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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 $Z^0 \rightarrow J/\Psi + X$, are presented. New world averages for the B-lifetime and the mixing parameter χ_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 $Z^0 \rightarrow J/\Psi + X$.

In the B lifetime and $B\bar{B}$ mixing analysis the $Z^0 \rightarrow b\bar{b}$ 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 -> lvX). In the primary b decays are also included the b -> τ -> lvX decays. Beyond b->c-> lvX the cascade decay includes also the decay chain b -> cW⁻ with W⁻ -> c̄ -> lvX. (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:

$$d_q(z) = \frac{1}{z} (1 - \frac{1}{z} - \frac{\varepsilon_q}{1-z})^{-2} \qquad q = \text{quark flavour} = c,b$$

where $z = (E + p_l)_{hadron}/(E+p_l)_{quark}$ and ε_q is a phenomenological parameter, expected to be inversely proportional to M^2q.

Often, instead of z, the variable $x = E_h/E_{beam}$ 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 Λ_b are under production threshold, while the c c̄ /b b̄ 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 τ_B yields a constraint on the K.M. matrix elements V_{cb} and V_{ub}. In fact the B meson semileptonic width Γ_{SL} can be expressed as:

$$\Gamma_{SL} = \frac{BR(B -> lvX)}{\tau_B} = \frac{G_F^2 M_b^5}{192\pi^3} (0.48|V_{cb}|^2 + 0.86|V_{ub}|^2)$$

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, Λ_b) lifetimes, is measured up to now.

The lifetime measurement is based on the lepton impact parameter distribution. The analysis proceeds as follows:

1)   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 δ of the lepton track with respect to the e+e- interaction point (I.P.) is measured in the r-ϕ vue (where the spatial resolution is better and the beam spread along the z axis is ininfluent).

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 δ if the decay appears to happen downstream (upstream) with respect to the I.P..

Because of the finite B lifetime the δ distribution has its average shifted toward a positive value of about 150 μm. 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 τ_B value the observed δ distribution is fitted with the b -> lvX decay signal contribution plus the other contributions (b->c->l, c->l, misidentif. hadrons and decay leptons). This implies the MC simulation of the true δ distribution for the b and c quarks and then its smearing according the experimental resolution on δ (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 δ 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 τ_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 I - Results of the B lifetime analysis (values of L3 in () refer to muons).

	p p_t cuts	e + μ	b->l purity	$<\delta>$ (μm)	τ_B (psec)
Aleph	5 2	1215+1758	66%	142 ± 7	1.29 ±.06 ±.10
Delphi	3 1	759	48%	161 ± 15	1.30 ±.12 ±.11
L3	4 1 (1.5)	673+712	83%	176 ± 8	1.31 ±.06 ±.08

The three values of τ_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 ± 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. B$\bar{\text{B}}$ MIXING

A neutral B_d^0 (B_s^0) meson can oscillate into a $\bar{B}_d^0$ ($\bar{B}_s^0$) meson because of the $\Delta B=2$ transition represented by the box diagrams:
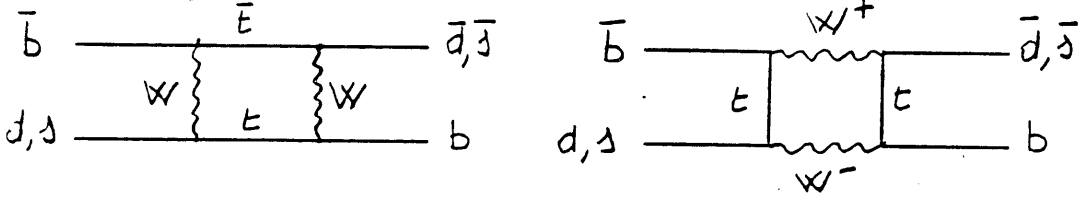
The mixing probability χ is given by:

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

where ΔM, $\Delta\Gamma$, Γ 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 χ_B of the χ values for B_d^0 and B_s^0 is measured:

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

where f_d, f_s and BR_d, BR_s are respectively the production fractions and the semileptonic branching ratios of the B_d^0, B_s^0 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 $\chi_B = f_d\chi_d + f_s\chi_s$. 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$\bar{\text{b}}$ sample χ_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:

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

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:

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

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 α is the charge aymmetry of the background. In the absence of charge correlations α 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 χ_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 χ_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_{t1}, p_2, p_{t2}. 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 χ_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]:

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

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

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

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 χ_d-χ_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 χ_d. The results tend to confirm the expectation of full mixing (χ_s =0.5) for the B_s^0 meson.

TABLE II - Results of the mixing analysis (values of L3 in () refer to muons).

	ALEPH		L3	
	high purity sample	full sample (fit)	high purity sample	full sample (fit)
lepton cuts (p p_t in Gev/c)	p>5 p_t >1	p>3 Prob>0.1	p>3 (4) p_t >1(1.5)	p>3 (4) no p_t cut
b->l purity	64 %	50 %	80 %	36 %
all dilepton same sign dilept " "MC (χ_B=0)	440 146 106	823 303 254	68 20 9	361 121
$10^3 \chi_B$	120 ± 30	132 ±22 $\pm^{15}_{12}$	130 ± 50	178 $\pm^{49}_{40}$ ±20

An alternative analysis to obtain the mixing parameter χ_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 dileton events.

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

$$Q_{jet} = \Sigma \, Q_i \, |p_{li}|^k \, / \Sigma \, |p_{li}|^k$$

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. $|<Q_{jet}>|$ is smaller than $|Q_{quark}|$, because of the fragmentation process.

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

$$\chi_B = 0.100 \pm 0.020 \pm^{0.014}_{0.016}$$

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 $D^* \to D^0\pi+$, with $D^0 \to \kappa{-}\pi+$ (+ 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 $M(\kappa\pi\pi)$-$M(\kappa\pi)$-ΔM where ΔM =145 Mev is the D^*-D^0 mass difference. For κ/π discrimination Opal uses the dE/dx information in a fraction of the data . The combinatorial background is reduced by requiring $|\cos\theta_\kappa^*| <0.8$ (θ_κ^* is the κ 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 ($x=E_{D^*}/E_{beam}$) 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:

$$dN/dx = BR(Z^0 \to c\bar{c})BR(c\to D^*)BR(D^* \to \kappa\pi\pi)\varepsilon(x)d_c(x) +$$

$$+ BR(Z^0 \to b\bar{b})BR(b\to D^*)BR(D^* \to \kappa\pi\pi)\varepsilon(x)d_b(x) + f_{backg}(x)$$

where the various branching ratios have been explicited and $\varepsilon(x)$ 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 ε_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 III - Fit to the x distribution for the D*

Aleph	Opal
input: (b->D*)/(c->D*)=0.95 ± 0.1	(b->D*)(D*->κππ)=(5.8 ± 1.3) 10^{-3}
(Z^0 ->c$\bar{c}$) and (Z^0 ->b$\bar{b}$) from standard model	(Z^0 ->b$\bar{b}$)/(Z^0 ->hadr)=0.215 ± 0.018

fit:
$\varepsilon_c = (48 \pm {}^{18}_{13} \pm 7) \ 10^{-3}$
 	
$<x_{D^*}> = 0.504 \pm {}^{0.013}_{0.017} \pm 0.008$
 	
(c->D*)(D*->κππ) =
    = (6.8 ± 0.4 ± 0.6) 10^{-3}
	$<x_{D^*}> = 0.52 \pm 0.03 \pm 0.01$
	
	$\dfrac{(Z^0 \to c\bar{c})}{(Z^0 \to hadr)}$(c->D*)(D*->κππ) =
	    = (1.36 ± 0.23 ± 0.15) 10^{-3}

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 $BR(Z^0 \to c\bar{c} \to D^* \to \kappa\pi\pi)$. Using from other measurements $BR(c \to D^* \to \kappa\pi\pi) = (7.3 \pm 0.6)10^{-3}$ Opal derives then the partial width of the Z^0 into $c\bar{c}$ quarks : $\Gamma(Z^0 \to c\bar{c}) = 323 \pm 61 \pm 35$ Mev in agreement with the standard model prediction of 296 ± 4 Mev.

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

Opal[12] has looked for the $J/\Psi \to \mu+\mu-$ 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/Ψ events. After background subtraction and efficiency corrections Opal gets an inclusive branching ratio: $BR(Z^0 \to J/\Psi + X) = (5.2 \pm 1.1 \pm 0.6 \pm 0.7) 10^{-3}$ where the last error reflects the error on $BR(J/\Psi \to \mu+\mu-)$. The above value can be compared with an expected value of $(3.4 \pm 0.5)10^{-3}$ which can be inferred using $BR(Z^0 \to b\bar{b})=0.151$ (standard model) and the Cleo/Argus measurements[13] $BR(B \to J/\Psi+X) = 1.12 \pm 0.18\%$ (assuming that all b-hadrons have the same branching ratio into $J/\Psi+X$).

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

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(*) *Note added in proof:* the CDF collaboration has presented at the subsequent Moriond week (17-24 March) a preliminary measurement $\chi_B = 0.176 \pm 0.028 \pm 0.041$.
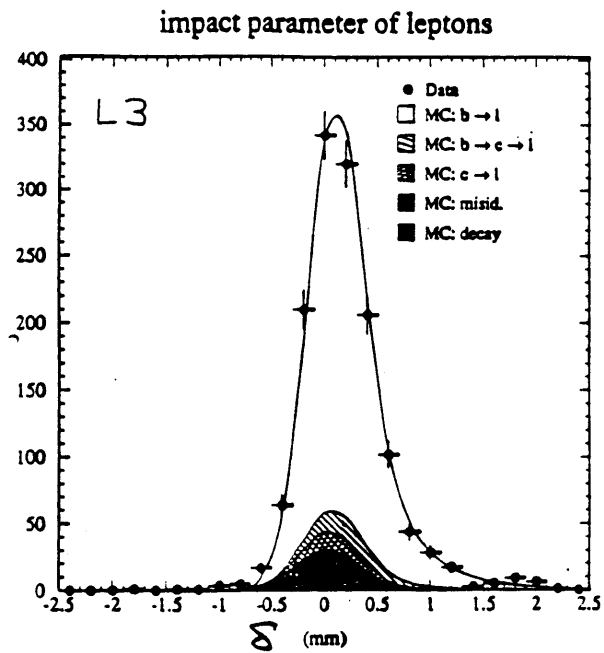
impact parameter of leptons

FIG.1 - Distribution of the lepton impact parameter. The full curves represent the fit to the various lepton sources. (Aleph)
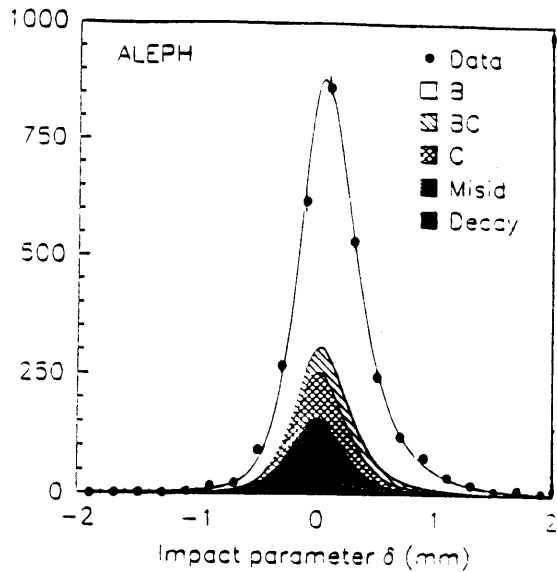

FIG. 2 - Distribution of the lepton impact parameter. The full curves represent the fit to the various lepton sources. (L3)
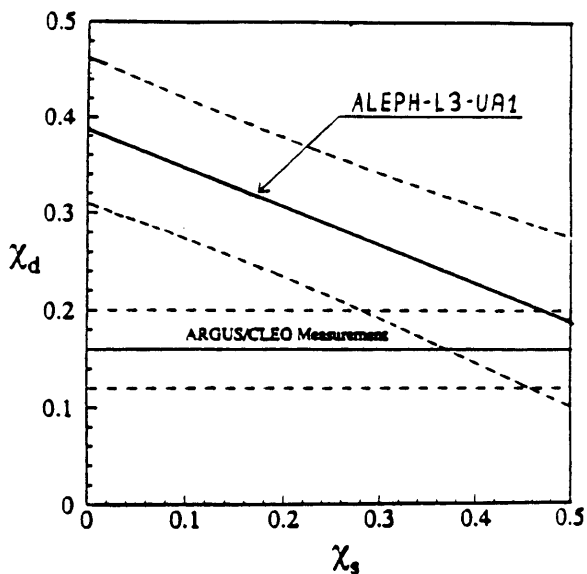

FIG. 3 - Plot of the average value of χ_B in the χ_d, χ_s plane. The measured value of χ_d by Cleo and Argus is also shown.
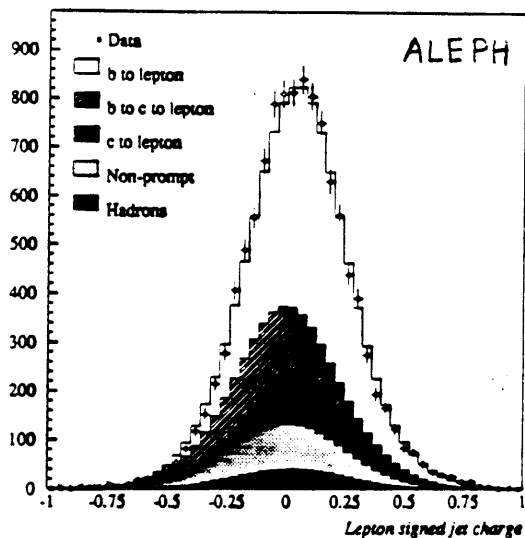
FIG. 4 - Distribution of - $Q_{jet}*Q_{lepton}$. The histograms represent the fit values for the various lepton sources. (Aleph).
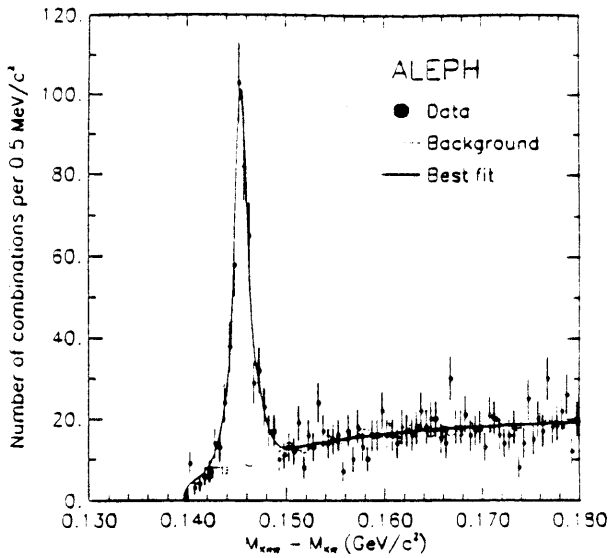
FIG. 5 - Distribution of M(κππ)-M(κπ). The κπ mass is selected between 1835-1895 Mev. The curve is a fit to the data
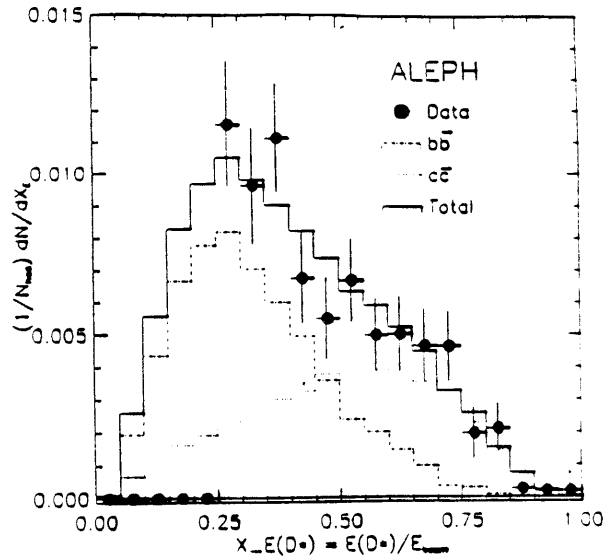

FIG. 6 - x distribution after background subtraction and acceptance corrections (Aleph).
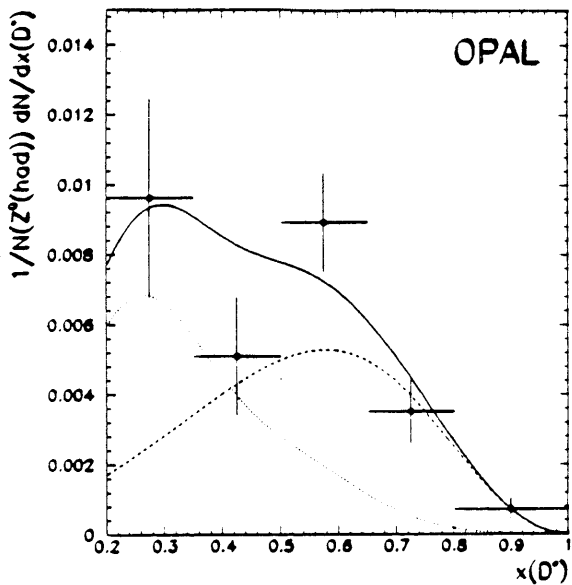

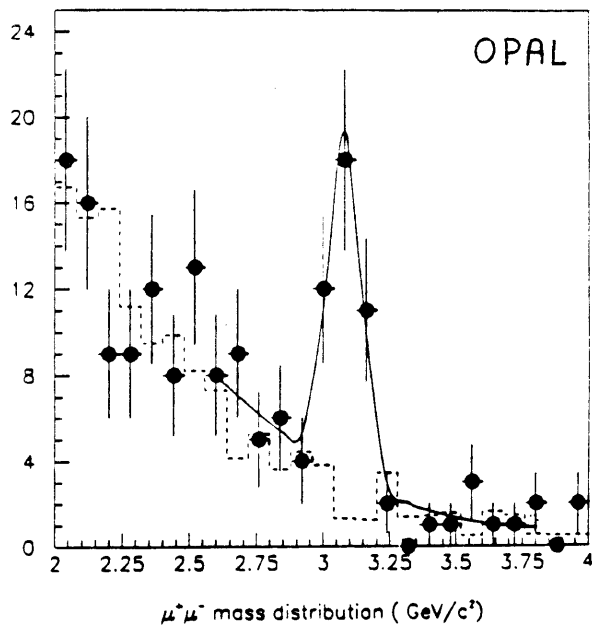**FIG. 7** - x distribution after background subtraction and acceptance corrections. (Opal)

FIG. 8 - μ+μ- invariant mass. The full curve is a fit, the histogram represents the MC prediction for the background.