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ELECTROWEAK PHYSICS WITH b QUARKS AT LEP

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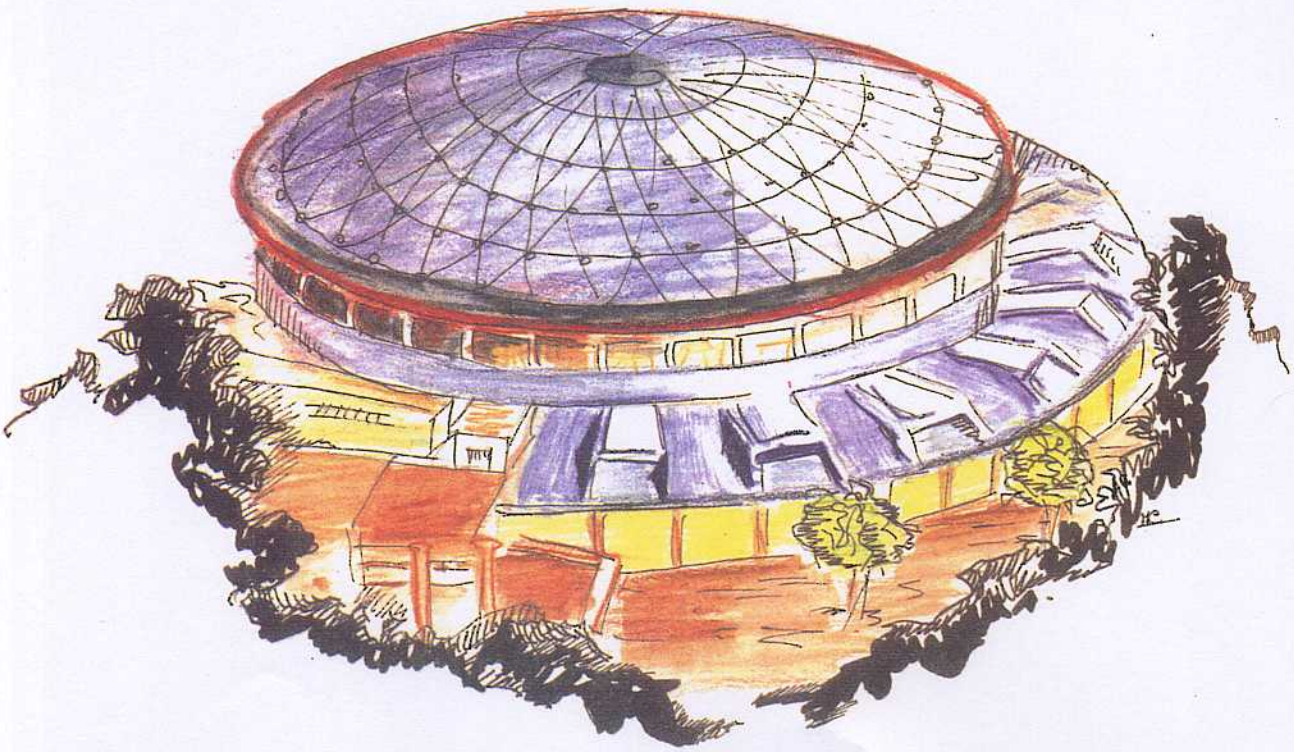

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ELECTROWEAK PHYSICS WITH b QUARKS AT LEP

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ABSTRACT

The four LEP experiments have collected up to now about 1 million of b flavoured hadrons. This amount of data can be used to test the Electroweak Sector of the Standard Model, with the measurements of $\Gamma_{b\bar{b}}$ and $A^b_{\rm FB}$. A summary of b tagging techniques is given, with a particular emphasysis on the detection of leptons from semileptonic decay of b quarks. Detector performances, sample purities and identification efficiencies are reviewed, together with a discussion of the systematical errors. The latest results from the four LEP Collaborations in the determination of $\Gamma_{b\bar{b}}$, $A^b_{\rm FB}$, and $B^0 - \overline{B^0}$ mixing are presented.

INTRODUCTION

The measurement of $\Gamma_{b\bar{b}}$ and of $A^b_{\rm FB}$ constitutes two of the most straightforward and precise tests of the Standard Model predictions [1]. In the Standard Model the partial decay of $Z \rightarrow q\bar{q}$ depends on the weak isospin of the quarks and is expected to be larger for down type quarks than for up type quarks. For light quarks the theoretical prediction of $\Gamma_{q\bar{q}}$ have uncertainties of about 10 MeV due to the unknown mass of the top quark. This fact limits the accuracy of Standard Model predictions in the light quark sector. On the contrary, due to the presence, unique to $b\bar{b}$ final states, of diagrams with top quarks which cancel the usual one loop contribution, $\Gamma_{b\bar{b}}$ is insensitive to the top mass and its value is expected to be 378 ± 3 MeV (see fig. 1). A high precision measurement of $\Gamma_{b\bar{b}}$ (at the level of 1%), could thus provide a decisive test of the Standard Model.

The forward-backward asymmetry ($A^b_{\rm FB}$) of b quark pairs is sensitive to the electroweak mixing angle through the well known formulas :

$$A^b_{\rm FB} \sim \frac{3}{4} A_e \, A_f$$

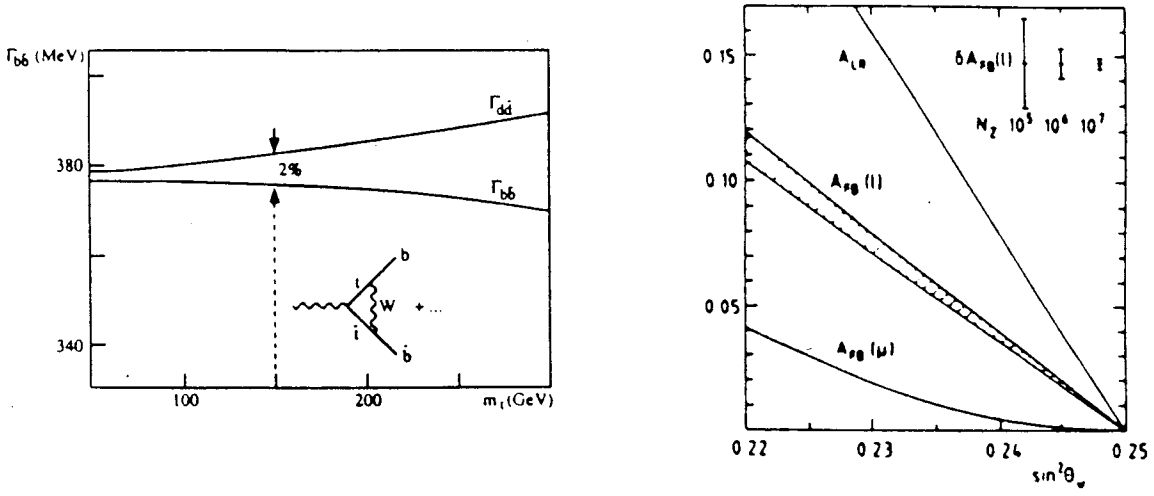

Figure 1: $\Gamma_{b\bar{b}}$ width as a function of the top mass (left) and the dependence of $A_{\rm FB}^b$ with respect to the $\sin^2\theta_W(m_Z^2)$ (right).

where

$$A_f = \frac{2\,(1-4\mid Q_f\mid \sin^2\theta_W(m_Z^2)\,)}{1+(1-4\mid Q_f\mid \sin^2\theta_W(m_Z^2)\,)^2} + (QED, QCD\ corrections)$$

It has to be noticed that the $B^0-\overline{B^0}$ mixing reduces $A_{\rm FB}^b$ by $(\,1-2\,\chi)\sim 0.75$, so that its precise measurement requires a good knowledge of the mixing parameter.

From fig. 1 one can see also that $\sin^2\theta_W(m_Z^2)$ dependence is stronger in $A_{\rm FB}^b$ with respect to $A_{\rm FB}^l$, allowing, in principle, a more precise determination of $\sin^2\theta_W(m_Z^2)$ with respect to one obtainable with the lepton line shape. In practice, taking into account b tagging efficiencies, one can envisage a measurement of $\sin^2\theta_W(m_Z^2)$ using $A_{\rm FB}^b$, at least as accurate as the one obtained with $A_{\rm FB}^l$.

LEP can be considered as a b factory: about 22 % of Z^0 hadronic decays generates a $b\bar{b}$ pair and the $\frac{\sigma_{b\bar{b}}}{\sigma_{c\bar{c}}}$ ratio is particurly good($\sim$ 1.3), reducing greatly the background coming from $c\bar{c}$ events.

The b flavoured hadrons produced at LEP have the following properties:
- they belong to well separated jets in opposite emispheres;
- the b quark direction is faithfully represented by the thrust axis ($\pm$2 degree);
- the boost is considerable and allows the detection of the b-hadron decay flight path (corresponding to about 2 mm);
- being the b quark mass high, leptons produced in semileptonic decays have a higher $p_\perp$ with respect to leptons coming from c decays or from misidentified hadrons;
- fragmentation of b quarks is hard and this leads to high momentum decay products (background from fragmentation is concentrated at low p);
- a mixture of b flavoured hadrons is produced: $B^0, B^\pm, \Lambda_b, B_s$ in a proportion which is expected to be $\sim$ 40:40:10:10 %.

Unlike the operation at low energy machines, beam energy constraint cannot be used at LEP to reconstruct final states due to the presence of the fragmentation. Taking advantage of the above b production features, tagging at LEP has been performed mainly using two techniques:

- *semileptonic decays*, requiring the lepton to have a high $p_\perp$ value in order to ensure a considerable reduction in background and to enrich the b sample;

- *event shape*, where b jet properties (thrust, sphericity, etc...) are studied, with the help of statistical methods too (such as discriminant analysis, neural networks, etc...), to obtain samples of events rich in b, with high efficiency;

In addition to this, the operation of silicon vertex detectors has opened the possibility of tagging b's through its decay path length. This method has the advantage of being statistically powerful, although the understanding of the systematics coming from the background (mainly charm decays) is heavily based on the Monte Carlo simulation. Various LEP Collaborations are currently analysing their data with this method. At the end of june the four LEP experiments had collected a sample of $9\ 10^5$ b's.

THE LEPTON IDENTIFICATION

All the four LEP experiments are equipped with lepton tagging systems. In Table 1 a review of the performances of the apparata for the identification of electrons and muons is reported. The quoted values for efficiencies and purities are indicative and may be different in the context of the various analysis.

THE SEMILEPTONIC DECAYS OF b QUARKS

As already pointed out, the semileptonic decays of b flavoured hadrons represents a well established technique of b tagging. The hard fragmentation of the b with respect to the c permits to obtain a high b purity with a simple $p_\perp$ cut. The b quark direction is, in good approximation, given by the thrust axis and the evaluation of the $p_\perp$ of the lepton is usually performed taking into account both charged particles and calorimetric neutral clusters, so to have a better approximation of jet energy and direction.

Two approaches have been used to reconstruct the jet direction: the first one includes the lepton in the jet definition, the second one excludes it. It has been evaluated that, if an "energy flow" determination of the jet axis has been used, little difference exists in the two methods, as far efficiency and b sample purity are concerned.

Due to the large difference in mass between quarks b and c, a cut based on the $p_\perp$ variable turns out to be highly discriminant against the background from charm decays. Also the background coming from misidentified hadrons is usually concentrated at low $p_\perp$.

Prompt leptons from b decays are due to the following process:

- $b \to l^- \nu c$, with a decay rate of about 10 %, per leptonic species;

- $b \to c \to l^+ \nu s$, with a decay rate of about 10 %, per leptonic species;

- $b \to c\bar{c}X \to l^- \nu s$, whose rate is experimentally unknown and is expected to be 10–20 % of the previous one;

- $b \to \tau^- X \to l^- X$ and $b \to \psi X \to l^+ l^- X$, give a contribution which can be considered negligible.

	ALEPH	DELPHI	L3	OPAL
Electron id method	$dE/dx, p/E$, shower profile in ECAL	$dE/dx, p/E$, longitudinal profile in HPC	Isolation,lateral shape in BGO	$dE/dx, p/E$, lateral profile in ECAL, shower presampler
ϵ_{id}	$\sim 74\%$	$\sim 58\%$	$\sim 50\%$ *	$\sim 52\%$
Kinematical cuts	$p > 3$ GeV, $p_\perp > 1.0$ GeV $\lvert cos\theta \rvert < 0.95$	$p > 4$ GeV, $p_\perp > 1.2$ GeV $\lvert cos\theta \rvert < 0.7$	$p > 3$ GeV, $p_\perp > 1.5$ GeV $\lvert cos\theta \rvert < 0.7$	$p > 3$ GeV, $p_\perp > 0.8$ GeV $\lvert cos\theta \rvert < 0.9$
Purity in $b \to e$	$\sim 84\%$	$\sim 55\%$	$\sim 84\%$	$\sim 77\%$
Muon id method	HCAL and Muon chambers	Muon chambers	Muon chambers in mag. field	HCAL and Muon chambers
ϵ_{id}	$\sim 89\%$	$\sim 78\%$	$\sim 85\%$ *	$\sim 78\%$
Kinematical cuts	$p > 3$ GeV, $p_\perp > 1.0$ GeV $\lvert cos\theta \rvert < 0.95$	$p > 4$ GeV, $p_\perp > 1.2$ GeV $\lvert cos\theta \rvert < 0.9$	$p > 4$ GeV, $p_\perp > 1.5$ GeV $\lvert cos\theta \rvert < 0.8$	$p > 4.5$ GeV, $p_\perp > 1.0$ GeV $\lvert cos\theta \rvert < 0.9$
Purity in $b \to \mu$	$\sim 78\%$	$\sim 64\%$	$\sim 78\%$	$\sim 75\%$
Jet definition	charged and neutrals lepton included	charged and neutrals lepton excluded	calorimetric energy lepton excluded	charged and neutrals lepton included

Table 1: Summary of the lepton identification of LEP apparata (* L3 values on ϵ_{lepton} are deduced from the ϵ_{lepton} after the kinematical cuts).

The main sources of background are represented by:

- $Z \to c\bar{c}$, $c \to l$, with a branching ratio of 8–10 %;
- misidentified leptons in $Z \to q\bar{q}$ events.
  Considering *electrons*, fake events can originate from pions undergoing charge exchange in the electromagnetic calorimeter, from gamma conversions and from Dalitz pairs. In the case of *muons*, hadrons can be misidentified for three reasons: decays in flight (nearly equally from pions and kaons); fragments from hadronic interactions that hit the muon chambers ("punch through"); hadrons that do not interact in the hadron calorimeter ("sail through"). These backgrounds depend on detector performance, lepton identification efficiency, etc... and amount to few per cent for each track. It has to be considered that the simulation could be not enough accurate to reproduce exactly these sources of background, introducing a systematical error in the determination both of $\Gamma_{b\bar{b}}$ and $A^b_{\rm FB}$. Several "test samples" of data are thus used to verify the accuracy of Monte Carlo predictions, such as $\mu^+\mu^-$, e^+e^-, $\gamma\gamma\mu^+\mu^-$, $\gamma\gamma e^+e^-$, $\tau \to leptons$, $\tau \to hadrons$, $K^0_S \to \pi^+\pi^-$.

Typical numbers which come out from LEP analysis, applying the kinematical cuts $p > 3$ GeV, $p_\perp > 1$ GeV, are a b tagging efficiency ≤ 5 % and a purity of the sample in $b \to l$ of 60–80 % (see Table 2). In fig. 2 a $p_\perp$ distribution is shown.

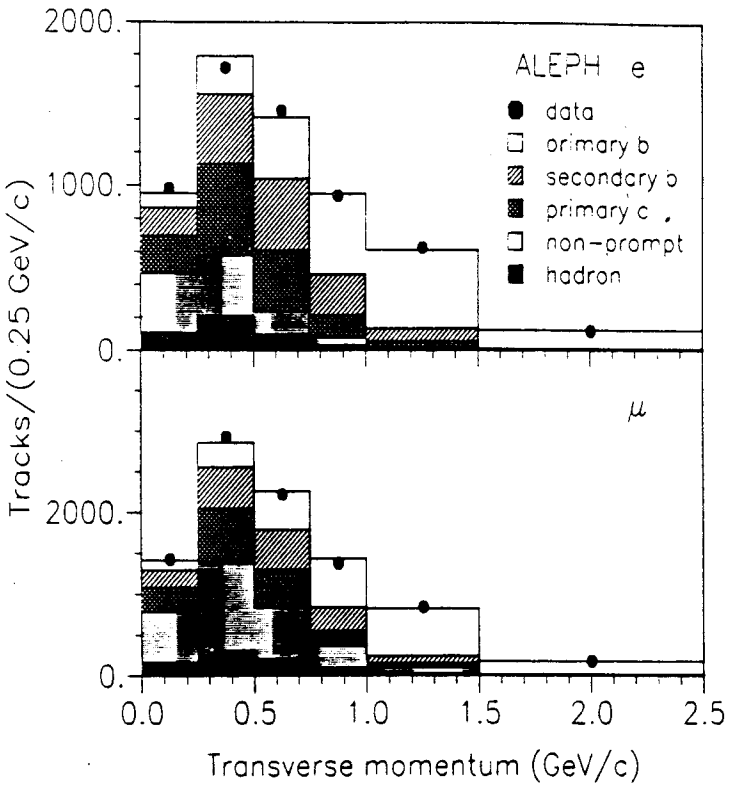

Figure 2: Spectrum of $p_\perp$ for electron and muon candidates for $p > 3$GeV, broken down into their various contributions (ALEPH data).

THE DETERMINATION OF $\Gamma_{b\bar{b}}$ FROM HIGH $p_\perp$ LEPTONS

The measurement of $\Gamma_{b\bar{b}}$ is strongly correlated to the knowledge of several physical quantities [3, 4, 5, 6]. One of the most straightforward methods of determining $\Gamma_{b\bar{b}}$ consists in the count of the number of leptons detected in a high p, $p_\perp$ region, that is related to the $Z \to b\bar{b}$ width through:

$$N_l^{\,b\to l} = 2\, N_{had}\, \frac{\Gamma_{b\bar{b}}}{\Gamma_{q\bar{q}}}\; B.R.(\, b \to l\,)\; \epsilon_{\,b\to l}$$

where $N_l^{\,b\to l}$ represents the number of leptons from b decay; N_{had} is the number of hadronic Z^0 decays in the sample; $\Gamma_{q\bar{q}}$ is the total hadronic width of the Z^0 ;

Category	μ $(p > 4)$	μ $(p > 4,\ p_\perp > 1.5)$	e $(p > 3)$	e $(p > 3,\ p_\perp > 1.5)$
$b \to l$	38.1	77.9	66.8	84.3
$b \to c \to l$	12.0	4.7	6.5	2.5
$b \to \tau \to l$	2.1	1.5	2.1	1.7
$b \to \bar{c} \to l$	1.9	0.6	0.3	0.1
$c \to l$	17.5	4.7	3.9	1.2
background	28.4	10.6	20.4	10.2

Table 2: Relative fractions (in %) of prompt, non prompt and fake leptons from the different sources (L3 data).

b hadron decay model	Isgur et al.	Altarelli et al.	Modified Isgur
$B.R.(\ b \to l\ )$	$9.9 \pm 0.1 \pm 0.4$	$10.5 \pm 0.2 \pm 0.4$	$11.2 \pm 0.3 \pm 0.4$
$B.R.(b \to c \to l)$	$11.3 \pm 0.7 \pm 0.6$	$9.7 \pm 0.8 \pm 0.6$	$9.0 \pm 0.8 \pm 0.6$
$\epsilon(b \to e)$ from JETSET	0.278		
Corrected $\epsilon(b \to e)$	0.274	0.270	0.261
$\Gamma_{b\bar{b}}$ / $\Gamma_{q\bar{q}}$	0.230 ± 0.008	0.226 ± 0.008	0.223 ± 0.008

Table 3: OPAL analysis of the correlation between the $b \to l$ decay models, the $B.R.(\ b \to l\ )$, the lepton identification efficiency and the $\Gamma_{b\bar{b}}$ measurement.

$B.R.(\ b \to l\ )$ the amplitude of the semileptonic b decay at LEP energies; $\epsilon_{\ b \to l}$ the efficiency in detecting the lepton, determined using the Monte Carlo.

On the other hand, we have

$$N_l^{\ b \to l} \ = \ N_l^{tot} - N_l^{\ c \to l} \ - N_{bck}$$

where N_l^{tot} is *the total number of leptons detected*, i.e. the quantity experimentally measured; $N_l^{c \to l}$ is the number of leptons coming from c decay; N_{bck} is the number of misidentified hadrons. This last value can be evaluated from a well tuned Monte Carlo. In addition

$$N_l^{\ c \to l} \ = \ 2\ N_{had}\ \frac{\Gamma_{c\bar{c}}}{\Gamma_{q\bar{q}}}\ B.R.(\ c \to l\ )\ \epsilon_{\ c \to l}$$

where $B.R.(\ c \to l\ )$ is the amplitude of the semileptonic c decay at LEP energies; $\epsilon_{\ c \to l}$ the efficiency in detecting the lepton, determined again with the simulation.

From this simple example it can be seen that the measurements of $\Gamma_{b\bar{b}}$, $\Gamma_{c\bar{c}}$, $B.R.(\ b \to l\ )$ and $B.R.(\ c \to l\ )$ are all intercorrelated. Also the details of the fragmentation (i.e. the chosen values of $\langle x_E^b \rangle, \langle x_E^c \rangle$) are relevant to the analysis and for the evaluation of the systematical error.

The most precise determinations of the value of the $B.R.(\ b \to l\ )$ come from measurements at Υ (4S) [2]. Although statistically significant (2% error), the direct use of these values in the analysis at LEP encounters two main problems:
- presence of a non negligible fraction (10 %) of b-flavoured baryons which could have a decay width in the semileptonic channel different to that of B mesons. Depending on estimates, this contribution to the systematics is of the order of 2–4 %;
- a 10 % systematical error in the ARGUS and CLEO measurements, essentially coming from the need of using a model to predict the shape of the lepton spectrum at low energies. This indetermination in the $B.R.(\ b \to l\ )$ directly affects the evaluation of $\Gamma_{b\bar{b}}$, turning out to be the largest contribution to the systematical error.

An analysis carried out by OPAL, has shown that, once the $b \to l$ events have been corrected according to the shapes of the lepton spectra given by the various models, the higher is the semileptonic branching ratio, the softer is the lepton spectrum so as to give a lower lepton identification efficiency (see Table 3). The analysis thus shows an anticorrelation between measured branching ratio at low energy machines and lepton identification efficiency at LEP. This result reduces to ~ 2 % the systematic error coming from the different models used for the b decay in the determination of $\Gamma_{b\bar{b}}$.

ALEPH and L3 have tried to evaluate the $B.R.(\ b \to l\ )$ directly from LEP data.

ALEPH	0.110 ± 0.006	(ALEPH)
DELPHI	0.100 ± 0.010	(CLEO)*
L3	0.117 ± 0.006	(L3/PEP/PETRA)
OPAL	0.102 ± 0.006	(CLEO)

Table 4: Branching ratios of the $b \to l$ decay; in parenthesis the sources of the measurements are reported (* value used in the forward backward asymmetry analysis).

	$\Gamma_{c\bar{c}}$ (MeV)	source	$B.R.(\ c \to l\ )$	source
ALEPH	$296 \pm 17 \pm 38$	p, $p_\perp$ fit	$0.088 \pm 0.003 \pm 0.009$	p, $p_\perp$ fit
DELPHI	298	Standard Model	0.100 ± 0.011	PDG
L3	298	Standard Model	0.096 ± 0.006	PEP/PETRA
OPAL	298	Standard Model	0.079 ± 0.011	PDG

Table 5: Values of the parameters used for the charm sector.

L3 measures the semileptonic decay width from the ratio of dilepton events (two leptons in opposite emispheres) to single lepton events in the high $p_\perp$ region:

$$\frac{N^{2l}}{N^{1l}} \propto \frac{\Gamma_{b\bar{b}}\ B.R.^2(\ b \to l\ )\epsilon^2(\ b \to l\ )}{\Gamma_{b\bar{b}}\ B.R.(\ b \to l\ )\epsilon(\ b \to l\ )}$$

where $\Gamma_{b\bar{b}}$ cancels out, and the identification efficiency and the backgrounds are evaluated from MonteCarlo. The value obtained is $0.112 \pm 0.010 \pm 0.006$. The systematical error introduced by the uncertainty on the lepton spectrum is not considered in this estimate. The accuracy of this method is currently limited by the statistics.

ALEPH determines $B.R.(\ b \to l\ )$, together with other physical parameters, from a global fit to the lepton spectrum in the p, $p_\perp$ plane. This technique will be discussed later on. The result obtained is $0.110 \pm 0.004 \pm 0.004$. In Table 4 we report the values of the decay rates of the b quark in the semileptonic channel as used from LEP experiments in their analysis ($\Gamma_{b\bar{b}}$, $A_{\rm FB}^b$, mixing).

THE CHARM SECTOR AND THE FRAGMENTATION PARAMETERS

As already pointed out, the value of the $\Gamma_{c\bar{c}}$ and of the $B.R.(\ c \to l\ )$ must be known in order to determine $\Gamma_{b\bar{b}}$. DELPHI, L3 and OPAL assume the value given from the Standard Model (298 MeV), while ALEPH measures $\Gamma_{c\bar{c}}$ and the $B.R.(\ c \to l\ )$ from a global fit in the p, $p_\perp$ plane.

Concerning the $B.R.(\ c \to l\ )$, among LEP experiments, DELPHI and OPAL assume PdG [8] value, L3 averages the value obtained at PEP and PETRA and ALEPH calculates its value from a fit to the full lepton momentum spectrum. It must be noticed that LEP experiments have different point of view concerning systematical errors introduced from uncertainty in semileptonic decay of both b and c quarks. A summary of the values used for the charm sector is given in Table 5.

The situation for the fragmentation function seems better defined. All the experiments obtain $\langle x_E^b \rangle, \langle x_E^c \rangle$ from a fit to the p, $p_\perp$ spectrum, with central values in good agreement

	$\langle x_E^b \rangle$	$\langle x_E^c \rangle$
ALEPH	0.70 ± 0.02	0.51 ± 0.02
DELPHI	0.69 ± 0.03	$\epsilon_c \sim 10\epsilon_b$
L3	0.69 ± 0.017	$\epsilon_c \sim 10\epsilon_b$
OPAL	0.73 ± 0.02	0.56 ± 0.03

Table 6: Fragmentation function parameters. All determinations are obtained from a fit to the p, $p_\perp$ spectrum.

between them (see Table 6). A Peterson-like fragmentation function is commonly used.

THE DETERMINATION OF $\Gamma_{b\bar{b}}$ FROM THE (p, $p_\perp$) FIT

The method of the global fit to the p, $p_\perp$ plane allows to extract the full information using the shape of the lepton spectrum. The p, $p_\perp$ plane is divided in k bins (p, $p_\perp$)$_i$ so that in each bin a sizeable number of events is collected, both for data and MonteCarlo. In each bin of simulated events, the amount of various contributions (leptons from b, from c and from background) can be considered a function of the physical parameters that can be left to vary freely in the fit: $\Gamma_{b\bar{b}}$, $\Gamma_{c\bar{c}}$, $B.R.(\, b \to l\,)$, $B.R.(\, c \to l\,)$, $\langle x_E^b \rangle, \langle x_E^c \rangle$, $A_{\rm FB}^b$, χ.

The actual procedure consists in minimizing with respect to the free parameters the quantity:

$$S^2 = \sum_{over\ bins\ i}^{k_{bins}} \frac{(N_i^{DATA} - N_i^{MC})^2}{N_i^{MC^2}}$$

with

$$N_i^{MC} = N_i^{MC,\ b\to l} + N_i^{MC,b\to c\to l} + N_i^{MC,\ c\to l} + N_i^{MC,bck} = F\ (fitted\ variables)$$

The ALEPH Collaboration makes use extensively of this technique to measure simultaneously $\Gamma_{b\bar{b}}$, $\Gamma_{c\bar{c}}$, $B.R.(\, b \to l\,)$, $B.R.(\, c \to l\,)$, $\langle x_E^b \rangle, \langle x_E^c \rangle$. This method appears very interesting, but extreme care must be taken, in order to correctly understand the errors on the variables, due to the strong correlations between the fitted parameters. The other experiments perform "reduced" fits, where some variables are constrained to the values expected from the Standard Model ($\Gamma_{c\bar{c}}$) or from independent experimental determination (e.g. heavy quarks semileptonic decay widths). It is worthwhile noticing that in this method, some of the systematical errors are transferred to the statistical ones.

The systematics affecting the $\Gamma_{b\bar{b}}$ measurement has a two-fold origin: the first is related to the knowledge of the detector performance (i.e. lepton identification efficiencies, MonteCarlo simulation, signal to background ratio); the second is given by the uncertainty in the knowledge of the details of the physical process (fragmentation, momentum spectrum of the semileptonic decays, composition of b hadrons at LEP energies, etc...). Combining data from different experiments at LEP, it must be taken into account that errors of the first kind are reduced accordingly to the square root of the total number of events, while systematical errors of the second class are in common between the experiments, although their evaluation is often different in the various experiments.

In Table 7 the sources of systematical errors in the determination of $\Gamma_{b\bar{b}}$ are shown for the four LEP experiments, while in fig. 3 a summary of LEP results on $\Gamma_{b\bar{b}}$ is given.

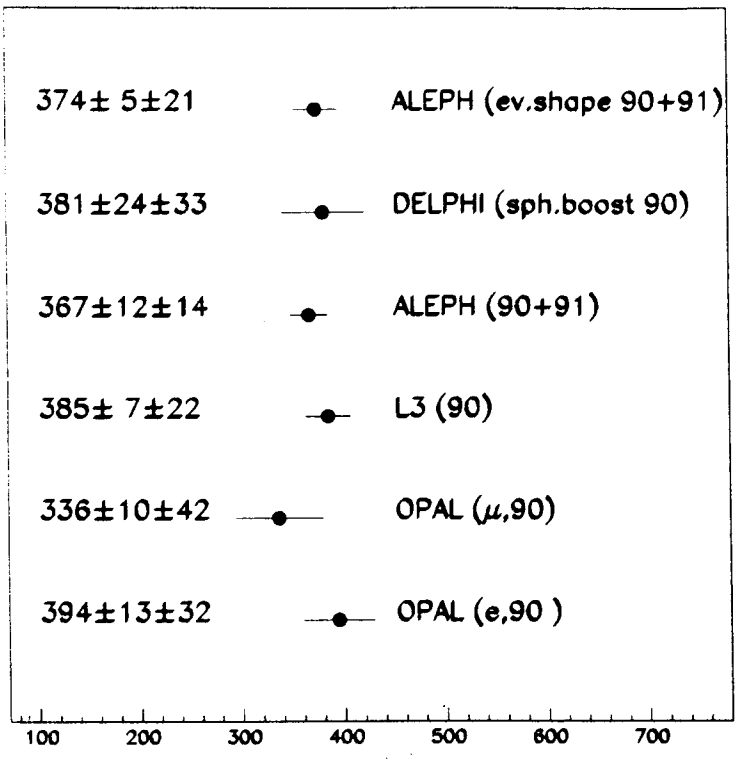

Figure 3: Summary of the LEP results on $\Gamma_{b\bar{b}}$. In parenthesis the samples of data used.

Combining the results and taking into account the above discussed correlations [9], an average LEP value of $\Gamma_{b\bar{b}} = 370 \pm 17$ is obtained. The measurement is limited by the systematical error and is still far from a decisive test of this sector of the Standard Model.

It is worthwhile noticing that, after about three years of data taking, the level of systematics coming from the imperfect knowledge of the detector still affects, at least in part, the precision of the measurement. This suggest a possible improvement in this sector of the systematical error. The understanding of the lepton identification efficiencies and of the background contamination is directly connected to the availability of an improved statistics in the "test samples" of data such as gamma gamma events, lepton pairs or pions from K^0_S, where the identification algorithms can be carefully studied.

THE MEASUREMENT OF $A^b_{\rm FB}$

The differential cross section of the quark production in $Z \to b\bar{b}$ events can be written as:

$$\frac{d\sigma}{d\Omega} = C(1 + cos^2\theta + \frac{8}{3} A^b_{\rm FB}\ cos\theta)$$

where the quark production angle θ is well approximated by the thrust axis direction. The observed $A^{b,obs}_{\rm FB}$ is connected to the actual $A^b_{\rm FB}$ by the formula:

$$A^{b,obs}_{\rm FB} = A^b_{\rm FB}\ (f_{\ b\to l} - f_{b\to c\to l^+} + f_{b\to\bar{c}\to l^-})(1-2\chi) - A^c_{\rm FB}\ f_{\ c\to l} - A^{bck}_{\rm FB}\ f_{bck}$$

where the f_i are the fractional populations of various sources in the lepton sample; $A^c_{\rm FB}$ is the c quark asymmetry, weakly dependent on the top mass, and usually assumed from

ALEPH	
lepton identification efficiency and background contamination	4 %
$B.R.(\ b \to l\ )^*$, $B.R.(\ c \to l\ )^*$	3 %
DELPHI	
electron identification efficiency	5 %
muon identification efficiency	3 %
$p_\perp$ definition	3 %
$B.R.(b \to c \to l)^*$	2 %
fragmentation*	2 %
fit procedure	3 %
L3	
electron identification efficiency	3 %
background	2 %
$p_\perp$ definition	2 %
D decays contribution *	2 %
$B.R.(\ b \to l\ )^*$	5 %
OPAL	
electron identification efficiency	4 %
muon identification efficiency	2 %
background to electrons	3 %
detector resolution (μ)	3 %
fragmentation *	3 %
$B.R.(\ b \to l\ )^*$ (b decay model 2 %)	4 %
$B.R.(\ c \to l\ )^*$	2 %

Table 7: Various sources of systematic errors in the $\Gamma_{b\bar{b}}$ measurement: (*) denotes correlated errors.

the Standard Model to be 0.73 $A_{\rm FB}^b$; $A_{\rm FB}^{bck}$ is the asymmetry coming from misidentified hadrons (can be considered compatible with zero, although with a certain error); χ is the average $B^0 - \overline{B^0}$ mixing parameter at LEP.

Likewise to the $\Gamma_{b\bar{b}}$ measurement, in the determination of $A_{\rm FB}^b$ [3, 4, 5, 6], two approaches have been used :
- events high $p_\perp$ leptons are selected to obtain samples enriched in b. The value of $A_{\rm FB}^b$ is extracted from a fit to the cos θ distribution (see fig. 4);
- the full p, $p_\perp$ spectrum is divided in bins and the value of $A_{\rm FB}^b$ is considered a free parameter of the fit.

The study of the systematics of this measurement has many analogies with the one previously discussed for the determination of $\Gamma_{b\bar{b}}$. In addition, an important role is played by the knowledge of χ.

The mixing [7] can be measured considering dilepton events $(ee, \mu\mu, e\mu)$ in opposite emispheres, being

$$\chi = \frac{B.R.(b \to \overline{B^0} \leftrightarrow B^0 \to l^+ X)}{B.R.(b \to l^\pm X)}$$

As previously, χ can be measured in the high $p_\perp$ region by counting the number of

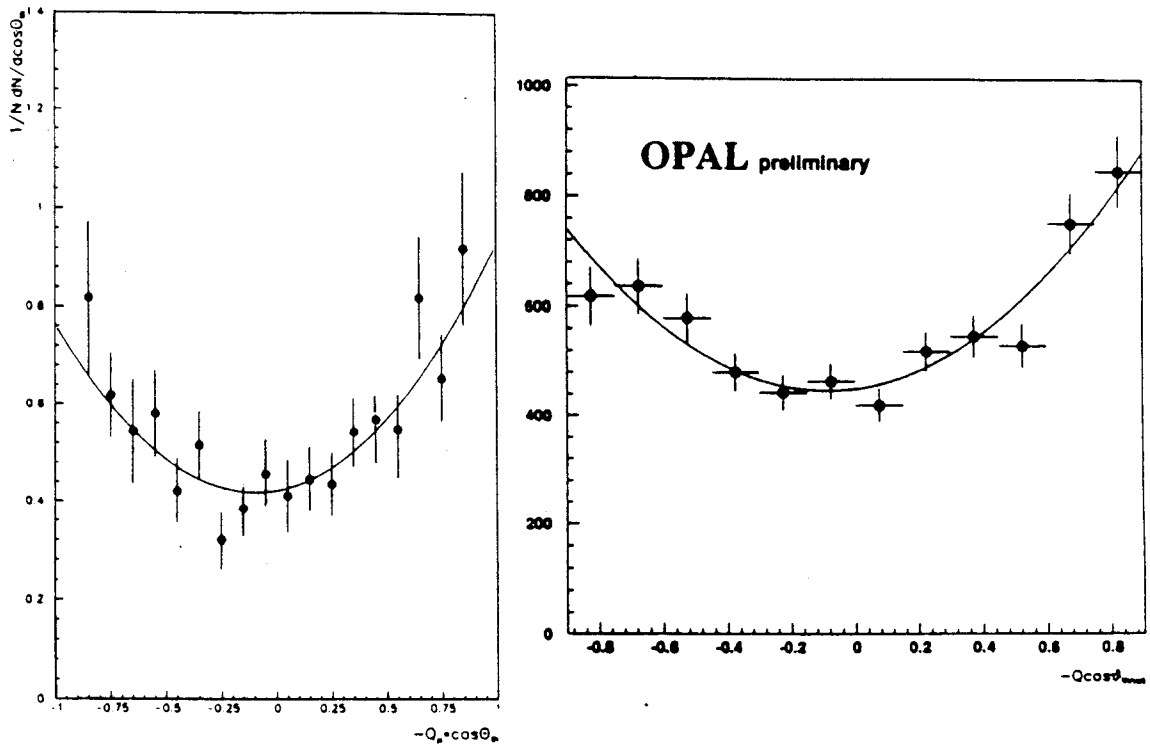

Figure 4: Polar angle distributions of the b quark direction: DELPHI(left) and OPAL data.

dilepton pairs with the same charge with respect to the total number of dilepton pairs

$$\frac{N^{\pm\pm}}{N^{\pm\pm} + N^{\mp\mp}} = \sum_k c_k \, f_k(\chi)$$

where the c_k and the $f_k(\chi)$, are, respectively, the fractions and the χ functional dependence of the various sources of dileptons:
$(b \to l \, , \, b \to l \,)$; $(b \to l \, , b \to c \to l)$; $(b \to l \, , c \to l)$; $(b \to l \, , fake\ lepton)$;
$(b \to c \to l, b \to c \to l)$; $(b \to c \to l, c \to l)$; $(b \to c \to l, fake\ lepton)$;
$(c \to l \, , \, c \to l \,)$; $(c \to l \, , fake\ lepton)$; $(fake\ lepton, fake\ lepton)$.

Also for the χ measurement a full p, $p_\perp$ fit can be used. At present, the measurement is statistically limited and its influence on the $A_{\rm FB}^b$ systematics, together with that coming from other sources, can be seen in Table 8.

Combining the LEP data (see fig. 5), considering correlated and uncorrelated systematic errors, a global value of $A_{\rm FB}^b = 0.093 \pm 0.015$ is obtained. This value corresponds to an electroweak angle determination of $\sin^2\theta_W(m_Z^2) = 0.2317 \pm 0.0027$, taking into account QED and QCD corrections. The error on this determination of $\sin^2\theta_W(m_Z^2)$ is similar to the one obtained from the combined fit to the lepton data of the LEP experiments [10].

CONCLUSION

The $\Gamma_{b\bar{b}}$, $A_{\rm FB}^b$ and χ have been measured at LEP, with an accuracy of, respectively, 5%, 16%, 10%. A very good determination of the $\sin^2\theta_W(m_Z^2)$ has been obtained

ALEPH	
$\chi = 0.134 \pm 0.013 \pm 0.008$	
from χ *	0.004
$B.R.(\ b \to l\ )$ *	0.002
asymmetry of the background	0.002
DELPHI	
$\chi_{LEP} = 0.126 \pm 0.012$	
$p_\perp$ definition	0.010
from χ *	0.004
asymmetry of the background	0.005 (μ)
c quark asymmetry*	0.005 (μ)
fit binning	0.016 (e)
background, $B.R.(\ c \to l\ )$ *	0.007 (e)
L3	
$\chi = 0.121 \pm 0.017 \pm 0.006$	
from χ *	0.007
$B.R.(\ b \to l\ )$ *	0.006
asymmetry of the background	0.006
c quark asymmetry *	0.006
fit binning	0.007
$p_\perp$ definition	0.006
OPAL	
$\chi = 0.125 \pm 0.016 \pm 0.015$	
from χ *	0.006
c quark asymmetry *	0.006
$B.R.(\ b \to l\ )$ *	0.006
asymmetry of the background	0.005 (μ)
electron identification efficiency	0.007

Table 8: LEP determinations of the mixing parameter and the sources of systematic errors in the $A_{\rm FB}^b$ measurement: all data, except for L3, refers to 1990+1991 analysis (* denotes correlated errors).

tagging b final states. While the accuracy on the $Z \to b\bar{b}$ width is currently limited by the understanding of the systematics, the other two measurements can be improved increasing the statistics. The semileptonic decay of the b has represented, up to now, a fruitful method to tag b events, although the determination of the $B.R.(\ b \to l\ )$ appears the limiting factor in the accuracy obtainable. Several other b tagging techniques (in particular those based on the shape variables) are becoming available and look statistically powerful. These facts, together with a deeper understanding of the detector performances and of the other systematics, brought in by the increase of Z^0 events, will probably allow the LEP I phase to carry out decisive tests of the Standard Model in the heavy quark sector.

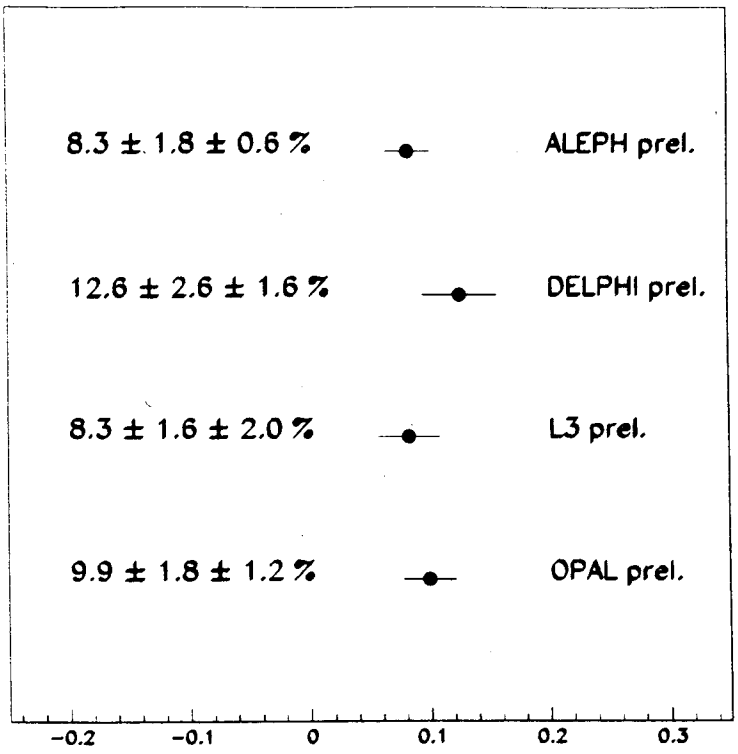

Figure 5: A_{FB}^{b} preliminary results from LEP (1990+1991 data).

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I tried to report as faithfully as possible numbers and results of various analysis "freezed" just before the Dallas Conference. I apologise since now for any inaccuracy the reader may found.
I feel also indebted to the Organizers of this Conference for inviting me and for the nice atmosphere they created in this lovely place. Finally, a special thank goes to my little baby Lorenzo (five months old) who stayed peacefully during the preparation this talk.

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