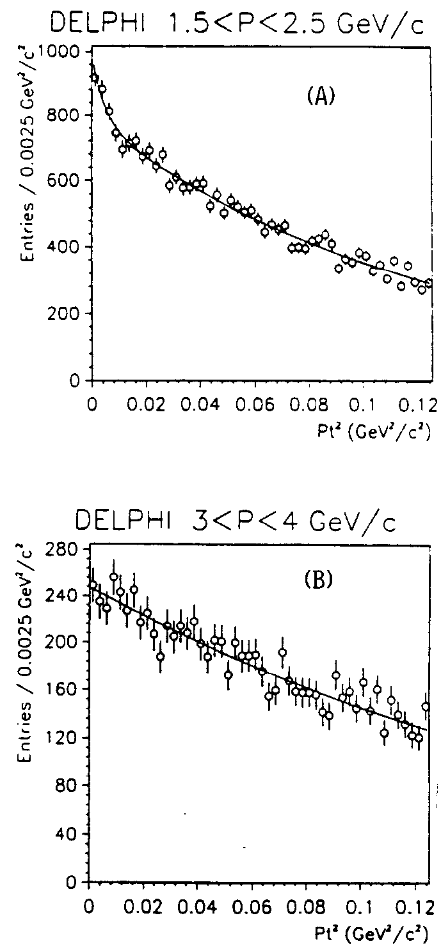

Fig. 7

where P_1 is the probability to produce a decay $D^{*+} \rightarrow D^0\pi^+$ in $Z \rightarrow c\bar{c}$, P_2 is the probability to reconstruct a charged pion taking into account the fact that the momentum range is limited from 1.5 to 2.5 GeV/c, P_3 is the efficiency of the fitting procedure. P_2 and P_3 are reliably estimated from the Monte Carlo simulation, their value is respectively .27±.02 and .78±.05 . P_1 is the more uncertain factor, the DELPHI collaboration uses P_1 =.31±.05 obtained by combining measurements of CLEO [7] and MARK III [8]. In extrapolating the measurements at low energy storage rings to LEP it is assumed that the fragmentation rate of charm into D^* does not change from 10.55 GeV to 91 GeV centre of mass energy. The preliminary value of the measured partial decay width is

$$\Gamma_{c\bar{c}} / \Gamma_{had} = 0.162 \pm 0.032(\text{stat.}) \pm 0.031(\text{syst.})$$

in good agreement with the Standard model and the ALEPH lepton tagging measurement. The largest contribution to the systematic error is the uncertainty on P_1.

2.2.2 ALEPH

The ALEPH analysis is based on about 91200 hadronic Z decays. The D^* direction is estimated from a jet analysis using the scaled-invariant mass clustering algorithm. Soft pions are selected in the range 1 to 3 GeV/c; this range is divided into four bins of 0.5 GeV/c each and a p_t^2 spectrum is obtained for each bin of soft pion momentum. The four p_t^2 spectra are simultaneusly fitted with a c quark component, a b quark component and a term for the continuum. The actual shape used for the D^* signal is

$$N_s \exp(-a p_t^2 - b p_t^4) ,$$

the p_t^4 term helps in fitting the tail of the signal when the D^* axis is not well estimated. The fit gives the preliminary result

$$\Gamma_{c\bar{c}} / \Gamma_{had} \times Br(c \rightarrow D^0\pi_{soft}) = 0.029 \pm 0.0035(\text{stat.}) \pm 0.0023(\text{syst.})$$

and

$$\langle x_c \rangle = 0.475 \pm 0.030 .$$

The systematic error on the charm partial decay width results from varing over a reasonable range the jet clustering parameter and the lower momentum cut for tracks to be included in the jet clustering itself. The error on $\langle x_c \rangle$ is purely statistical. The branching ratio $Br(c \rightarrow D^0\pi_{soft})$ is equivalent to the probability P_1 defined in the analysis of DELPHI, divided by a factor 2 . Taking for the branching ratio the value 0.174 (obtained from the LUND Monte Carlo) yields

$$\Gamma_{c\bar{c}} / \Gamma_{had} = 0.167 \pm 0.021(\text{stat.})$$

in agreement with the lepton tagging measurement of ALEPH and the measurement of DELPHI using the same technique. Since $Br(c \rightarrow D^0\pi_{soft})$ is the most uncertain factor it is interesting to see that assuming the Standard Model prediction of 0.171 for the $Z \rightarrow c\bar{c}$ partial decay width gives

$$Br(c \rightarrow D^0\pi_{soft}) = 0.176 \pm 0.021 .$$

2.3 Boosted sphericity product

The use of shape variables to disentagle different quark flavours heavily relies on predictions from Monte Carlo simulations, but has the advantage of using all the available events, not a particular channel only. A typical separation variable that has been used by the TASSO collaboration at PETRA is the boosted sphericity product [9]. In a two-jet event each of the two jets is independently boosted along the sphericity axis toward the hypotethical rest frame of the b hadron and the sphericities for each jet in the new frames, S_1 and S_2, are calculated. Since the mass of b hadrons is large, $b\bar{b}$ events appear to have a larger value for S_1 and S_2. A separation variable, $S_1 \times S_2$, is defined as the product of the two boosted sphericities. The DELPHI collaboration has used this variable to measure the partial decay width of $Z \rightarrow b\,\bar{b}$ [10]. In Fig.8 the distribution of the separation variable $S_1 \times S_2$ is plotted for $b\bar{b}$ and non $b\,\bar{b}$ events in a Monte Carlo simulation of the DELPHI detector. A boost β=.96 has been used. The $b\,\bar{b}$ component is enhanced in the region of high boosted sphericity product.

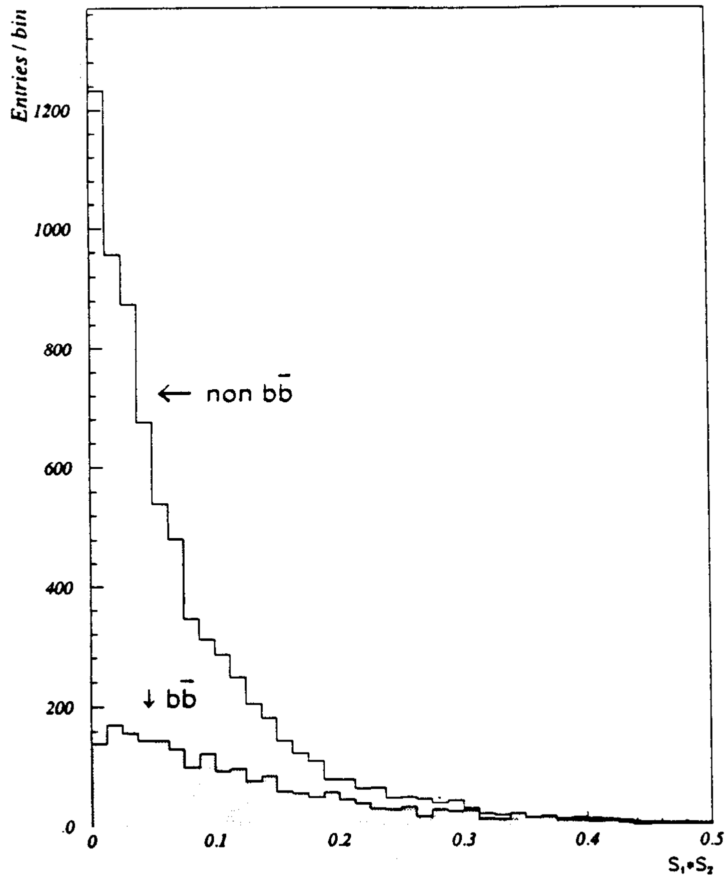

Fig.8

The analysis of real data is performed on a sample of 17700 two-jet events selected from more than 24500 hadronic events with the scaled invariant mass algorithm. For this sample the differential distribution $dN/d(S_1 \times S_2)$ is calculated. In Fig.9 experimental data are shown and the Monte Carlo curves for a pure $b\bar{b}$ sample, for the Standard Model prediction, and for a mixture of *udsc* quarks only are superimposed. Data clearly agree with the Standard Model hypothesis. A fit of the data yields

$$\Gamma_{b\bar{b}} / \Gamma_{had} = 0.211 \pm 0.020(\text{stat.}) \pm 0.031(\text{syst.}) .$$

The systematic error includes the model dependence of the fit, uncertainties on the fragmentation parameters and on the $c\bar{c}$ branching fraction.

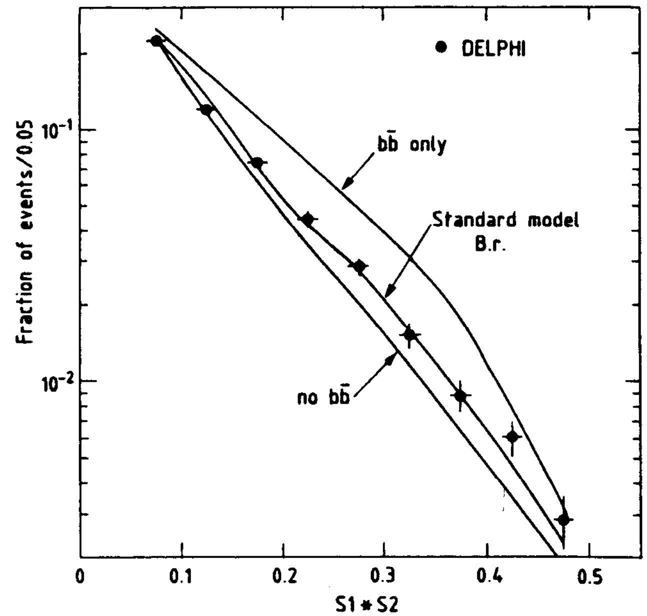

Fig.9

3. B^0-$\overline{B^0}$ mixing

In semileptonic decays of *b* hadrons the charge of the lepton is correlated in sign to the charge of the initial quark, therefore B^0-$\overline{B^0}$ mixing can be measured from a sample of hadronic Z decays having two high p, p_t leptons in the opposite hemispheres. Since at LEP centre of mass energies both B_d^0 and B_s^0 are produced what is measured is the average mixing parameter

$$\overline{\chi} = f_d \chi_d + f_s \chi_s$$

where f_d (f_s) is the fraction of B_d^0 (B_s^0) in the *b* sample and the χ parameters are defined as

$$\chi_{d,s} = \frac{Pr(B_{d,s}^0 \rightarrow \overline{B_{d,s}^0})}{Pr(B_{d,s}^0 \rightarrow B_{d,s}^0) + Pr(B_{d,s}^0 \rightarrow \overline{B_{d,s}^0})}$$

In the ideal case of a pure sample in which both leptons come from a direct semileptonic decay of a *b* hadron (primary *b* 's) $\overline{\chi}$ can be easily measured bycountingthe number of likewise sign dileptons over the total; this ratio can be written as $2\overline{\chi}(1-\overline{\chi})$. However there are competitive processes as semileptonic decays of charm, both from primary charm production or from the cascade; and background processes as hadron misidentification, electrons from photon conversion or π^0 decays, and muons from pion and kaon decays in flight. In particular, background dilepton events, which usually have one true lepton from an heavy flavour decay and one track wrongly identified as a lepton , are not half like and half unlike charge as one might naively assume, because of hadron-parent quark correlations. This can precisely be measured with real events by analysing single lepton events, and pairing the lepton with any opposite hemisphere track that satisfies all analysis requirements but the lepton identification. In the B mixing analysis of the ALEPH collaboration, which will be described in this chapter, the ratio like charge events to the total is measured for the background to be 0.554 ± 0.009 . The ALEPH analysis is based on a sample of 80000 hadronic Z decays. Dileptons are selected with the same lepton identification criteria used in the lepton tagging section and requiring that each lepton be of momentum greater than 5 GeV/c and of transverse momentum with respect to the jet direction greater than 1 GeV/c. The two leptons should be well separated, an angle of at least 90 degrees between the two is required. A total of 202 events are selected, distributed as follows :

ee	32 unlike	11 like
eμ	69 unlike	31 like
μμ	34 unlike	25 like
Total	135 unlike	67 like .

If $\overline{\chi}$ were zero (i.e., if there were no mixing) 160 unlike sign events and 42 like sign events would be expected. The prediction on the composition of the sample, based on the results of the fit of p, p_t described in the lepton tagging section, is that 66% of the dilepton events are pairs of direct semileptonic decays of *b* hadrons (primary *b* - primary *b*), 15% are made of a direct semileptonic decay of a *b* and of a cascade charm decay (primary *b* -secondary *c*), 2% are from primary *c* - primary *c* and 16% are from background. The events that do not depend on mixing (primary *c* - primary *c* and background) are subtracted taking into account the fact that, as we mentioned, the background it is not neutral in sign. Then $\overline{\chi}$ is determined by solving the equation

$$\text{Number of like sign events} = 2\overline{\chi}\,(1-\overline{\chi})\times(\text{Number of prim. } b \text{ - prim. } b\,) + (1-2\overline{\chi}\,(1-\overline{\chi}))\times(\text{Number of prim. } b \text{ - second. } c\,)$$

and assuming no CP violation and D^0 mixing. The preliminary result is

$$\overline{\chi} = 0.129\,^{+0.045}_{-0.039}(\text{stat.})^{+0.016}_{-0.020}(\text{syst.})$$

where the systematic error comes from the uncertainties on the components of the dilepton sample (prim. *b* - prim. *b* , etc.) , from the error on the background average charge and from the error on the fragmentation parameters. Since this result constrains $\overline{\chi}$ at the 90% confidence level to $0.073 < \overline{\chi} < 0.190$ we can conclude that a significant mixing is observed at LEP.

4. Measurement of the inclusive B lifetime

The measurement of the average lifetime for the mixture of *b* hadrons produced in Z decays, which we will call inclusive B lifetime or τ_b in this chapter, is interesting for a number of reasons. Since the spectator quark model is expected to be a good approximation for *b* hadron decays it can be shown that V_{cb}, the *cb* element of the CKM matrix, can be evaluated by combining the measurement of τ_b with the mean semileptonic branching ratio for bottom hadrons [11]. In addition, from a purely experimental point of view, the measurement of the inclusive B lifetime is a testing ground for the measurement of the individual lifetimes of *b* hadrons.

We will present here a preliminary measurement of τ_b based on the analysis by the ALEPH collaboration of a sample of 55000 hadronic Z decays. The aim is to select semileptonic *b* decays by means of the lepton tagging technique described in section 2.1.1 and then measure the lepton impact parameter with respect to the primary vertex. The impact parameters of the lepton tracks are presently measured in ALEPH using the ITC (a cylindrical multiwire drift chamber with a precision on the measurement of Rϕ coordinates of 100 μm) and theTPC. In the future the use of the MINIVERTEX (a microstrip silicon detector) to improve the impact parameter measurement is foreseen. Since the best track resolution is obtained in the plane transverse to the beam (Rϕ) the impact parameter projected onto this plane is used. The average position of the centre of the beam spot provides an estimate of the production vertex. This is determined for each LEP fill with a precision of 30 μm. The size of the beam spot is 11 μm in the vertical and 240 μm in the horizontal direction. In order to define a variable sensitive to the lifetime a signed impact parameter is used, as sketched in Fig. 10. The direction of the *b* hadron is assumed to be equal to the jet direction. If the distance from the primary vertex to the point at which the lepton track crosses the jet axis is positive (D>0), then the impact parameter δ is signed positive. The finite track resolution and errors in the *b* hadron direction can yield negative values of δ. Bottom hadron candidates are selected searching for leptons having a momentum of at least 5 GeV/c and p_t greater than a certain cut. Results for p_t cuts of 1 and 2 GeV/c will be given. The p_t definition and jet reconstrution algorithm are the same as in section 2.1.1.

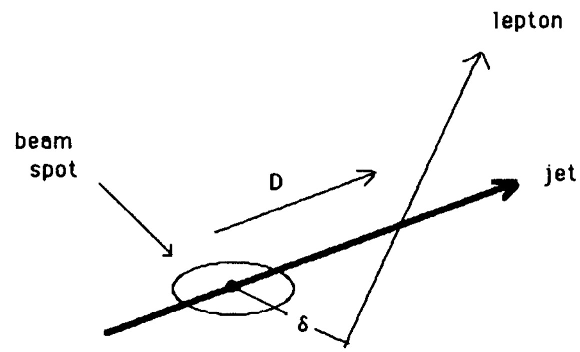

Fig. 10

The number of selected events, as a function of the p_t cut and the lepton nature is

	muons	electrons
p_t > 1 GeV/c	1162	1139
p_t > 2 GeV/c	459	505 .

The distribution of the impact parameter is skewed to positive values, with a mean of 175 μm (140 μm) for a p_t cut of 1 GeV/c (2 GeV/c) . In order to extract the inclusive B lifetime, the impact parameter for the selected events is fitted with a method close to that used by the MARK II collaboration at PEP. This technique is described in detail in Ref. [12]. In the fitting procedure five possible kinds of events are considered : primary *b* decay, secondary *b* decay (cascade), primary *c* decay, misidentification background (for instance fake muons from punch-through hadrons) and decay background (for example,decays in flight of π,K or photon conversions).

The probability that a lepton is from each of these sources has been determined as a function of p, p_t. Then a fitting function F^i is defined for event i as

$$F^i = \sum_{j=1}^{5} f^i_j P_j(\delta^i, \sigma^i_\delta, \tau_b, \tau_c)$$

where P_j is the probability density function for each of the five sources (it depends on the impact parameter, the error on the impact parameter and, for non-background sources, on the lifetimes) and f^i_j is the probability for event i to be from source j (calculated, as we have said, as a function of p, p_t). The method to determine the probability density functions is described in detail in ref. [12]. A likelihood function is constructed as the product of the fitting functions F^i for all the events. A maximum likelihood fit is performed, leaving one single free parameter, τ_b. The average charm lifetime, 0.68±0.10 ps, is taken for τ_c. The impact parameter distribution is shown in Fig. 11 for a p_t cut of 2 GeV/c, the result of the fit for each of the five sources is superimposed. The *b* hadron purity is predicted to be about 68% for the 1 GeV/c cut and 75% for the 2 GeV/c cut. The contributions to the systematic error on τ_b are summarised here for the two p_t cuts (the units are [ps]):

	p_t > 1 GeV/c	p_t > 2 GeV/c
Lepton source fractions	0.060	0.055
Misidentification background	0.005	0.005
Decay background	0.120	0.070
Prob. density functions	0.075	0.090
Average charm lifetime	0.010	0.010
Fragmentation hypothesis	0.005	0.005
TPC field distortions	0.020	0.020
Total (in quadrature)	0.150	0.119 .

Since the systematics are lower for p_t > 2 GeV/c this cut is used to give the preliminary value of the ALEPH measurement of the inclusive B lifetime

$$\tau_b = 1.29 \pm 0.11 \text{ (stat.)} \pm 0.12 \text{ (syst.) ps} .$$

The result for p_t > 1 GeV/c is τ_b = 1.26 ± 0.07 (stat.) ± 0.15 (syst.) ps . This measurement of τ_b is in agreement with the previous world average [13] of 1.13±0.15 ps and it has the lowest error when compared to other single experiments.

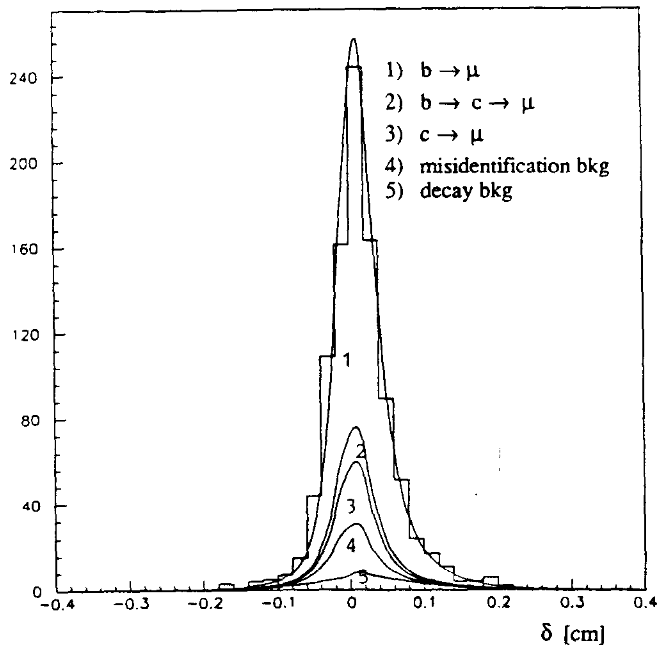

Fig. 11

References

[1] D. Decamp et al., ALEPH Collab., Phys. Lett. B **B244** (1990) 551.

[2] B. Adeva et al., L3 Collab., L3 Preprint 6 (1990).

[3] A. Djouadi, J.H. Kühn and P.M Zerwas, MPI-PAE/PTh/48/89.

[4] S. Abachi et al., HRS Collab., Phys. Lett. **B205** (1988) 411.

[5] W. Braunschweig et al., TASSO Collab., DESY 89-053 (1989).

[6] T. Sjôstrand and M. Bengtsson, Comp. Phys. Comm. **43** (1987) 367.

[7] D. Bortoletto et al., CLEO Collab., Phys. Rev. **D37** (1988) 1719.

[8] J. Adler et al., MARK III Collab., Phys. Rev. Lett. **60** (1988) 89.

[9] W. Braunschweig et al., TASSO Collab., DESY 88-159 (1988).

[10] P. Abreu et al., DELPHI Collab., CERN-PPE/90-118 (1990).

[11] K.Kleinknecht, Proc. XXIV Int. Conf. on High Energy Physics, Munich 1988, ed. by R.Kotthaus and J.H. Kühn (Springer-Verlag, Berlin Heidelberg, 1989) p. 98.

[12] R. A. Ong, Ph.D. Thesis, SLAC-Report-320 (1987).

[13] L. Lyons, A.J. Martin and D.H.Saxon, Phys. Rev. **D41** (1990) 982.