ICHEP'96 Ref. pa01-063
Submitted to Pa 1, Pa 5, Pa 7
Pl 1, Pl 7, Pl 9

DELPHI 96-106 CONF 33
25 June, 1996

Determination of $P(c \to D^{*+})$ and $BR(c \to l)$ at LEP

Preliminary

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Abstract

The probability that a charm quark from direct Z^0 decay into $c\bar{c}$ fragment in a D^* meson, $P(c \to D^{*+})$, and the $c \to l$ semi-leptonic branching fraction were measured using a double tag method based on the detection of exclusively reconstructed D mesons accompanied by a slow pion or a lepton in the opposite hemisphere.

From the analysis of ~3.8 Million Z^0 events collected in 1991-95 runs, a sample of (4868 ± 102) D^* decays with high charm purity was selected. In this sample, a signal of (517 ± 41) low momentum pions originating from a second D^* decay in the opposite hemisphere was observed. The product of the $c \to D^{*+}$ fragmentation probability times the $D^{*+} \to D^0\pi^+$ branching fraction was measured to be :

$$P(c \to D^{*+}) \cdot BR(D^{*+} \to D^0\pi^+) = 0.169 \pm 0.014(stat) \pm 0.012(syst)$$

Using the world averaged value: $BR(D^* \to D^0\pi) = 0.681 \pm 0.013$, the fragmentation probability was determined to be :

$$P(c \to D^{*+}) = 0.248 \pm 0.020(stat) \pm 0.018(syst)$$

Using the same D^* sample in the data collected in the '91-'94 runs and an independent sample of 960 ± 53 fully reconstructed $D^0 \to K\pi$ decays ($(75 \pm 3)\%$ produced in $c\bar{c}$ events), a sample of 248 ± 21 identified leptons opposite to the reconstructed D mesons was selected. From this sample the charm semi-leptonic branching ratio was measured to be :

$$BR(c \to l) = 0.098 \pm 0.010(stat) \pm 0.006(syst)$$

1 Introduction

The measurement of the probability $P(c \rightarrow D^*)$ for a charm-quark produced in Z^0 decays to fragment in a D^* meson is of great interest, since it is an important quantity for the determination of the charm partial width of the Z^0 boson, $R_c = \Gamma_c/\Gamma_h$. The current experimental uncertainty on R_c dominates the systematic error in the $R_b = \Gamma_b/\Gamma_h$ measurement [1].

A recent measurement by the DELPHI experiment was based on a double tagging method [2], relying on the detection of a pair of low momentum pions in opposite hemispheres, supposed to originate from $D^* \rightarrow D^0\pi$ decays. This inclusive method provides a large sample of double D^* events, which allows the determination of physical quantities like R_c and $P(c \rightarrow D^*)$. However the background level in the sample is large, and the subtraction procedure to extract and fit the charm signal introduces important contributions to the systematic error.

In this note a complementary method is presented, based on the exclusive reconstruction of a D^* correlated to a low momentum, oppositely charged pion in the hemisphere opposite to the reconstructed D^*. This method, pioneered by the OPAL experiment [3], substantially reduces the non-charm background, although at the price of a large reduction of the available statistics.

The same D^* sample and an independent sample of D^0 meson (not coming from D^* decays) was used to determine the charm semi-leptonic branching fraction, by measuring the yield of leptons in the hemispere opposite to the D meson. This branching fraction is measured with rather large errors in low energy experiments [4]. Its uncertainty is an important source of systematic error for the Γ_b measurement using b semi-leptonic decays [1] and for the study of B^0 oscillation based on the lepton-jet charge correlation [5].

2 Exclusive D^* selection

Charged D^* mesons were reconstructed through their $D^{*+} \rightarrow D^0\pi^+$ decay (charged conjugate states are always implied throughout this paper), with the D^0 meson fully reconstructed in the channels $D^0 \rightarrow K\pi, K3\pi, K^0\pi\pi$ or partially reconstructed using the decay channels $D^0 \rightarrow Kl\nu X$ and $D^0 \rightarrow K\pi X$.

To reduce the combinatorial background and to enrich the D^* signal sample of mesons coming from the c-quark fragmentation, D^* candidates with $X_E = E(D^*)/E_{beam} > 0.30$ (0.25 for the $K\pi$ and $K^0 2\pi$ channels) and pion momentum greater than 1 GeV/c were selected. The momenta of all the D^0 decay products must be greater than 1 GeV/c. The D^0 decay length projected onto the plane transverse to the beam direction was required to be greater than the error on the vertex position. The D^0 flight direction must be compatible within 5^0 with the direction of the reconstructed D^0 momentum. The pion track candidates were required to be incompatible with the kaon hypothesis according to the RICH identification [6]. In addition, the charged kaon candidate must have the lowest energy loss in the TPC among all the charged tracks of the secondary vertex or had to be identified as kaon by the RICH.

In all the considered D^0 decay channels except the $D^0 \rightarrow K\pi$ one, χ^2 probability of the the vertex fit was required to be bigger than 0.001. Finally, the following cuts were applied to the invariant mass of the charged track system :

- $D^0 K\pi$ channel: $1.80 < M(K\pi) < 1.92\ GeV/c^2$;
- $D^0 K\pi(n\pi^0)$ channel: $1.40 < M(K\pi) < 1.70\ GeV/c^2$;
- $D^0 K3\pi$ channel: $1.83 < M(K3\pi) < 1.90\ GeV/c^2$;
- $D^0 Kl\nu X$ channel: $1.30 < M(\pi\pi) < 1.70\ GeV/c^2$;
- $D^0 K^0 2\pi$ channel: $1.80 < M(K^0 2\pi) < 1.92\ GeV/c^2$.

The distributions of the mass difference $\Delta M = M(D^0\pi) - M(D^0)$ for the selected candidates in the five D^0 decay modes considered are shown in Figs.1b-f respectively. In the first four channels, the background distribution obtained in the data by considering the 'wrong-sign' D^* combinations (i.e. $D^0\pi$ pairs with the pion having the same charge as the charged kaon candidate in the D^0 decay) is also shown (dashed-line histogram). The background-subtracted distribution of the energy (normalized to the beam energy) of D^* candidates with ΔM within the ranges shown by the arrows in Fig.1 (referred as 'ΔM signal range' in the following) is shown in Fig.1a and compared with the simulation prediction for the $Z \to q\bar{q}$ hadronic channels ($q = c, b$ and uds). In the simulation, the value $r = R_b \cdot P(b \to D^*)/R_c \cdot P(c \to D^*) = 1.12$ was assumed for the D^* meson production in Z^0 hadronic decays.

The simulation predicts a non-negligible contribution of D^* coming from $b\bar{b}$ events in the selected sample. To reduce this contribution, an anti-b tag selection was applied, based on the event probability P_{btag} defined by the b-tagging algorithm used in the R_b measurement [7]. The distribution of this probability for the events with a reconstructed D^* candidates with ΔM in the signal range is shown in Fig.2. A final sample of events enriched in D^* mesons originating from c-quark fragmentation was selected imposing the cut $P_{btag} > 0.001$. In this preliminary analysis, this cut was not applied to the 1995 data. The resulting ΔM distributions are shown in Figs.3a-e. The corresponding background subtracted distributions are shown in Figs.4a-e and compared with the distribution predicted by the simulation (normalized to the total number of signal events in each channel) from genuine D^* particles originated from $b\bar{b}$ and $c\bar{c}$ events. The background subtraction in the first four channels was done using the wrong sign D^* combinations; in the $D^0 \to K^0 2\pi$ channel the background was estimated using the simulation. The number of signal events for each D^0 channel and the fraction f_c of the D^* signal coming from the $c\bar{c}$ final state as predicted by the simulation are reported in Table 1. The error on the number of signal events includes the statistical error from the background subtraction procedure. The total number of reconstructed D^* was $N_{D^*} = 4868 \pm 102$. The fractions f_c were computed from the equation : $f_c = 1/(1 + r \cdot r_\epsilon)$, where $r_\epsilon = \epsilon_b/\epsilon_c$(=0.41, averaged on all the considered channels) is the simulation prediction for the ratio between the overall reconstruction and selection efficiencies for D^* from b and c decays. The error on the fractions f_c includes the statistical error of the simulation sample and the systematic error originating from the uncertainties on the charm and beauty relative productions and decay properties. In the f_c computation, the prediction of the simulation for this quantity was corrected using the experimental value $r = R_b \cdot P(b \to D^*)/R_c \cdot P(c \to D^*) = 1.225 \pm 0.09$ [8].

3 Measurement of $P(c \to D^{*+})$

3.1 Slow π selection

The search of a slow pion originating from the decay of a second D^* in the event, named π^* in the following, was performed using all the charged tracks with momenta $1.0 < p <$

Table 1: Number of D^* decays in the selected samples and corresponding fractions f_c of the D^* signal coming from $c\bar{c}$ events predicted by the simulation.

D^0 channel	Nr.of signal events	f_c
$D^0 \to K\pi$	1283 ± 41	0.67 ± 0.02
$D^0 \to K\pi(\pi^0)$	1959 ± 75	0.74 ± 0.02
$D^0 \to Kl\nu X$	738 ± 37	0.77 ± 0.02
$D^0 \to K3\pi$	708 ± 36	0.68 ± 0.02
$D^0 \to K^0 2\pi$	180 ± 22	0.60 ± 0.04
All channels	4868 ± 102	0.69 ± 0.02

$3.5 GeV/c$ in the hemisphere opposite to the one of the reconstructed D^*.

Jets in the event were defined by the LUCLUS algorithm with default parameters. The direction of the jet to which the candidate π^* belongs was defined excluding the π^* from the jet and following the same iterative procedure used in the DELPHI double pion tagging method [2] mentioned in Sect.1. The transverse momentum p_T^2 of the pion candidate was computed w.r.t. this jet direction. The resulting p_T^2 distribution is shown in Figs.5a,b and compared with the simulation prediction for pions with opposite charge and same charge as the reconstructed D^* respectively. A clear excess of tracks in the region $p_T^2 < 0.01(GeV/c)^2$ is present in opposite charge $D^*\pi$ pairs (referred as 'signal sample' in the following) w.r.t. the same charge combinations. The shaded and double shaded histograms show the simulation prediction for π^* originating from D^* decays in $b\bar{b}$ and $c\bar{c}$ events respectively.

The background distribution was parametrised by the function :

$$f(p_T^2) = A/(B \cdot p_T^2 + 1.) \qquad (1)$$

and the A and B parameters were fitted from the p_T^2 distribution of the 'background sample' defined by the same charge $D^*\pi$ pairs (Fig.5b) and the $D^*\pi$ combinations (both of same and opposite charge) in which the D^* candidate had the wrong sign (dashed-line histograms in Figs.3a-d). The simulation shows that both in the signal and background samples, a small amount of π^* from D^* decays in the low p_T region ($p_T^2 < 0.01$) is associated to reconstructed fake vertices in the opposite hemisphere. This signal is shown for the same sign $D^*\pi$ sample by the shaded area in Fig.5b. For this reason the fit to the background shape was limited to the region $p_T^2 > 0.006$ and the effect of the presence of this additional D^* signal was taken into account as will be discussed in the next section.

The p_T^2 distribution of the π^* signal was studied on the data and in the simulation using the pions from the fully reconstructed D^* decays, referred as 'exclusive sample' in the following. The same algorithm used to define the direction of the jet to which the π^* belongs was applied to the jet containing the reconstructed D^*. The resulting p_T^2 distribution of the pion from the reconstructed D^* candidate, after the background subtraction performed using the wrong sign D^*, is shown for real (points) and simulated data (histogram) in Fig.6. A three parameter fit to the data using a 'signal function' defined by the sum of two exponential functions gave the two slopes : $p_{T1} = (0.0021 \pm 0.0002)(GeV/c)^2$ and $p_{T2} = (0.0095 \pm 0.0008)(GeV/c)^2$, with the first component accounting for a fraction $f_1 = 0.70 \pm 0.02$ of the total signal. The result of the fit is shown by the full line in Fig.6. The same fit to the simulated data gave $p_{T1} = (0.0024 \pm 0.0002)(GeV/c)^2$, $p_{T2} = (0.0112 \pm 0.0008)(GeV/c)^2$ and $f_1 = 0.75 \pm 0.02$, in fair agreement with real data. The p_T^2 distribution of the π^* originating from a D^* not fully reconstructed, referred as 'inclusive sample' in the following, is predicted by the simulation to be broader than the distribution observed in the exclusive D^* sample. This is because the jet direction is better defined when the D^o is fully reconstructed in the detector. The p_T^2 slopes in the simulation were in this case $p_{T1} = (0.0030 \pm 0.0003)(GeV/c)^2$ and $p_{T1} = (0.0128 \pm 0.0020)(GeV/c)^2$, with a fraction $f_1 = 0.69 \pm 0.04$.

To determine the number of events with two D^* decays in the sample, the p_T^2 distribution of the signal sample (Fig.5a) was fitted using the signal function superimposed to the function describing the background, with the number of π^* left as single free parameter. The integral of the fitted function was normalized to the total histogram area and the three parameters describing the signal function were fixed to the values predicted by the simulation for the inclusive sample. The result of the one parameter fit, shown by the full line in Fig.7, was :

$$N_{\pi^*} = 517 \pm 41(stat) \pm 30(syst).$$

This result was used for the determination of $P(c \to D^{*+})$ described in the next section. The histogram in Fig.7 shows the p_T^2 distribution of the background sample described above, normalized to the signal sample distribution above $p_T^2 > 0.014$.

The same fitting procedure applied to the simulation sample selected from about 6 Million Z^0 hadronic decays gave the result: $N_{\pi^*} = 1158 \pm 66(stat)$, in good agreement with the known number (1140) of D^* decays in the sample, as shown in Fig.8.

The systematic error was determined varying the quantities p_{T1}, p_{T2} and f_1 in the signal function parametrization within their quoted error and the parameter B describing the background shape within the statistical error obtained in the fit to the background sample. Different descriptions of the background (using a double exponential function or a 2^{nd} order polynomial in the denominator of expression (1)) were tried: the fitted value of N_{π^*} was inside the range indicated by the quoted systematic error. Finally, if in the signal parametrization the exponential slopes obtained in the real data using the exclusive sample were used, the result was: $N_{\pi^*} = 504 \pm 40(stat)$, with a variation of the central value well within the quoted systematic error.

3.2 Determination of $P(c \to D^{*+})$

The fragmentation probability $P(c \to D^{*+})$ can be determined from the ratio of the number of events with two D^* decays, $N_{D^*}^{double}$, divided by the number of events with a single reconstructed D^*, N_{D*}, according to the following equation :

$$\begin{aligned} N_{D^*}^{double}/N_{D*} &= [f_c \cdot P(c \to D^{*+})\epsilon_\pi^c + (1-f_c)\cdot P(b \to D^*)\epsilon_\pi^b \cdot (1-\chi_{eff})]\cdot BR(D^* \to D^0\pi) \\ &= [f_c \cdot \epsilon_\pi^c + (1-f_c)\cdot r \cdot (R_c/R_b)\cdot \epsilon_\pi^b \cdot (1-\chi_{eff})]\cdot P(c \to D^{*+})\cdot BR(D^* \to D^0\pi) \end{aligned} \quad (2)$$

where f_c and $(1-f_c)$ are the fractions of D^* from $c\bar{c}$ and $b\bar{b}$ events in the selected sample respectively; ϵ_π^q $(q = b, c)$ is the reconstruction efficiency for the pion from the D^* decay in $q\bar{q}$ events and χ_{eff} is an effective mixing parameter which describes the probability that B^o-mixing destroys the $D^*\pi$ charge correlation in $b\bar{b}$ events. This probability is given by :

$\chi_{eff} = 2\chi_{D^*}(1 - \chi_{D^*}) = 0.24 \pm 0.04$, where $\chi_{D^*} = (1. - f_+)\chi_d$, $\chi_d = 0.168 \pm 0.019$ is the world averaged value for the B_d^0 mixing parameter [9] and $f_+ = 0.16$ is the assumed branching fraction for the decay $B^+ \to D^{*+}X$, based on the measurement of the D^* production in semileptonic charged B meson decays [10]. Finally $r = 1.225 \pm 0.094$ is the quantity measured by DELPHI introduced in Sect.2.

The fraction f_c was determined by the simulation in each of the considered D^0 channels (see Table 1), being on average 0.69 ± 0.02. The number $N_{D^*}^{double}$ in the above formula does not coincide with the result of the fit, N_{π^*}. This is because of the non-negligible combinatorial background present below the D^* signals shown in Fig.3. The observed signal N_{π^*} thus contains genuine π^* from D^* decays opposite to fake D^* vertex candidates coming from different charm states. This can be seen in Fig.9a, where the simulation prediction for π^* in events containing a single D^* (i.e. having a fake reconstructed D^* on the opposite side) is shown. A similar effect is also present in the 'wrong sign' distribution of pions with the same D^* charge (Fig.5b). Further, the 'wrong-sign D^*' samples for the first four D^0 channels (corresponding to the dashed-line histograms in Figs3a-d) are also considered. Again, in the distribution for these samples, in which by definition only fake D^* vertices are present, a clear signal of π^* from events with a single D^* decay is seen both in the data and in the simulation.

The correction factor to determine the actual number $N_{D^*}^{double}$ in the sample was determined from the simulation to be : $k = N_{D^*}^{double}/N_{\pi^*} = 0.85 \pm 0.01$ where the quoted error comes from the statistical error of the simulation. As a cross-check, the p_T^2 distributions in the data for the samples of Fig.5b and 9b were fitted applying the same fitting function used for the signal sample. The total number of signal π^* in these samples was found to be : $N_{\pi^*}^{back} = 77 \pm 34$; after applying the proper normalization factor (0.53) between the signal and background samples, this lead to the correction factor $k = (0.88 \pm 0.05)$, in agreement with the Monte Carlo simulation prediction.

From the above numbers, the number of events with two $D^* \to D^0\pi$ decays was determined to be :

$$N_{D^*}^{double} = k \cdot N_{\pi^*} = 439 \pm 35(stat) \pm 25(syst).$$

The reconstruction and selection efficiency for pions originating from the D^* decay was studied in the simulation. Due to the different production spectra shown in Fig.10a, the overall efficiency for pion momenta bigger than 1 GeV/c was different for c and b events, being $\epsilon_\pi^c = 0.654 \pm 0.018$ and $\epsilon_\pi^b = 0.406 \pm 0.018$, where the quoted errors include the error on the selection efficiency due to the uncertainties on the c and b fragmentation processes and the systematic error on the track reconstruction efficiency in the Delphi detector. The average energies for D^* meson from b and c quarks were assumed to be $< X_E(D^*) >_b = 0.702 \pm 0.008$ and $< X_E(D^*) >_c = 0.492 \pm 0.011$ [2] respectively. The reconstruction efficiency is a smooth function of the pion momentum, as shown in Fig.10b, for momenta above the selection cut applied. The background-subtracted momentum spectrum of the reconstructed pion for the selected D^* samples in the real data, shown by the points in Fig.10c, is in good agreement with the simulation prediction for the D^* signal (histogram).

The uncertainty on the value of f_c, which depends on the ratio r, was dominated by the statistical error of the simulation; therefore, the small anti-correlation between its contribution to the total systematic error on $P(c \to D^*)$ and the contribution deriving from the uncertainty on r in eq.(2) was negligible.

Table 2: Contributions to the systematic error in the computation of $P(c \to D^{*+})$.

Error Source	Variation	Syst.error
Signal function	see text	± 0.0068
Backgr. shape parameter B	37.3 ± 2.1	± 0.0071
ϵ_{π}^{c}	0.654 ± 0.018	∓ 0.0027
ϵ_{π}^{b}	0.406 ± 0.018	± 0.0012
χ_{eff}	0.241 ± 0.040	± 0.0016
$r = R_b \cdot P(b \to D^*)/R_c \cdot P(c \to D^*)$	1.225 ± 0.094	∓ 0.0023
f_c	0.69 ± 0.02	± 0.0045
R_b	0.221 ± 0.0036	± 0.0005
Total	–	± 0.0117

From eq.(2), using the measured value $R_b = 0.221 \pm 0.0036$ [1] and the Standard Model value $R_c = 0.172$, the following result was obtained:

$$P(c \to D^{*+}) \cdot BR(D^* \to D^0\pi) = 0.169 \pm 0.014(stat) \pm 0.012(syst).$$

The different contributions to the systematic error are listed in Table 2. Using the world averaged value: $BR(D^* \to D^0\pi) = 0.681 \pm 0.013$, the fragmentation probability was determined to be :

$$P(c \to D^{*+}) = 0.248 \pm 0.020(stat) \pm 0.018(syst)$$

4 Measurement of $BR(c \to l)$

4.1 D^* and D^0 mesons selection

The same D^* selection described in the previous section was applied. In addition, tighter X_E cuts were used, requiring $X_E > 0.30, 0.45, 0.40, 0.35$ for the $D^0 \to K\pi$, $D^0 \to K\pi n\pi^0$, $D^0 \to Kl\nu X$ and $D^0 \to K3\pi$ channels respectively. The $D^0 \to K^0 2\pi$ channel was not used in this analysis, which was restricted to the 1991-94 data set. To increase the available charm statistics, an independent selection of the $D^0 \to K\pi$ channel was used, based on a tighter identification of the decay D^0 products : the kaon candidate track must be identified as kaon according to the tight RICH selection defined in [6] or have a 'standard' kaon identification in the RICH and an energy loss measurement in the TPC at least 0.5 standard deviations lower than the expected value for the pion hypothesis; the pion track candidate must not be identified as kaon or proton by the RICH and must have an energy loss in the TPC, if measured, compatible with the pion hypothesis within 2.3 standard deviations. The resulting $M(K\pi)$ invariant mass spectrum for candidates not coming from D^* decays, after the anti-btag selection and the cut $X_E > 0.40$, is shown in Fig.11. A fit to the distribution with a Gaussian superimposed to a sum of two exponential functions parametrizing the background gives a D^0 yield :

Table 3: Electron and muon efficiencies for the 1993 and 1994 data. The error takes into account both the indetermination of $\epsilon^{DT,nom}$ and the amount of Montecarlo statistics used to compute the correction.

	1993 data	1994 data
$\epsilon_e^{DT,thr}\%$	44.9 ± 1.0	48.8 ± 0.8
$\epsilon_\mu^{DT,thr}\%$	72.1 ± 1.0	73.8 ± 1.0

$$N_{D^0} = 960 \pm 53$$

where the statistical error takes into account the background subctraction; the purity in $c\bar{c}$ events was $f_c = 0.75 \pm 0.03$. In the f_c computation, the prediction of the simulation for this quantity was corrected using the experimental value :

$$r = R_b \cdot P(b \to D^0)/R_c \cdot P(c \to D^0) = \frac{R_b}{R_c} \cdot (1.07 \pm 0.15 \pm 0.08) = 1.38 \pm 0.21 \text{ [2]}.$$

4.2 Lepton selection

Lepton identification is described in [6, 11]. The electron identification efficiency inside the angular acceptance of the barrel electromagnetic calorimeter (HPC) was measured on the data and found to be $\epsilon_e^{DT,nom} = (61.7 \pm 1.0)\%$ and $\epsilon_e^{DT,nom} = (59.4 \pm 0.7)\%$ respectively for 1993 and 1994 data, with a hadron misidentification probability of $(0.4 \pm 0.1)\%$. The muon identification efficiency inside the angular acceptance of the muon chambers was $\epsilon_\mu^{DT,nom} = (82.3 \pm 0.7)\%$ and $\epsilon_\mu^{DT,nom} = (81.2 \pm 0.5)\%$ for the same periods, with a hadron misidentification probability of $(0.7 \pm 0.1)\%$.

Semileptonic decays of charm quark were selected by looking for electrons and muons with momenta $p > 3\ GeV/c$ in the hemisphere opposite to the reconstructed D mesons. The D^* candidates must be in the same regions in the invariant mass difference $M(D*) - M(D^0)$ as in the $P(c \to D^*)$ analysis (shown by the arrows in Fig.4); D^0 candidates are in the $M(K\pi)$ invariant mass region shown by the arrows in Fig.11.

The total amount of D mesons after the cuts was:

$$N_{D^0+D^*} = 3176 \pm 85$$

out of which a fraction $f_c = 0.81 \pm 0.03(stat) \pm 02(syst)$ were estimated by the simulation to be produced in $c\bar{c}$ events. To avoid the forward regions with poorer lepton identification power, the cut $|\cos(\theta_{thrust})| \leq 0.95$ was imposed on the thrust axis direction. The nominal lepton efficiencies for electrons and muons quoted before were then corrected comparing the simulation prediction for the leptons inside the angular acceptance of the relevant detectors with those predicted after the only cut on the thrust axis direction:

$$\epsilon^{DT,thr} = \frac{\epsilon^{MC,thr}}{\epsilon^{MC,nom}} \epsilon^{DT,nom}$$

Table 3 shows the resulting lepton efficiencies for 1993 and 1994 data together with the experimental errors. Only the leptons with opposite charge respect to the slow pion in the D^* sample (or with the same charge as the kaon in the D^0 analysis) were selected, in order to tag the semileptonic decay of the c quark in the opposite hemisphere respect to

D meson and to reduce the contamination due to the decays of b quarks. No requirement was imposed on the transverse momentum of the lepton, p_T, w.r.t. its jet axis. The p and p_T distributions of the selected lepton candidates are shown in Fig.12.

4.3 Determination of $BR(c \to l)$

The combinatorial background subtraction in the $D^*-lepton$ analysis was performed using the wrong sign D^* as described in Sect.2.; in the $D^0 - lepton$ analysis the background in the region $1.816\ GeV/c^2 < M(K\pi) < 1.920\ GeV/c^2$ was obtained from the fit. The effect of kinematic reflections from true $D^0/\bar{D}^0$ decays with the wrong $M(K\pi)$ assignement was studied on the simulation and found negligeable. After the background subtraction, the number of leptons in the opposite hemisphere respect to the D mesons and with the right charge correlation was:

$$N^e(p > 3\ GeV/c) = 89 \pm 13$$
$$N^\mu(p > 3\ GeV/c) = 159 \pm 17$$

For each of the two flavours, the total amount of leptons is the sum of different contributions:

$$(3) \qquad N^{lep} = [N_c^{true} + N_c^{fake}]h_c + [N_b^{true} + N_b^{fake}]h_b$$

where $N_{c,b}^{true}$ are the yields of the true leptons coming from the semileptonic decays of c, b quarks and $N_{c,b}^{fake}$ take into account both the number of the leptons from the decay of light particles and the amount of the misidentified hadrons in $c\bar{c}$ and $b\bar{b}$ events respectively. The factors h_c and h_b in the previous formula are Monte Carlo corrections taking into account the fact that, due to hard gluon radiation, the two heavy partons could hadronize in the same hemisphere. The fractions of $c\bar{c}$ and $b\bar{b}$ events in which the heavy mesons are producted in opposite hemispheres are $h_c = 0.965 \pm 0.001$ and $h_b = 0.976 \pm 0.001$ according to the simulation.

The number of the true leptons coming from b decays with the right charge correlation with the slow pion (kaon) from the $D^*(D^0)$ decays is given by:

$$(4)\ N_b^{true} = \epsilon^{lep} N_D^b[\chi_{eff}^D(BR_{b\to l}F_{b\to l} + BR_{b\to\bar{c}\to l}F_{b\to\bar{c}\to l} + BR_{b\to\tau\to l}F_{b\to\tau\to l}) + (1 - \chi_{eff}^D)BR_{b\to c\to l}F_{b\to c\to l})]$$

where N_D^b is the number of D meson in the selected sample originating from b-quark predicted by the simulation, ϵ^{lep} is the lepton efficiency, and χ_{eff}^D is the effective mixing parameter $\chi_{eff}^D = \chi_D(1-\chi) + \chi(1-\chi_D)$ (with χ_D defined in Sect.3.2 and $\chi = f_d\chi_d + f_s\chi_s = 0.133 \pm 0.011$ [9]).

$F_{b\to x}$ are the fractions of leptons with momentum greater than 3 GeV/c for the different semileptonic decays characterized by the branching fractions $BR_{b\to x}$. To determine the kinematic acceptances, the simulated leptons were weighted to reproduce the data according to the results reported by the Electro Weak Working Group [12]. For the description of the b semileptonic decays was assumed the $ACCM$ model and the systematic error on $F_{b\to x}$ was given comparing the result with the predictions of the $IGSW$ and $IGSW^{**}$ models. For the c semileptonic decay the Altarelli model was used and the

Table 4: Branching fractions for the semileptonic decays of b quark fixed to the $EWWG$ prescriptions and lepton kinematic acceptances for the cut $p > 3\ GeV/c$. The first error is the statistical one, the second is due to the semileptonic modelling and the third to the uncertainty on X_E.

Decay	BR	$F(p > 3\ GeV/c)$
$b \to l$	0.1120 ± 0.0040	$0.767 \pm 0.004 \pm 0.007 \pm 0.002$
$b \to c \to l$	0.0820 ± 0.0120	$0.423 \pm 0.003 \pm 0.006 \pm 0.003$
$b \to \tau \to l$	0.0045 ± 0.0007	$0.573 \pm 0.017 \pm 0.004 \pm 0.003$
$b \to \bar{c} \to l$	0.0130 ± 0.0050	$0.432 \pm 0.010 \pm 0.005 \pm 0.002$
$c \to l$	$-$	$0.598 \pm 0.005 \pm 0.008 \pm 0.002$

systematics were estimated comparing the results obtained with different choices for m_s and the Fermi momentum P_F. The simulated leptons were weighted in terms of z_{fragm} to reproduce the average ratio between the heavy mesons energy and the energy of the beam measured for $c\bar{c}$ and $b\bar{b}$ events: $X_{E,c} = 0.484 \pm 0.008$, $X_{E,b} = 0.702 \pm 0.008$.

The b semileptonic branching fractions, fixed to the $EWWG$ values, are reported in Tab. 4 together with the kinematic acceptances for the different semileptonic decays of the b and the c quarks. Equation 3 can be written as:

$$(5) \qquad N^{lep} = \frac{N_c^{true}}{P_c^D} h_c + \frac{N_b^{true}}{P_b^D} h_b$$

where $P_{c,b}^D = \frac{N_{c,b}^{true}}{N_{c,b}^{true} + N_{c,b}^{fake}}$ are the fractions of the true leptons in the D mesons subsample coming from $c\bar{c}$ ($b\bar{b}$) events. These fractions were computed from the data in the following way. For the D subsample produced in $c\bar{c}$ events, it is possible to express P_c^D in terms of the fraction of the true leptons in the inclusive $c\bar{c}$ sample, P_c^{incl}:

$$P_c^D = \frac{P_c^{incl}}{P_c^{incl} + B_c(1 - P^{incl})}$$

where B_c is the fraction of the fake leptons with the right charge correlation with the slow pion(kaon), predicted by the simulation. For the D subsample produced in $b\bar{b}$ events, the situation is complicated by the presence of the effective mixing which destroys the charge correlation between the lepton and the slow pion(kaon), thus:

$$P_b^D = \frac{P_b^{incl}}{P_b^{incl} + B_b(1+R)(1 - P_b^{incl})}$$

where $R = 1.63 \pm 0.14$ is the ratio between the numbers of the true leptons from b decays with the wrong and the right charge correlation w.r.t. the D^*. The latter is N_{true}^b given by eq.(4); the former is obtained by eq.(4) by inter-changing χ_{eff}^D and $(1 - \chi_{eff}^D)$ in the formula. Table 5 shows the simulation prediction for the fractions $B_{c,b}$.

The quantities $P_{c,b}^{incl}$ were determined on the data from the fit to the inclusive (p, p_T) spectra of the leptons [1]. The error on these fractions is due to the statistics of real data and Montecarlo used in the fit to the lepton spectra, the indetermination on the fitted parameters, the lepton identification efficiencies and the hadron misidentification probability. The resulting values for $P_{c,b}^D$ are reported in Table 6.

The yields of leptons coming from charm decays, obtained from equation (5) were:

Table 5: Fraction of fake leptons with the right charge correlation with the slow pion(kaon) in the $D^*(D^0) - lepton$ analysis.

	Electrons	Muons
$B_c\%$	38.7 ± 2.4	30.4 ± 2.0
$B_b\%$	43.8 ± 1.3	36.8 ± 1.3

Table 6: Fraction of true leptons in the sample of D mesons produced in $c\bar{c}$ and $b\bar{b}$ events.

	Electrons	Muons
$P_c^D(\%)$	80.1 ± 2.9	89.0 ± 1.9
$P_b^D(\%)$	78.7 ± 1.7	82.4 ± 1.5

$$N_c^{e,true} = 60 \pm 11(stat) \pm 2(syst)$$
$$N_c^{\mu,true} = 123 \pm 15(stat) \pm 3(syst)$$

The branching fraction $BR(c \to l)$ was obtained from the relation:

$$N_c^{true} = \epsilon^{lep} f_c N_{D^*+D^0} F_{c \to l} BR(c \to l)$$

where $F_{c \to l}$ is the last entry in Table 4. The results on $BR(c \to l)$ for the $D^* - lepton$ and the $D^0 - lepton$ analysis, separately for electrons and muons are reported in Table 7 together with their statistical error. The table shows also the average result.

The result obtained combining the two analysis and averaging the two lepton flavours was:

$$BR(c \to l) = 0.098 \pm 0.010 \pm 0.006$$

The different contributions to the systematic error are listed in Table 8. The error due to the lepton purity quoted in the table takes into account the effect of the statistics used in the fit, the indetermination on the fitted parameters, the hadron misidentification probability together with the uncertainties on R and $B_{c,b}$. The error source quoted as "D^0 fit" takes into account the definition of the side bands in the $M(K\pi)$ invariant mass spectrum for the combinatorial background subtraction. The errors due to the lepton efficiency, hadron misidentification and $B_{c,b}$ were considered as uncorrelated in the average of the results for electrons and muons.

Table 7: Results on $BR(c \to l)$ for the different samples with the statistical error.

	D^*	D^0	$D^* + D^0$
$BR(c \to e)(\%)$	8.4 ± 1.7	8.5 ± 3.2	8.4 ± 1.5
$BR(c \to \mu)(\%)$	11.1 ± 1.6	10.7 ± 2.7	11.0 ± 1.4
$BR(c \to l)(\%)$	9.8 ± 1.2	9.8 ± 2.1	9.8 ± 1.0

Table 8: Contributions to the systematic error in the computation of $BR(c \to l)$.

Error Source	Variation	Syst.error
$\chi_{eff}(D^*)$	0.24 ± 0.04	∓ 0.0004
$\chi_{eff}(D^0)$	0.17 ± 0.02	∓ 0.0002
$r = R_b \cdot P(b \to D^*)/R_c \cdot P(c \to D^*)$	1.225 ± 0.094	± 0.0001
$r = R_b \cdot P(b \to D^0)/R_c \cdot P(c \to D^0)$	1.38 ± 0.21	± 0.0001
f_c	0.81 ± 0.02	∓ 0.0012
Lepton purity	see text	± 0.0043
ϵ^{lep}	"	∓ 0.0021
$BR_{b \to l}$	0.1120 ± 0.0040	∓ 0.0003
$BR_{b \to c \to l}$	0.0820 ± 0.0120	∓ 0.0014
$BR_{b \to \tau \to l}$	0.0045 ± 0.0007	∓ 0.0001
$BR_{b \to \bar{c} \to l}$	0.0130 ± 0.0050	∓ 0.0001
Cinematic acceptances:		
a) MC Statistics	see Table 4	∓ 0.0009
b) Decay models	"	± 0.0014
c) Fragmentation	"	∓ 0.0004
D^0 fit	–	± 0.0006
Total	–	± 0.0055

5 Conclusions

Using a double tag method based on the detection of a slow pions or a lepton opposite to fully reconstructed D^* and D^0 mesons, the fragmentation probability times the $D^{*+} \to D^0\pi^+$ branching fraction and the charm semileptonic branching fraction were measured from a sample of $Z \to c\bar{c}$ decays selected with high purity at LEP. The following results were found :

$$P(c \to D^{*+}) \cdot BR(D^{*+} \to D^0\pi^+) = 0.169 \pm 0.014(stat) \pm 0.012(syst);$$
$$BR(c \to l) = 0.098 \pm 0.010(stat) \pm 0.006(syst)$$

Using the world averaged value: $BR(D^* \to D^0\pi) = 0.681 \pm 0.013$, the fragmentation probability was determined to be :

$$P(c \to D^{*+}) = 0.248 \pm 0.020(stat) \pm 0.018(syst)$$

References

[1] DELPHI Collaboration, P.Abreu et al., Z.Phys. **C66** (1995) 323.

[2] DELPHI Collaboration, 'Study of Charm Mesons Production in Z^0 Decays and Measurement of Γ_c/Γ_h', DELPHI 95-101 PHYS 536, contributed paper to EPS-HEP 95, ref.0557, Brussels 1995;
DELPHI Collaboration, 'Double Tag Measurement of R_c and $P(c \to D^*)$ using Inclusive D^*', subm.to this Conference, pa1-059.

[3] OPAL Collaboration, 'A Measurement of $B(c \to D^*$ and Γ_c/Γ_h using a Double Tagging Method', OPAL PN 175, contributed paper to EPS-HEP 95, Brussels 1995.

[4] ARGUS, CLEO measurements on $P(c \to l)$

[5] DELPHI Collaboration, measurements on B^0 oscillations

[6] DELPHI Collaboration, P.Abreu et al., 'Performance of the DELPHI Detector', CERN-PPE/95-194, submitted to Nucl.Instr.Meth.A.

[7] G.V. Borisov, 'Lifetime Tag of Events $Z \to b\bar{b}$ with the DELPHI Detector', Internal Note, DELPHI-94-125, PROG 208, 1994.
G.V. Borisov and C. Mariotti, 'Fine Tuning of the Impact Parameter Resolution in the DELPHI Detector', Internal Note, DELPHI-95-142, PHYS 567, 1995.

[8] D.Bloch et al., 'Double Tag Measurement of R_c and $P_{\mathrm{c}\to\mathrm{D}^{*+}}$ using inclusive $\mathrm{D}^{*\pm}$', contribution pa01-059 to the XXVIII International Conference on High Energy Physics.

[9] Particle Data Group, Phys.Rev. **50** (1994) 1173.

[10] ALEPH Collaboration, D.Buskulic et al., Phys.Lett. **B307** (1993) 194;
OPAL Collaboration, P.D.Acton et al., Phys.Lett. **B307** (1993) 247.

[11] K.D.Brand, I.Roncagliolo, F.Simonetto, 'Electron Identification for Electro-Weak b,c Physics', Internal Note, DELPHI-96-23, PHYS 598, 1996;
F.Stichelbaut, G.R.Wilkinson, 'Performance of Muon Identification in DELPHI for the 93 and 94 Data',
Internal Note, DELPHI-95-140, 1995.

[12] The Electro-Weak-Working-Group,LEPHF/96-01/Draft 3.0

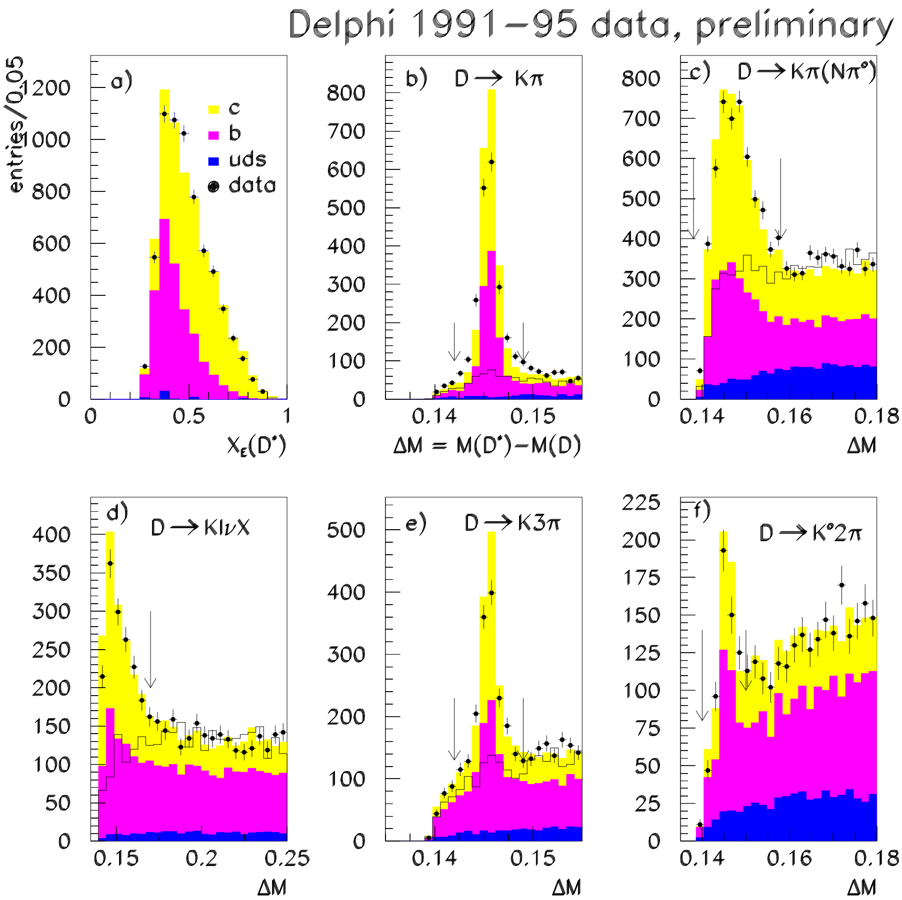

Figure 1: a) normalized energy distribution of the background-subtracted D^* signal for $D^* \to D^0\pi$ candidate decays with pion momentum bigger than 1 GeV/c and $X_E(D^*) > 0.25$; b-f) $\Delta M = M(D^*) - M(D^0)$ mass difference distribution for the D^* candidate decays in the five D^0 channels considered.

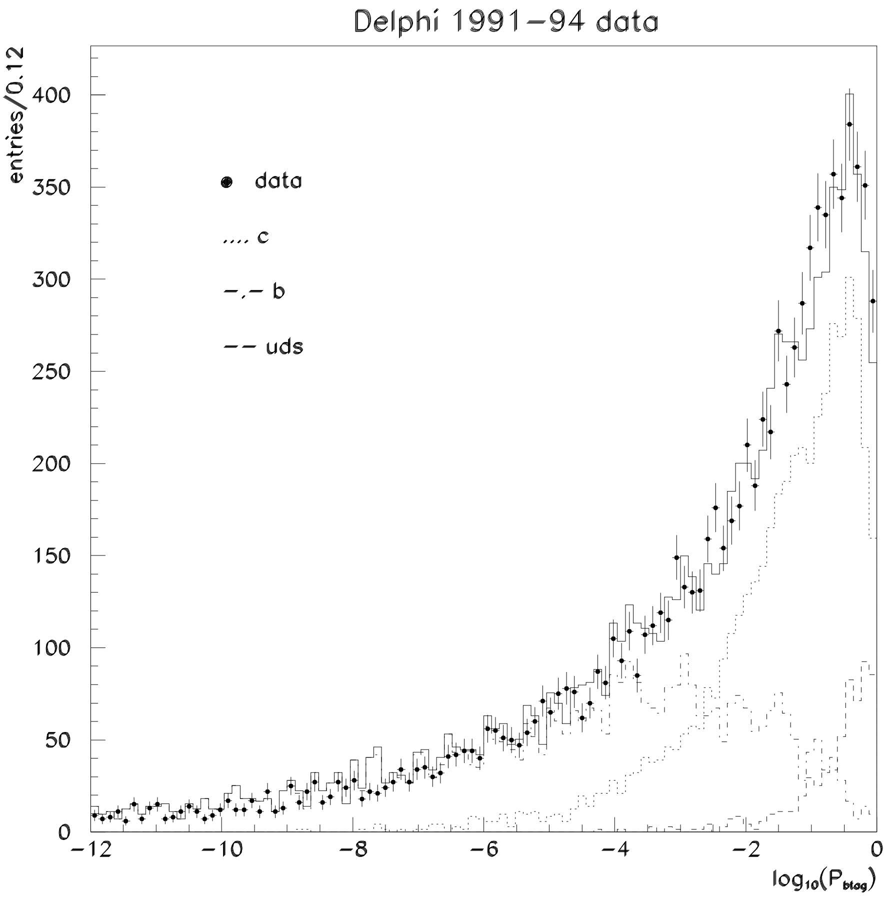

Figure 2: b-tagging event probability distribution for events with a reconstructed D^* candidate in the ΔM signal range.

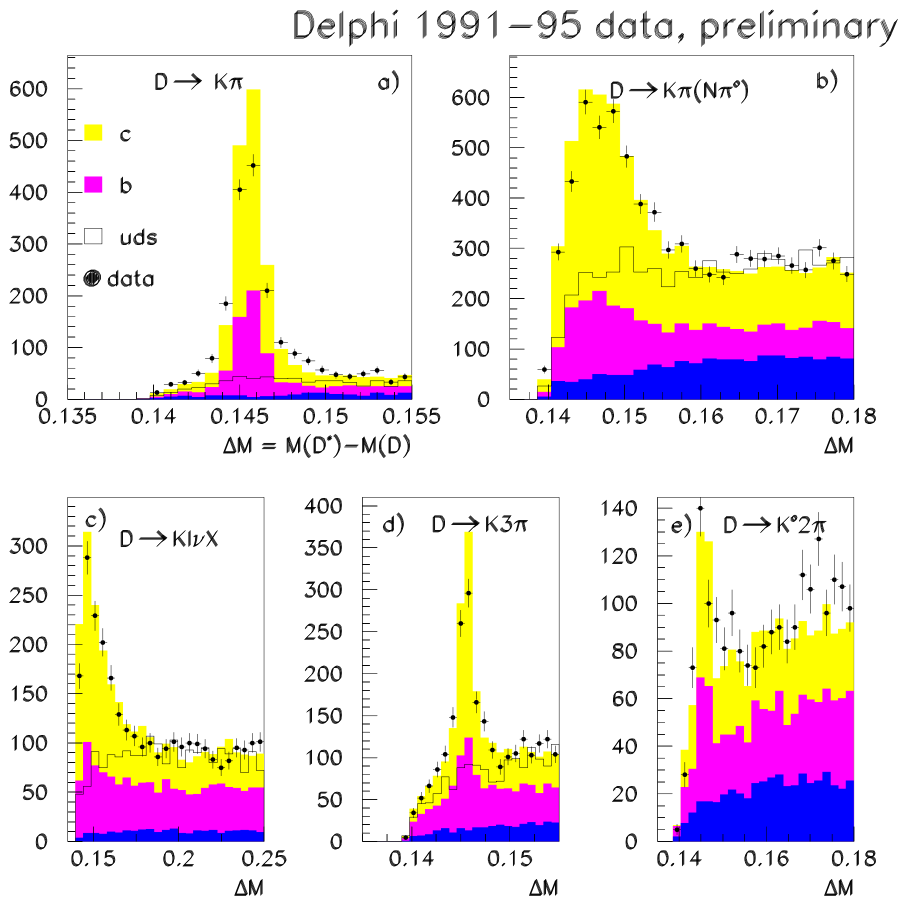

Figure 3: a-e) $\Delta M = M(D^*) - M(D^0)$ mass difference distribution for D^* candidate decays after the anti-b tag selection.

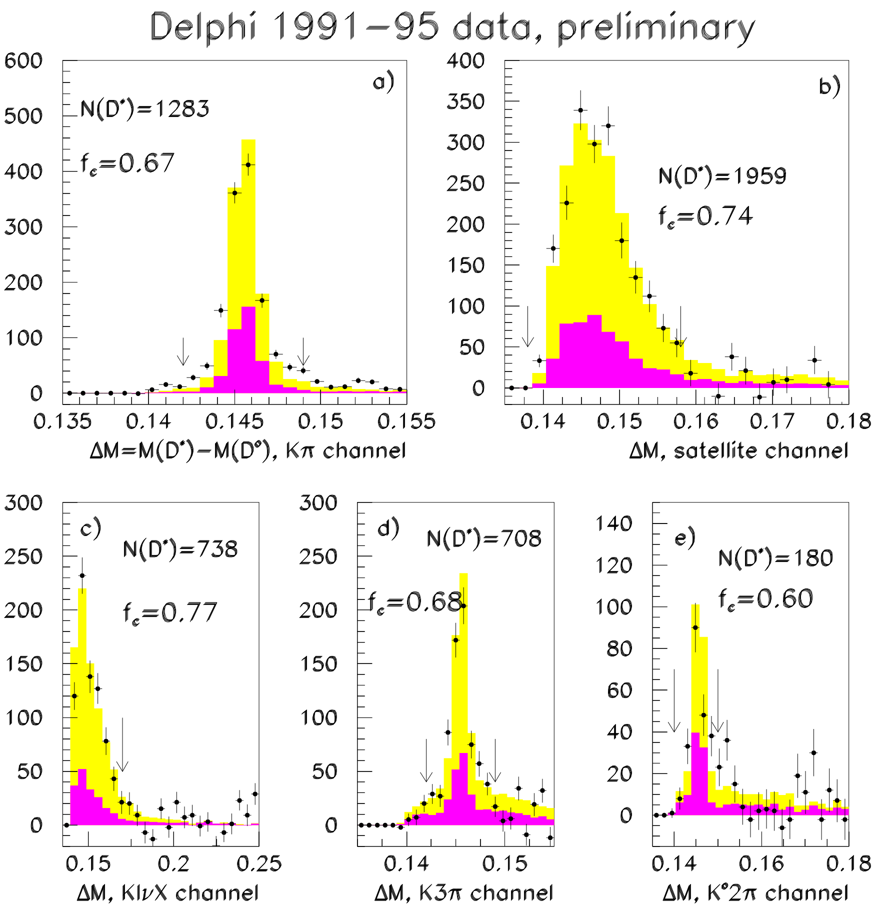

Figure 4: a-e) Background subtracted $\Delta M = M(D^*) - M(D^0)$ mass difference distribution after anti-b tag selection.

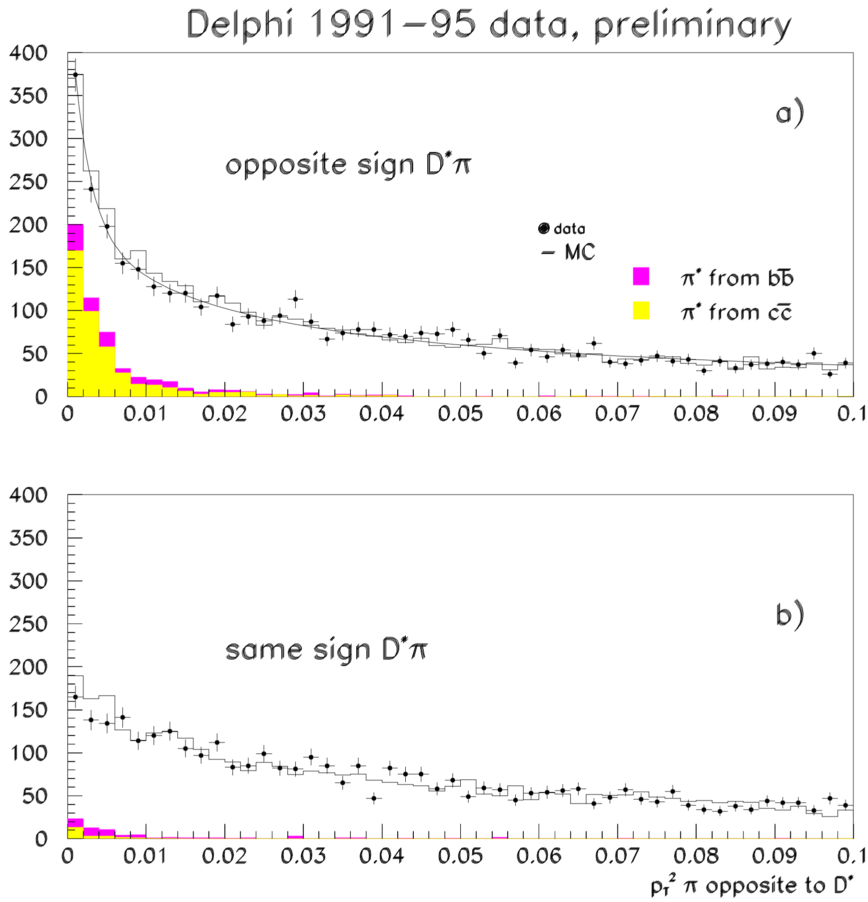

Figure 5: a) p_T^2 distribution of pions with momenta in the range $1. < p < 3.5 GeV/c$ and charge opposite to the D^* charge, in the hemisphere opposite to the reconstructed D^* candidate for real data (dots) and simulation (full line histogram); the shaded histograms show the distribution for true π^* predicted by the simulation; b) same distribution for pions with same charge as the D^*.

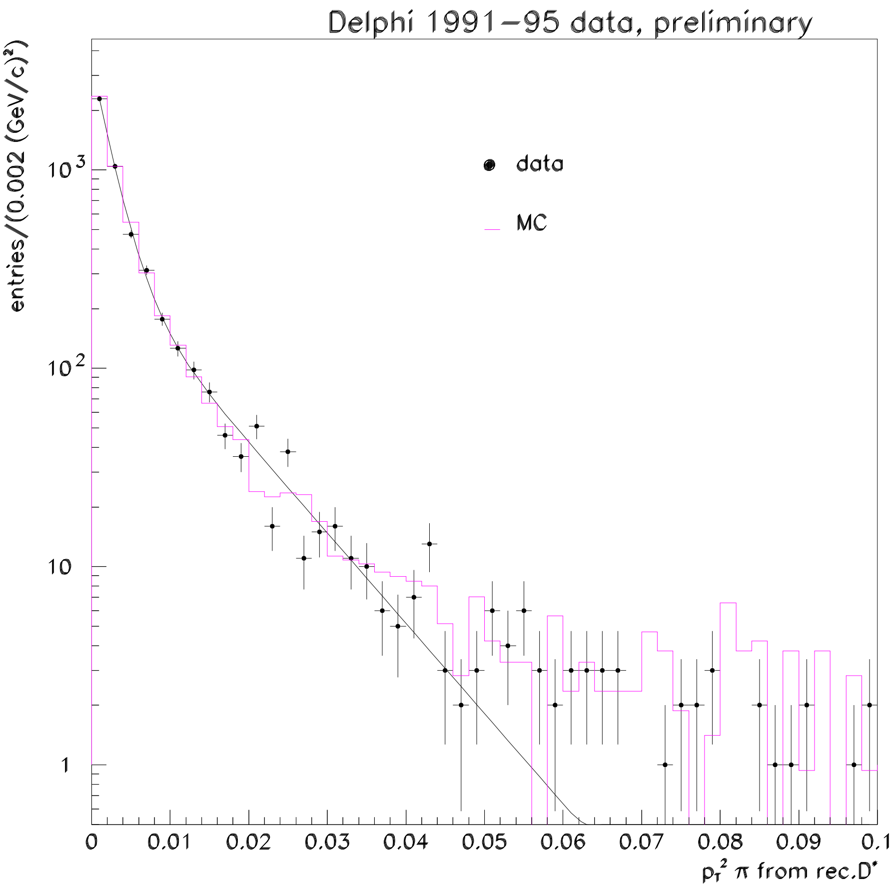

Figure 6: p_T^2 distribution for pions from fully reconstructed D^*, after the background subtraction performed using the spectrum from wrong sign D^* candidates, for real (points) and simulated data (histogram). The full line is the result of the three parameter fit described in the text.

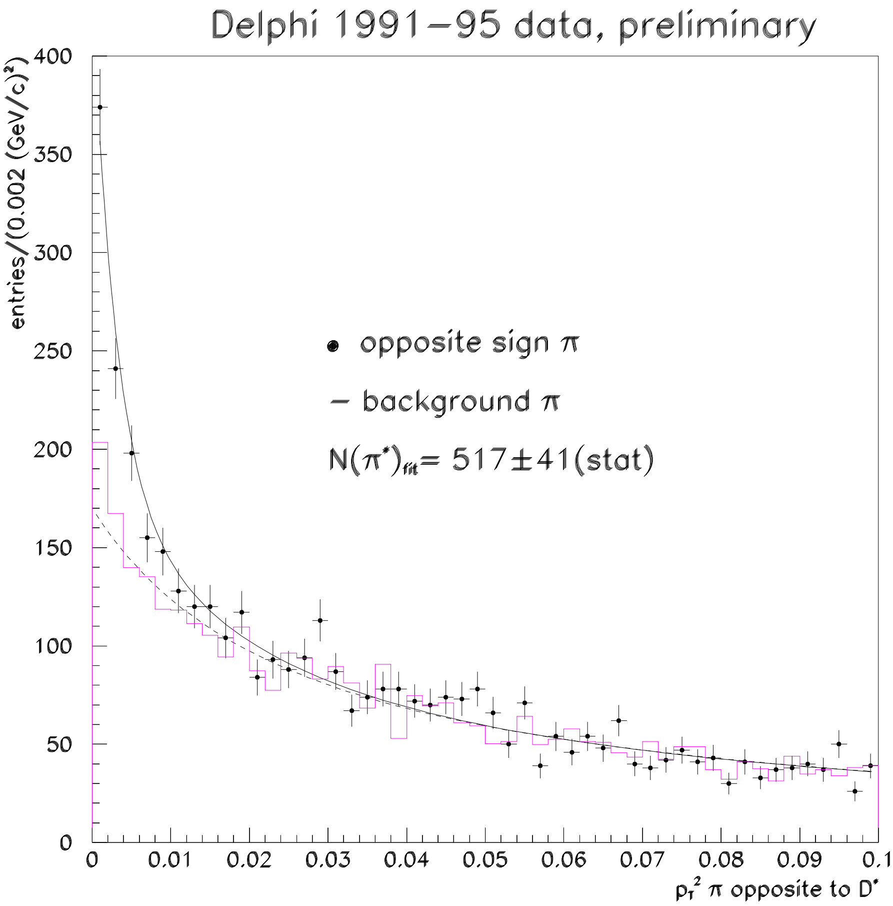

Figure 7: p_T^2 distribution for pions in the signal sample (points) and in the background sample (histogram), normalized to the integral of the distributions above $p_T^2 > 0.014$. The full line is the result of the one parameter fit described in the text; the dashed line represents the fitted background.

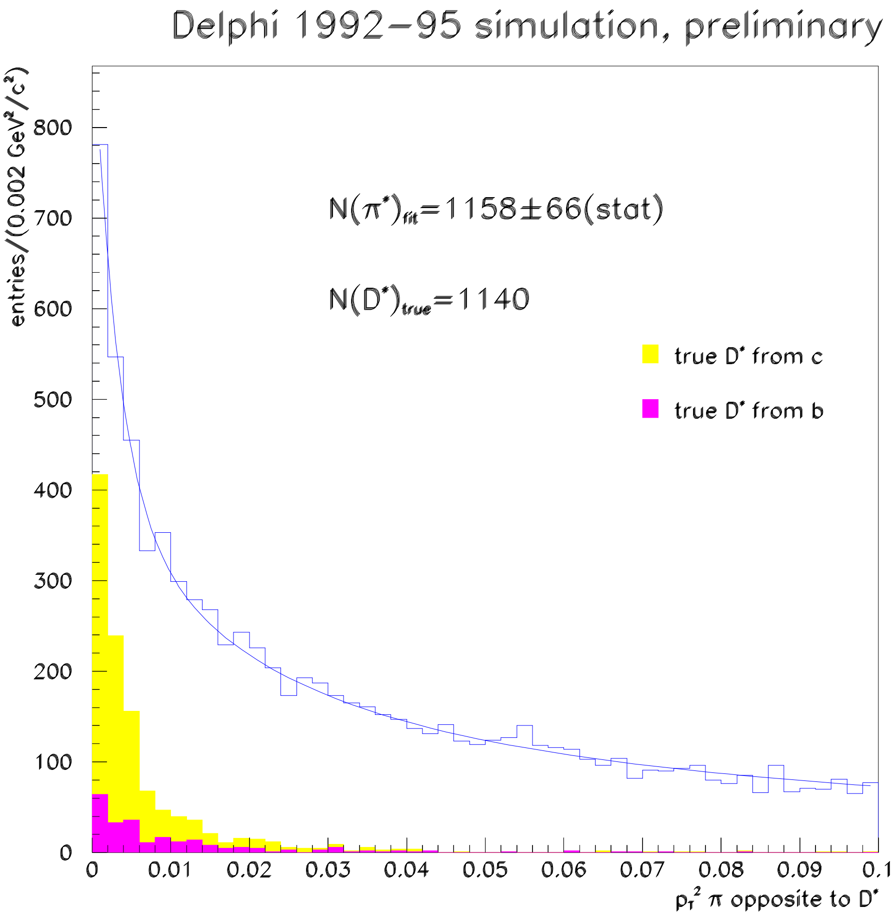

Figure 8: Same as Fig.7, for the simulated data. The full line is the result of the one parameter fit described in the text; the dashed line represents the fitted background. The yields of pions from true D^* decays in $c\bar{c}$ and $b\bar{b}$ events are shown by the shaded histograms.

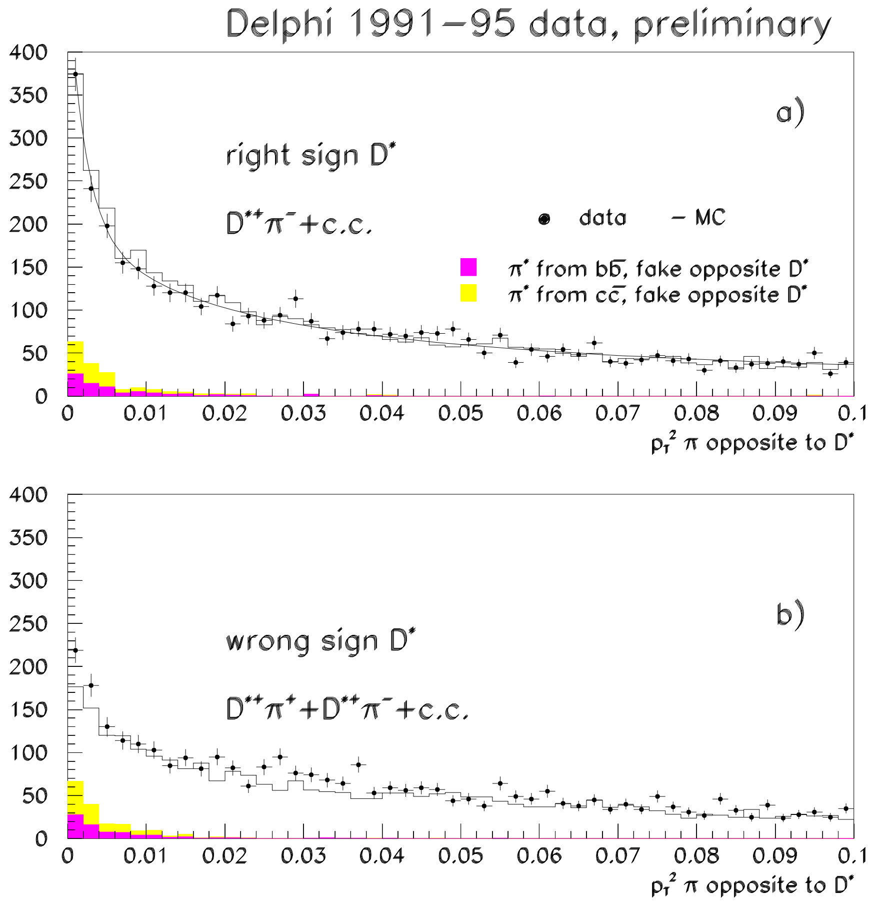

Figure 9: a) p_T^2 distribution of same charge pions for real data (points) and simulated data (full histogram); the shaded histogram show the distribution predicted by the simulation for true π^* accompanied by a fake reconstructed vertex in the opposite hemisphere; b) same distribution for pions accompanied by a 'wrong sign' D^* candidate in the opposite hemisphere (both same charge and opposite charge $D^*\pi$ combinations are considered).

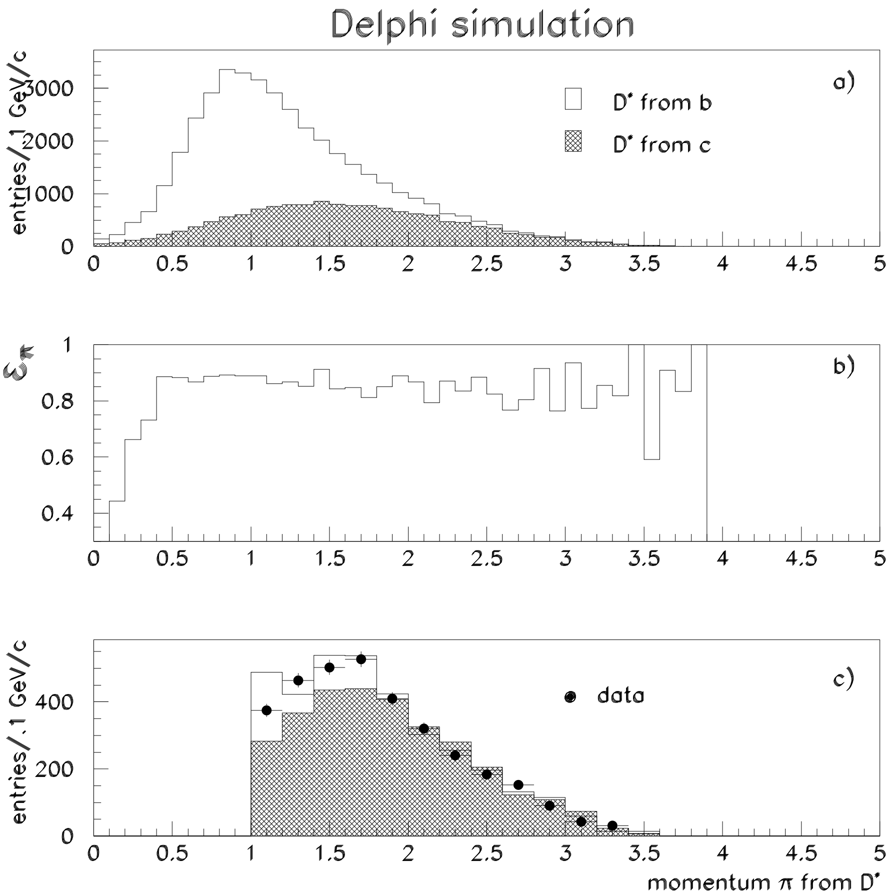

Figure 10: a) momentum distribution of generated pions from $D^* \to D^0\pi$ decays produced in $b\bar{b}$ (white area histogram) and $c\bar{c}$ (shaded area histogram) events; b) reconstruction efficiency predicted by the simulation for pions originating from D^* decays; c) background-subtracted momentum spectrum for pions from the selected D^* candidates in the 'signal mass regions': real data (points) and simulated data (histograms).

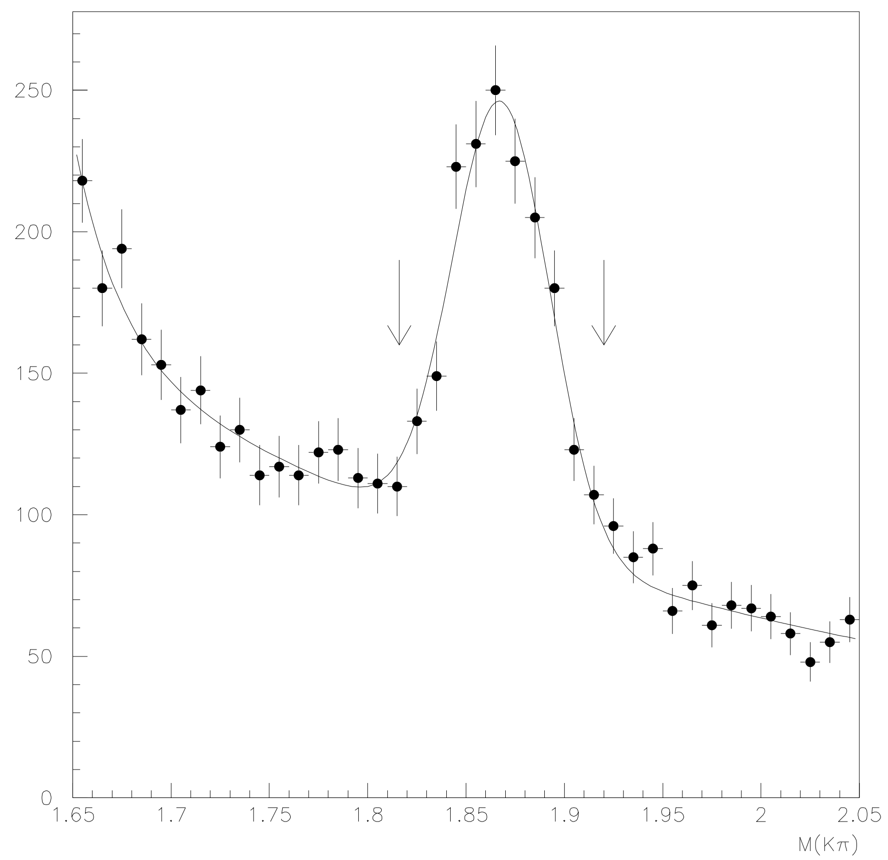

Figure 11: $M(K\pi)$ invariant mass spectrum for D^0 candidate decays selected with a tight particle identification of the D^0 decay products (see text); D^0 from D^* decays are excluded from this plot.

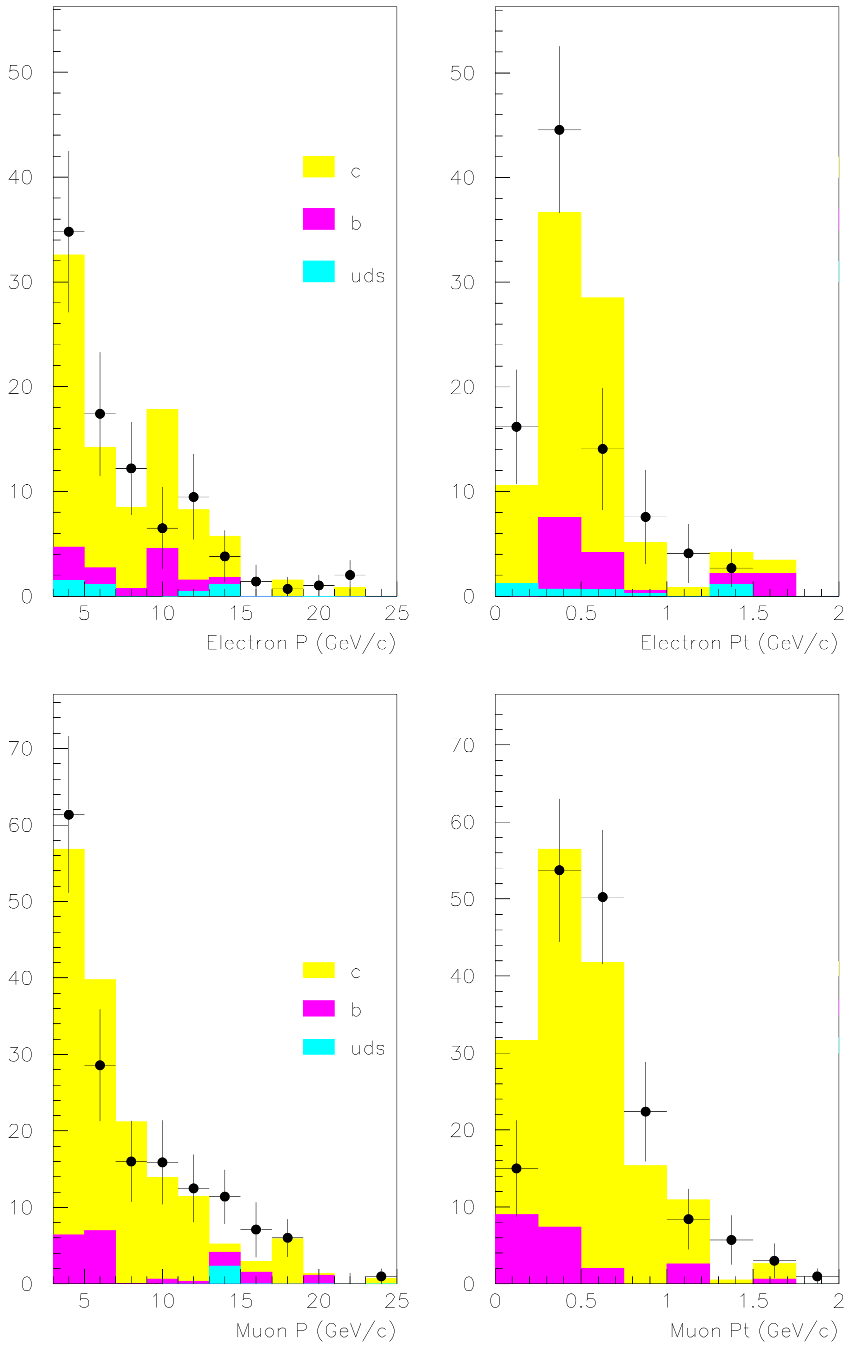

Figure 12: a,b) momentum distribution of muons and electron candidates with $p > 3GeV/c$ opposite to reconstructed D mesons; c,d) transverse momentum distribution for muons and electrons candidates.