

New DELPHI Results from Semileptonic b , c Decays

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The inclusive direct and cascade semileptonic branching ratios of the b quark were measured from a fit to the lepton momentum spectrum in the B -hadron rest frame, exploiting the charge correlation between the lepton and the heavy meson:

$$\begin{aligned} BR(\bar{b} \rightarrow l^+) &= 10.32 \pm 0.12(stat.) \pm 0.27(syst.)_{-0.21}^{+0.31}(model)\% \\ BR(\bar{b} \rightarrow \bar{c} \rightarrow l^-) &= 7.32 \pm 0.26(stat.) \pm 0.32(syst.)_{-0.16}^{+0.06}(model)\% \\ BR(\bar{b} \rightarrow c \rightarrow l^+) &= 0.94 \pm 0.16(stat.) \pm 0.28(syst.)_{-0.50}^{+0.33}(model)\% \end{aligned}$$

The value of the $|V_{cb}|$ element in the CKM quark mixing matrix was computed from the differential decay width of the process $B^0 \rightarrow D^{*+}l^-\nu$, measured as a function of the product ω of the B and D^* 4-velocities, using an inclusive method of D^* reconstruction:

$$|V_{cb}| = 41.70 \pm 2.35(exp.) \pm 1.38(th.) \times 10^{-3}$$

A measurement of the ratio $\frac{|V_{ub}|}{|V_{cb}|}$ has been obtained by using the reconstructed secondary hadronic mass in semileptonic decays of B hadrons, and found to be:

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.104 \pm 0.012(stat.) \pm 0.015(syst.) \pm 0.009(model)$$

The charm semileptonic branching ratio was measured using a double tag method based on the detection of exclusively reconstructed D mesons accompanied by a lepton in the opposite hemisphere, giving:

$$BR(c \rightarrow l) = (9.58 \pm 0.42(stat.) \pm 0.28(syst.))\%$$

I. SEMILEPTONIC BRANCHING RATIOS IN B DECAYS

Leptons in b -hadron decays can be produced both from direct $\bar{b} \rightarrow l^+$ and cascade $\bar{b} \rightarrow \bar{c} \rightarrow l^-$ decays which can be separated exploiting the correlation between the lepton charge and the b -hadron flavour. The wrong sign charm decay $\bar{b} \rightarrow c \rightarrow l^+$, can be isolated from the direct decay by the low momentum signature of the leptons; the present analysis gives the first direct measurement of $BR(\bar{b} \rightarrow c \rightarrow l^+)$.

From about 1.4 million hadronic Z^0 decays collected during 1994, a $b\bar{b}$ event sample was selected with efficiency $\epsilon^b \sim 50\%$ and purity $Pur^b \sim 95\%$ by means of the impact parameter, energy and angular distributions of the reconstructed charged tracks.

An inclusive B reconstruction was performed from the high rapidity particles in the jet and a secondary vertex was fitted; the energy and angular resolutions were $\sigma(E_B) \sim 7\%$ and $\sigma(\theta_B) \sim 0.8^\circ$ respectively. The charge of the B hadron was determined as $Q_B = \sum Q^i \cdot Pr_b^i$ where Q^i is the charge of the i^{th} track and Pr_b^i is the probability for the track to come from B decay, computed using a neural network in terms of kinematical and topological variables.

A second neural network was used in order to determine the b -hadron flavour, exploiting the charge of identified K and slow pions from D^* decay, the jet charge and Q_B . A flavour discrimination $Pur(b \leftrightarrow \bar{b}) \sim 85\%$ was obtained with an efficiency $\epsilon(b \leftrightarrow \bar{b}) \sim 45\%$.

The lepton energy in the b -hadron rest frame k_l^* was computed from the B and the lepton 4-momenta with a resolution $\sigma(k_l^*) \sim 0.1 GeV/c$. The background due to non b -events, fake b -hadrons and fake leptons was determined from the simulation and subtracted from the experimental k_l^* distribution. From a fit to $\frac{dN}{dk_l^*}$ the following preliminary results were obtained:

$$\begin{aligned} BR(\bar{b} \rightarrow l^+) &= 10.32 \pm 0.12(stat.) \pm 0.27(syst.)_{-0.21}^{+0.31}(model)\% \\ BR(\bar{b} \rightarrow \bar{c} \rightarrow l^-) &= 7.32 \pm 0.26(stat.) \pm 0.32(syst.)_{-0.16}^{+0.06}(model)\% \\ BR(\bar{b} \rightarrow c \rightarrow l^+) &= 0.94 \pm 0.16(stat.) \pm 0.28(syst.)_{-0.50}^{+0.33}(model)\% \end{aligned}$$

The dominant systematics came from the lepton identification, the neural networks performances and the heavy flavour semileptonic decay models. Figure 1 shows the results of the fit for the same and opposite sign (B, l) charge correlation samples obtained using the ACCM model.

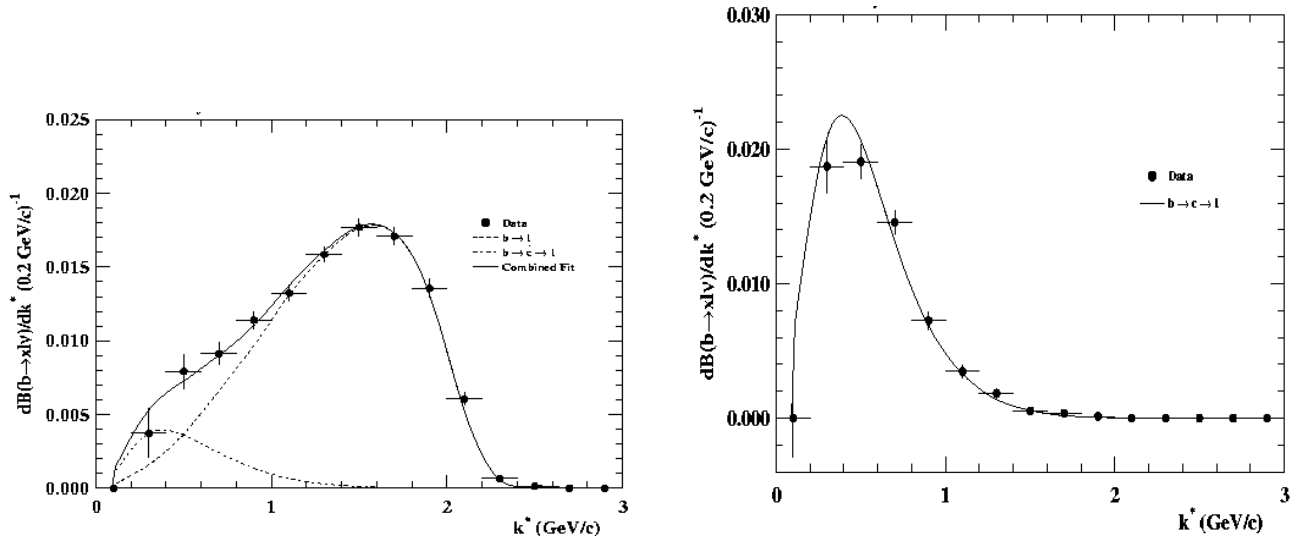


FIG. 1. Fitted k_l^* spectrum in B semileptonic decays. Left: same sign (B, l), Right: opposite sign (B, l).

II. $|V_{CB}|$ MEASUREMENT

The Heavy Quark Effective Theory [1] allows a precise determination of $|V_{cb}|$, the element of the CKM mixing matrix relating the b and the c quarks, from the analysis of the semileptonic decay $\bar{B}^0 \rightarrow D^{*+} l^- \bar{\nu}$. The following relation holds:

$$\frac{d\Gamma}{d\omega} = \frac{1}{\tau_B} \cdot \frac{d\mathcal{B}r}{d\omega} \propto G(\omega) \times A_1^2(\omega) \times |V_{cb}|^2 \quad (1)$$

where $\omega = v_B \cdot v_{D^*}$ is the product of the two heavy mesons 4-velocities and is related to the momentum transfer: $q^2 = (P_{\bar{B}^0} - P_{D^{*+}})^2 = M_{\bar{B}^0}^2 + M_{D^{*+}}^2 - 2M_{\bar{B}^0}M_{D^{*+}}\omega$.

$G(\omega)$ is a phase space function and $A_1(\omega)$ is a model dependent form factor, which can be expressed in terms of a single unknown parameter $\rho_{A_1}^2$ [2]:

$$A_1(\omega) = A_1(1) \times \mathcal{F}(\rho_{A_1}^2) \quad (2)$$

In the limit in which the D^* meson is produced at rest in the B reference frame ($\omega = 1 \leftrightarrow q^2 = 10.7 \text{ GeV}^2/c^4$), the theory predicts [3]

$$A_1(1) \approx 0.91 \pm 0.03 \quad (3)$$

Experimentally, the goal is to measure $\frac{d\Gamma}{d\omega}$ at the point of zero recoil $\omega = 1$. Due to the vanishing of phase space, the product $A_1(1) \cdot |V_{cb}|$ was determined by an extrapolation from the $\frac{dN}{d\omega}$ distribution.

The data collected from 1992 to 1995 were used in the analysis. D^0 mesons were inclusively reconstructed from all the particles in the lepton jet, by means of their rapidity and impact parameter. Pions with charge opposite to the lepton were then added to build a D^* , and events finally tagged based on the mass difference $M_{D^0\pi} - M_{D^0} < 0.165 \text{ GeV}/c^2$.

The combinatorial background shape was estimated from the (D^*, l) sample with the wrong charge correlation. A signal sample of $N_{D^{**}} = 7075 + 164$ events was found with a selection efficiency $\epsilon = (14.7 \pm 0.1)\%$. Figure 2 shows the ω distribution for the final sample.

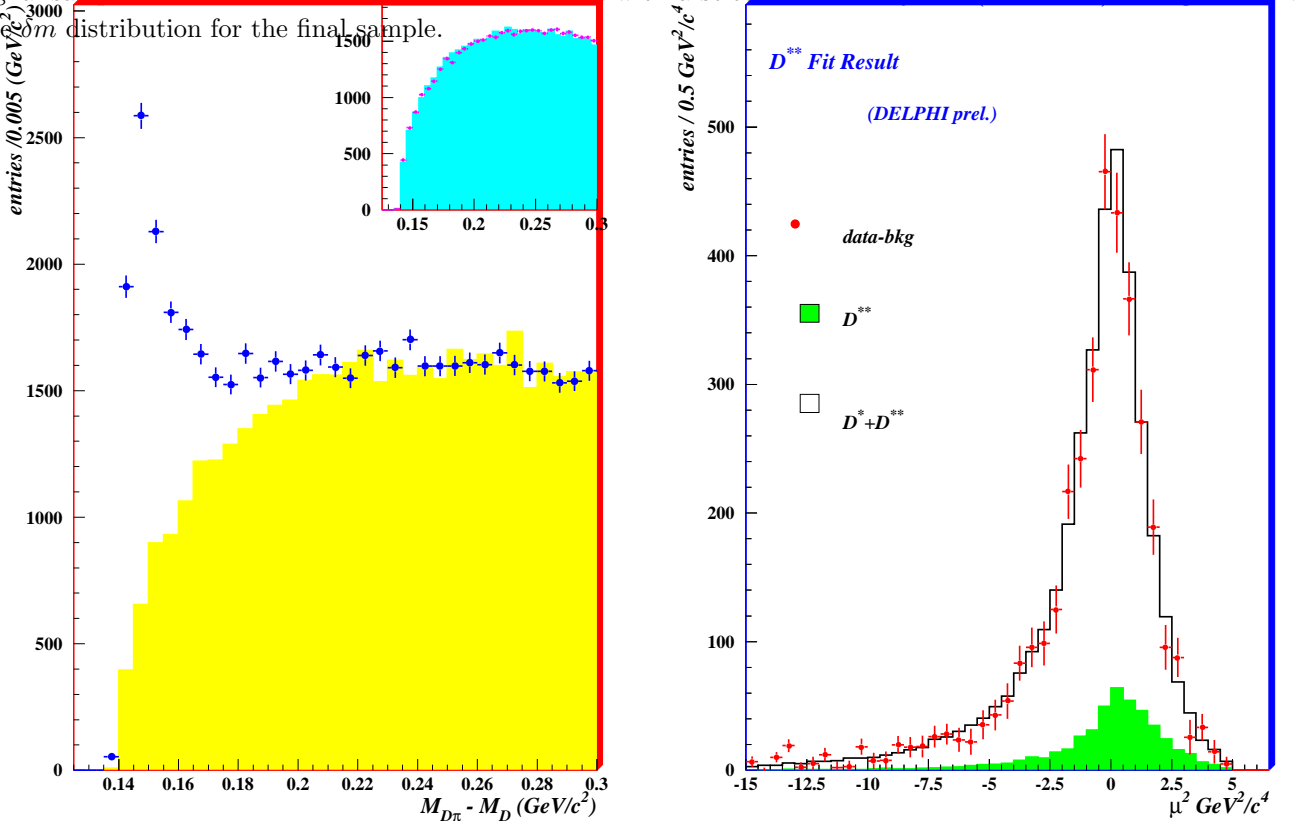


FIG. 2. Left: Mass difference $M_{D^{0}\pi} - M_{D^0}$. Right charge (crosses), wrong charge (shaded area), normalised in the side band. Box: simulation: combinatorial from right charge (crosses), compared to wrong charge sample; Right: fit to the μ^2 distribution for the determination of the D^{**} contamination.

The 4-momentum of the B was obtained from energy and momentum conservation and from the secondary vertex reconstruction; the energy and angular resolutions were $\sigma(E_{B^0}) \sim 10\%$ and $\sigma(\theta_{B^0}) \sim \sigma(\phi_{B^0}) \sim 1^\circ$ respectively. The dominant physics background was due to the semileptonic decays $B \rightarrow D^{**}l\nu$, $D^{**} \rightarrow D^*X$. Signal events can be distinguished from the cascade ones exploiting the Squared Recoil Mass $\mu^2 = (P_{B^0} - (P_{D^*} + P_l))^2 \equiv M_\nu^2$ which should be zero for signal events, whereas is usually greater than zero in case of background processes due to additional particles produced in the D^{**} decay. From a fit to the μ^2 distribution with the $\mu^2(D^{**})$ shape fixed to HQET prediction [4], the ratio

$$R^{**} = \frac{BR(b \rightarrow D^{**}l\nu)}{BR(b \rightarrow D^{**}l\nu) + BR(B^0 \rightarrow D^* + l\nu)} = 0.18 \pm 0.11(stat.) \pm 0.05(syst.)$$

was determined. Figure 2 shows the result of the fit.

From the comparison of the ω distribution with the model function 1, taking into account the experimental resolution and using the result 3, the values:

$$|V_{cb}| = (41.70 \pm 2.35(exp.) \pm 1.38(th.)) \times 10^{-3}$$

$$\rho_{A_1}^2 = 1.39 \pm 0.13(stat.) \pm 0.18(syst.)$$

were obtained, where the dominant systematics come from $BR(b \rightarrow \bar{B}^0)$, $\tau_{\bar{B}^0}$, $BR(D^* \rightarrow D^0\pi)$, the experimental resolution and the D^{**} fraction and decay models. Figure 3 show the result of the fit together with the $\frac{d\Gamma}{d\omega}$ and the decay form factor unfolded distributions.

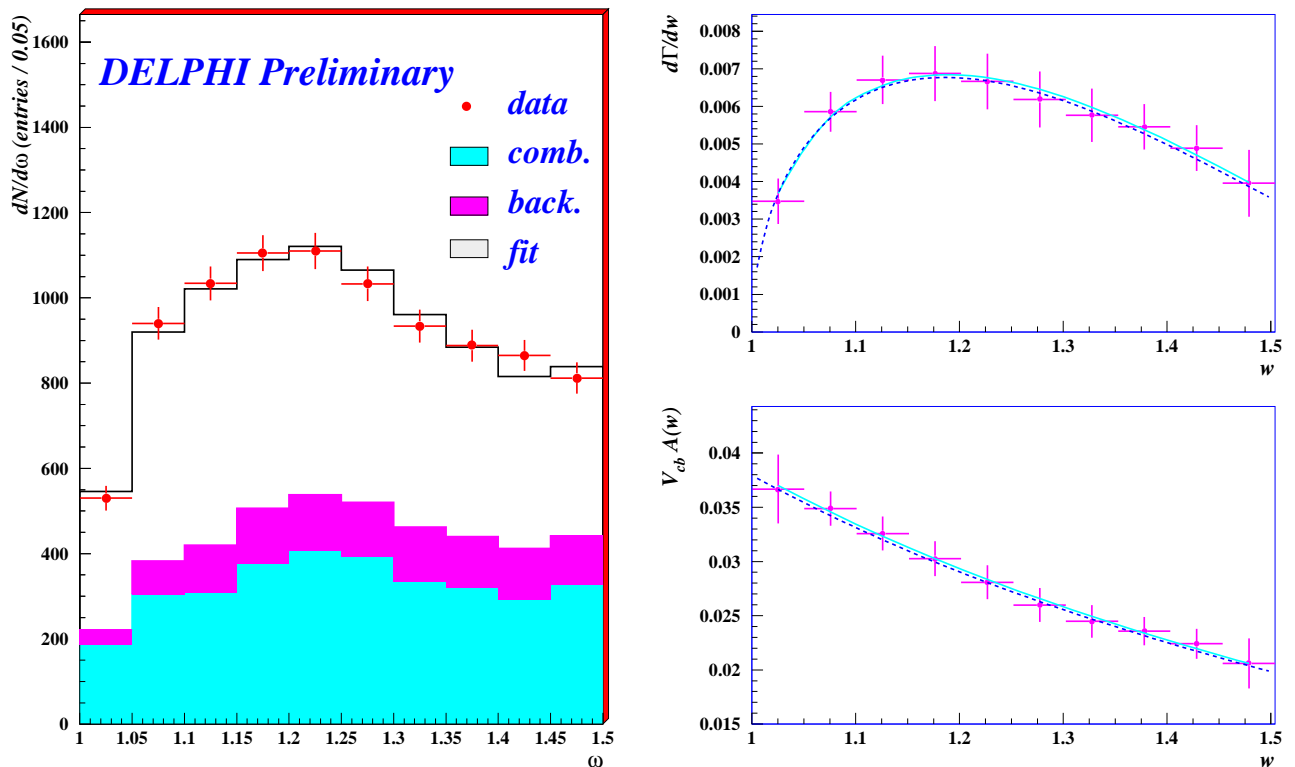


FIG. 3. Left: fit to the ω distribution; Upper Right: unfolded differential decay width. Lower Right: unfolded decay form factor.

III. $\frac{|V_{ub}|}{|V_{cb}|}$ FROM THE HADRONIC RECOIL MASS SPECTRUM IN B SEMILEPTONIC DECAYS

The measurement of the branching ratio for the decay $b \rightarrow ul\nu$ provides the most precise way to determine the $|V_{ub}|$ element of the CKM mixing matrix. Evidence of the non-zero value of $|V_{ub}|$ has been obtained both by observing leptons produced in B decays with momentum above the charm kinematic threshold [5] and by the measurement of the charmless exclusive decays $B \rightarrow \pi l\nu$, $\rho l\nu$ [6]. These analyses were dominated by the theoretical error due respectively to the model dependence in the extrapolation to low lepton momentum and to the uncertainty on the hadronic matrix elements.

According to HQET predictions at $O(1/m_b^3)$ [7], $|V_{ub}|$ can be extracted from the inclusive width $\Gamma(B \rightarrow X_u l\nu)$ with a theoretical error $\delta(V_{ub})_{th} \sim 4\%$, dominated by the uncertainties on the mass of the b quark and α_s . Experimentally, a way to discriminate between the signal events and the dominant background due to the decay $B \rightarrow X_c l\nu$ is provided by the Hadronic Recoil Mass M_X which extends to higher values for the charmed final states with respect to the charmless ones [8]. According to recent calculations [9], the signal region can be defined by the cut $M_X < 1.6 \text{ GeV}/c^2$ which represents a good compromise between a reasonable high $b \rightarrow cl\nu$ rejection and a little model dependence in the calculation of the efficiency for the signal events ($\delta\epsilon(b \rightarrow ul\nu) \sim 10\%$).

From the data collected between 1993 and 1995, a $b\bar{b}$ enriched sample was selected with purity $Pur^b \sim 65\%$ and efficiency $\epsilon^b \sim 85\%$. The Hadronic Secondary System was then reconstructed with an efficiency of about 75% from all the tracks classified as coming from B decays by means of kinematical and topological variables. The background from $b \rightarrow cl\nu$ was depleted according to the lepton impact parameter w.r.t the secondary vertex, K identification and D^* inclusive reconstruction. The lepton energy in the B rest frame was computed with a resolution $\sigma(E_l^*) \sim 14\%$.

In the $b \rightarrow u$ enriched sample, an excess of $N_{b \rightarrow ul\nu} = 205 \pm 56$ events was found in the data compared to the expected background; the selection efficiency for signal events was $\epsilon \sim 11\%$. Figure 4 shows the E_l^* distribution after the background subtraction for the $b \rightarrow u$ enriched and depleted samples. The fraction of $b \rightarrow ul\nu$ events in the selected sample is proportional to the ratio $\frac{|V_{ub}|}{|V_{cb}|}$. From a fit to the E_l^* distribution the preliminary value:

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.104 \pm 0.012(stat.) \pm 0.015(syst.) \pm 0.009(model)$$

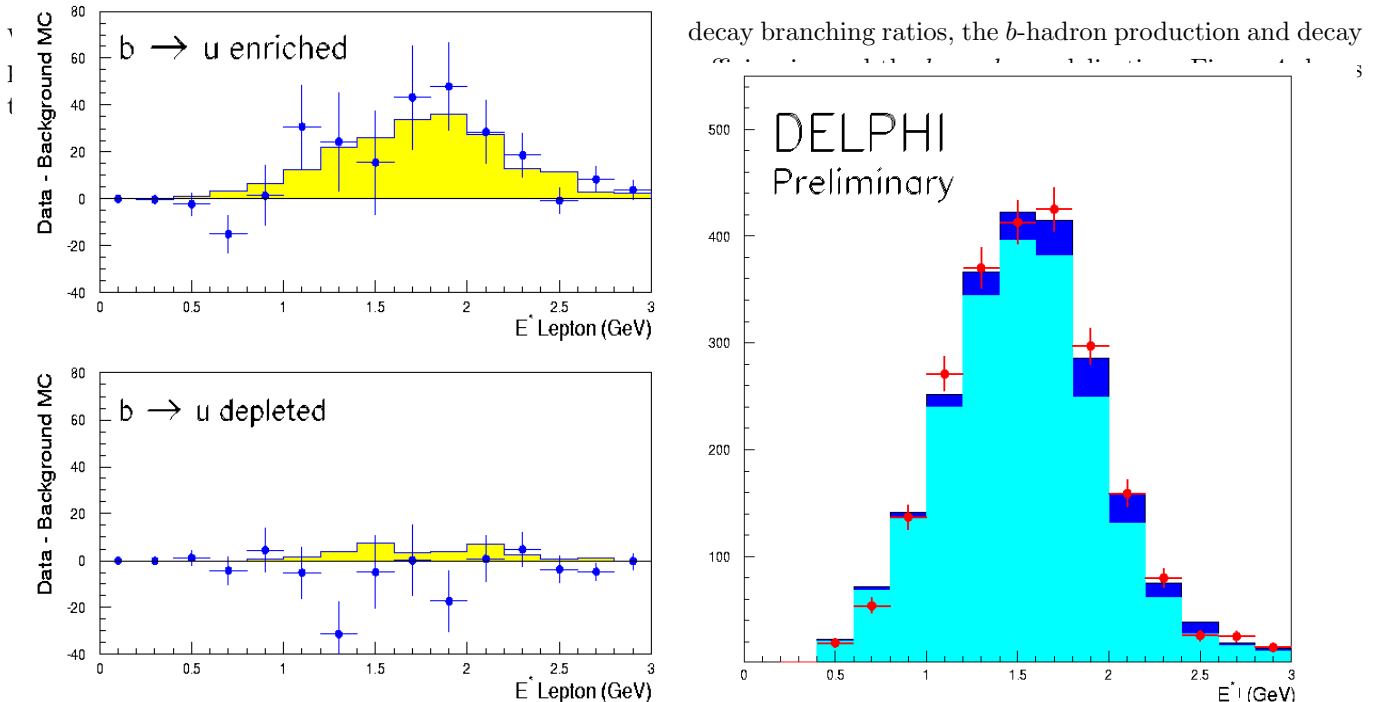


FIG. 4. Left: background subtracted E_l^* distributions ($M_X < 1.6 \text{ GeV}/c^2$) for the enriched (upper plot) and depleted (lower plot) $b \rightarrow ul\nu$ samples; Right: fit to the E_l^* distribution; the dark area shows the $b \rightarrow ul\nu$ fitted sample.

IV. CHARM SEMILEPTONIC BRANCHING RATIO

The semileptonic branching fraction of the c quark was determined with a rather large error in low energy experiments [10]. The measurement of this quantity at a different energy scale is of great interest due to its correlation with the mixture of charmed hadrons in the final state; a recent OPAL measurement [11] shows excellent agreement with the low energy results. At LEP the uncertainty on the average from the low energy experiments $BR(c \rightarrow l) = 9.8 \pm 0.5\%$ is an important source of systematic error for a number of measurements based on lepton tag analyses.

From an anti- b tagged sample of hadronic Z^0 decays collected between 1992 and 1995, $c\bar{c}$ events were selected by means of an exclusive D^* , D^0 and D^+ reconstruction in several channels. Charm enrichment was obtained by cutting on the fraction X_E of the beam energy retained by the D mesons. A total of $N_D = 21898 \pm 216$ charmed mesons were reconstructed with a purity $f_c = 80.9 \pm 1.1\%$. Figure 5 shows the reconstructed D meson spectra for the different channels.

The branching fraction $BR(c \rightarrow l)$ was obtained from the amount N^l of the identified leptons with $P > 2 \text{ GeV}/c$ in the hemisphere opposite to the reconstructed D meson and with the right charge correlation:

$$N^l = N_c^{true} + N_b^{true} h_b^{true} + N_c^{bkg} h_c^{bkg} + N_b^{bkg} h_b^{bkg}.$$

In the previous expression N_c^{true} is the number of the true leptons coming from c decays, either directly produced in $Z^0 \rightarrow c\bar{c}$ events or originating from the gluon splitting process $g \rightarrow c\bar{c}$ in $Z^0 \rightarrow q\bar{q}$ ($q = b, c$). N_b^{true} accounts for the true leptons from b semileptonic decays and was computed in terms of the b semileptonic branching fractions and the effective mixing which destroys the charge correlation between the lepton and the D meson. $N_{c,b}^{bkg}$ is the sum of the contributions due to fake leptons and true leptons from light particle decays in c, b events. Small corrections h due to hard gluon radiation were obtained from the simulation.

The lepton efficiencies were computed from the simulation tuned to reproduce the data, taking into account the detector acceptances and found to be: $\epsilon^e = (51.4 \pm 1.3)\%$ and $\epsilon^\mu = (60.8 \pm 1.3)\%$ for electrons and muons respectively. The number $N_{c,b}^{bkg}$ of background leptons was determined from the observed multiplicity of charged particles in the lepton hemisphere and the misidentification probabilities $f_{fake}^e = (0.52 \pm 0.03)\%$ and $f_{fake}^\mu = (0.63 \pm 0.03)\%$.

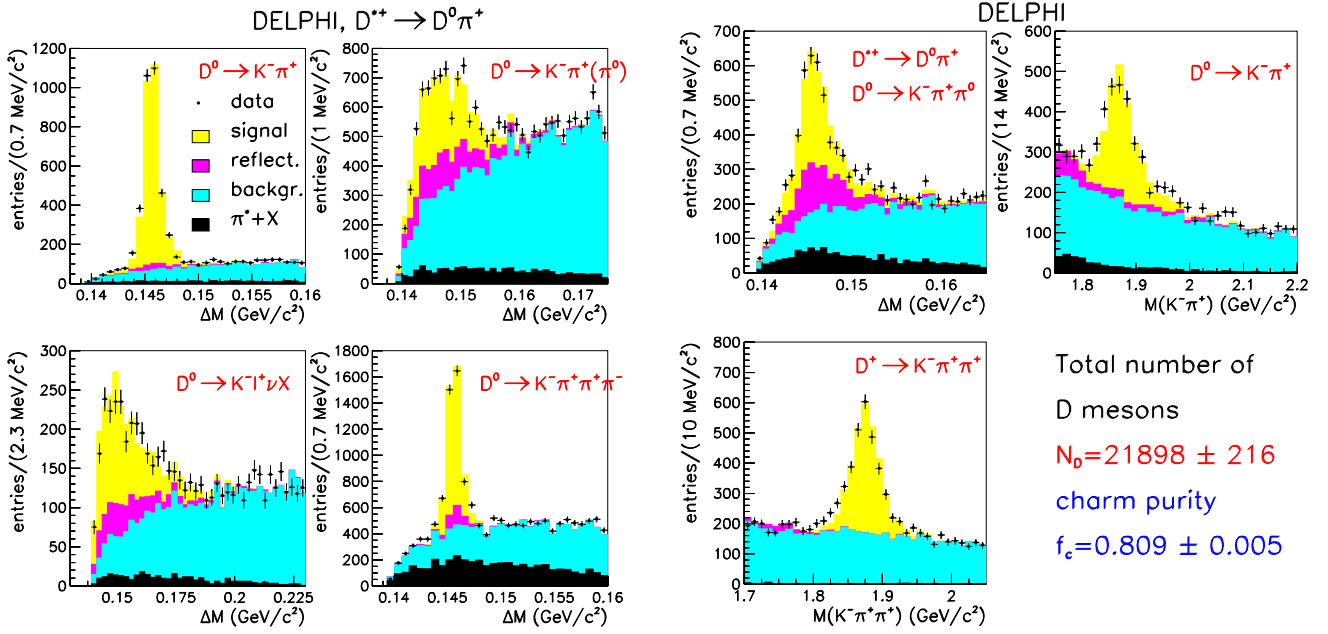


FIG. 5. ΔM (invariant mass) distribution for the D^* (D^0, D^+) candidate decays in the different channels with the various contributions predicted by the simulation.

The fraction of leptons from the decays of b and c hadrons surviving the momentum cut was obtained reweighting the simulation in order to reproduce the experimental values for $X_E(B) = 0.702 \pm 0.008$ and $X_E(D) = 0.484 \pm 0.008$. Different semileptonic decay models were considered according to the results reported by the LEP Heavy Flavour Working Group [12]. After the background subtraction a yield of $N_c^{true} = 1187 \pm 51$ leptons from c semileptonic decays was found. From the ratio $\frac{N_c^{true}}{N_D}$ the $BR(c \rightarrow l)$ was obtained to be:

$$BR(c \rightarrow l) = (9.58 \pm 0.42(stat.) \pm 0.28(syst.))\%$$

where the dominant systematics came from the lepton identification and the c decay models. Figure 6 shows the momentum and transvers momentum spectra for the selected leptons. Figure 7 shows the comparison of the measured P^t lepton spectrum with the predictions from the ACCORD model with different values of the parameters used to fit DELCO and MARK III data [13].

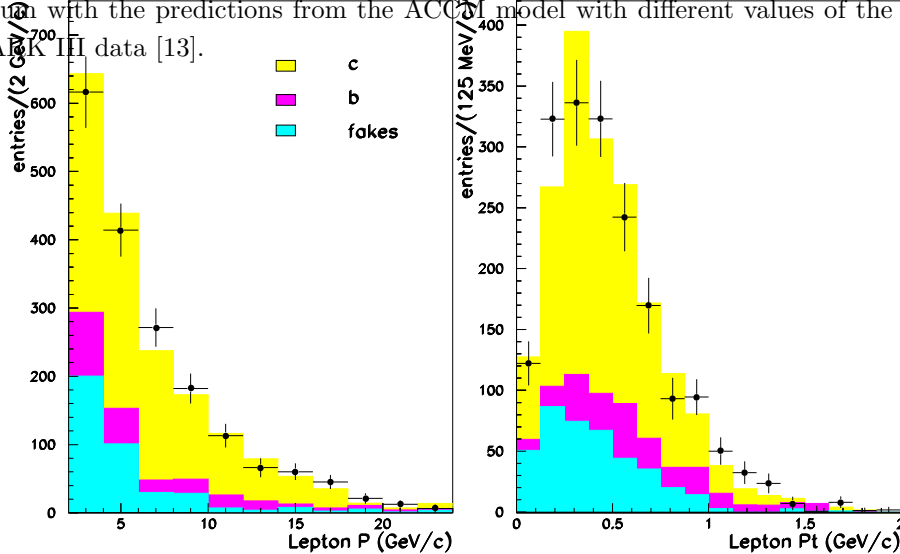


FIG. 6. P and P^t lepton candidates spectra.

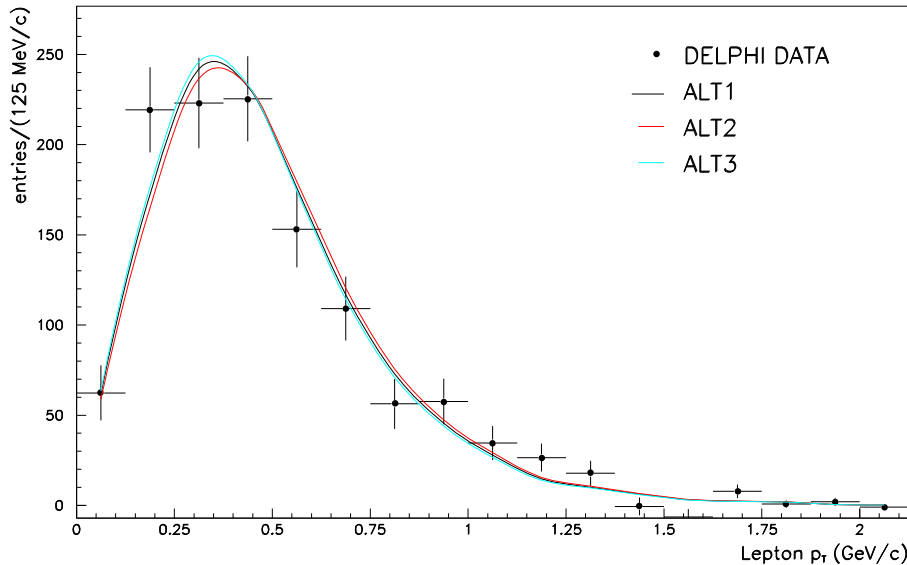


FIG. 7. Reconstructed P^+ lepton spectrum from charm decay compared with the predictions from the ACCM model. Labels ALT1, ALT2, ALT3 refer to different values for the strange quark mass and the Fermi momentum according to [13]

V. ACKNOWLEDGMENTS

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