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Nuclear Physics A663&664 (2000) 655c–658c

NUCLEAR PHYSICS A

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Measurement of the B Semileptonic Branching Fraction into Excited Charm Mesons

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A study of b semileptonic decays into D, $D\pi^{\pm}$ and $D^{*}\pi^{\pm}$ final states is presented. The D^0, D^+ and D^{*+} are exclusively reconstructed using Z decays data recorded from 1992 to 1995 in the DELPHI experiment at LEP.

1. INTRODUCTION

Present measurements of $\bar{B}$ meson semileptonic decays into $D\ell^-\bar{\nu}_\ell$ and $D^*\ell^-\bar{\nu}_\ell$ account for only 60% to 70% of all $\bar{B}$ semileptonic decays [1]. The remaining contribution could be attributed to the production of higher excited states or non–resonant $D^*\pi$ final states, hereafter denoted D^{**}.

This paper describes a measurement of the branching fraction of $\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$ ($l = \mu, e$) decays in the DELPHI experiment at LEP. D^0, D^+ and D^{*+} decaying into $D^0\pi_*^+$ are exclusively reconstructed[1]. The analysis of $D^{**} \to D\pi_{**}$ in $\bar{B}$ semileptonic decays[2] relies on the impact parameter (i.p.) of the π_{**} candidate, defined as its distance of closest approach to the reconstructed primary vertex (p.v.). A similar technique has been applied previously in ALEPH [2] and DELPHI [3].

2. ANALYSIS

The DELPHI detector has been described in detail elsewhere [4]. For the event selection, the criteria described in [5] have been used. A total of 3.52 million hadronic events were obtained from the 1992-1995 data. Simulated hadronic events were generated using the JETSET 7.3 Parton Shower program. The B meson mean lifetime was set to $\tau_B^{MC} = 1.6$ ps.

2.1. $D\ell^-$ selection

Only the main selection criteria are described here. More details can be found in [5]. The D meson candidates were exclusively reconstructed in the following decay channels: $D^0 \to K^-\pi^+$ or $K^-\pi^+\pi^+\pi^-$ (for D^0 not coming from a D^{*+} decay), $D^+ \to K^-\pi^+\pi^+$ and $D^{*+} \to D^0\pi_*^+$ with a D^0 decaying into $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ or $K^-\pi^+(\pi^0)$ where the π^0 was not reconstructed. In order to increase the $b\bar{b}$ purity of the selected sample, the probability that all these tracks originate from the p.v. was required to be smaller than

[1] π_* denotes the charged pion from the $D^{*+} \to D^0\pi^+$ decay.
[2] D stands for D^0 or D^+ , π_{**} denotes the charged pion from the D^{**} decay.

0375-9474/00/$ – see front matter
PII S0375-9474(99)00702-2

0.1. This probability is extracted using the i.p. (w.r.t. the p.v.) of all measured tracks in the event.

Only charged particles produced in the same direction as the lepton were considered for the reconstruction of charmed mesons. The kaon candidate from the $D^{0/+}$ decay was required to have the same charge sign as the identified lepton. Any charged particle with a momentum between 0.3 GeV/c and 4.5 GeV/c and a charge opposite to that of the kaon was used as pion candidate of the $D^{*+} \to D^0\pi_*^+$ decay channel. To reduce the combinatorial background in all channels, the kaon candidate of the $D^{0/+}$ (except in the $D^{*+} \to (K^-\pi^+)\pi_*^+$ decay) was required to be identified using RICH and dE/dx informations.

In each channel, the scaled D energy, $X_E(D) = E(D)/E_{\text{beam}}$, had to be larger than 0.15. In order to reduce the fraction of leptons from b semileptonic decay into τ and from $b \to \bar{c} \to \ell$ or $b \to c \to \bar{\ell}$ decays, the lepton transverse momentum relative to the D meson momentum vector was required to be larger than 0.7 GeV/c.

Finally a $D\ell$ vertex (candidate "B" vertex) was fitted. The D invariant mass distributions were fitted with a signal component described by the sum of Gaussian functions, and a combinatorial background parametrised with a polynomial form. In each channel, the relative amounts and relative widths of the Gaussian functions describing the D signal were tuned according to the simulation. The mass distributions of the wrong sign $D\ell^+$ events were fitted with the same shape parameters as the right sign distributions. This allowed to determine the contribution of fake lepton events to be subtracted.

2.2. $D^{**}\ell^-$ selection

The selection criteria for the additional π_{**} candidate were identical in all decay channels. All charged particles with a momentum greater than 0.5 GeV/c and produced in the same direction as the $D\ell^-$ momentum vector were considered as π_{**} candidates. The invariant $D\pi_{**}\ell$ mass had to be smaller than 5.5 GeV/c^2. The i.p. of this π_{**} , relative to the previously fitted $D\ell$ vertex, had to be smaller than 100 μm.

2.3. Backgrounds

For $D\pi\ell$ events, two sources of background had to be subtracted: fake D associated to a lepton candidate (estimated by using events in the tails of the D invariant mass distributions) and true D's associated to a fake lepton (due to charged hadrons misidentified as leptons, subtracted by using the π_{**} candidates produced in the same direction as a wrong sign $D\ell^+$ event).

After the subtraction of these backgrounds, all the remaining pions can be attributed to b decays into $D\pi\ell^-X$ final state. However, four kinds of pions are still to be considered: genuine π_{**} from $\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$ decays, particles from jet fragmentation, "$\tau, c \to \ell$" background (it includes pions from D^{**} produced in $b \to D^{**}\tau^-\bar{\nu}_\tau$, or from the other charm quark in $b \to \bar{c} \to \ell$ or $b \to c \to \bar{\ell}$ transitions) and "hadronic" background (due to other hadrons produced from the $\bar{c}$ in $b \to \bar{c} \to \ell$ decay events or from the c in $b \to c \to \bar{\ell}$ when the other charm quark fragments into a D meson).

Despite the momentum and transverse momentum cuts applied to the lepton, the previous last two classes were not fully eliminated. Their i.p. distributions were found similar to the i.p. distribution of genuine π_{**} from b semileptonic decays. These two contributions were thus fitted together with the genuine π_{**} signal and subtracted afterwards.

2.4. Total yield

In the real data, the impact parameter distributions of the π_{**} candidates of the "right" sign $D^0\pi^+\ell^-$, $D^+\pi^-\ell^-$ and $D^{*+}\pi^-\ell^-$ samples are shown in Figure 1. They were fitted, fixing the fake D and fake lepton backgrounds, but letting free the normalisation of the fragmentation and π_{**} components. Similar fits were performed to the "wrong" sign $D^0\pi^-\ell^-$, $D^+\pi^+\ell^-$ and $D^{*+}\pi^+\ell^-$ samples.

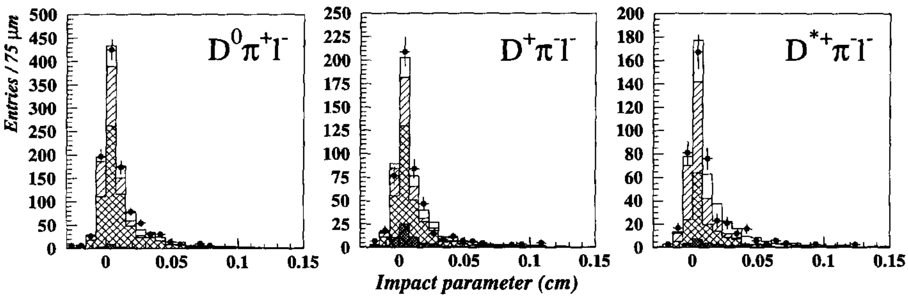

Figure 1. Impact parameter (w.r.t the p.v.) in real data for "right" sign $D^0\pi^+$, $D^+\pi^-$ and $D^{*+}\pi^-$ candidates. The dark grey and cross-hatched histograms are the estimated contributions from fake leptons and fake D mesons (resp.). The hatched and empty area histograms are the fitted contributions from jet fragmentation and π_{**} from D^{**} decays, respectively.

The semileptonic branching fraction of a b quark into $D\pi$ final state was measured as follows:

$$\mathrm{BR}(b \to D\pi\ell^- X) = \frac{\epsilon_Z}{N_Z}\,\frac{1}{2R_b}\,\frac{N(D\pi\ell^-)}{2\,\epsilon_{D\ell}\,\epsilon_{**}}\,\frac{f_{\tau_B}}{f_{\mathrm{cor}}}\,\frac{1-f_{\tau,c\to\ell}}{\mathrm{BR}_D} - \mathcal{F}_{\mathcal{H}} - \mathcal{F}_{\mathcal{D}^*}$$

where $R_b = 0.2166 \pm 0.0007$ is the Z hadronic decay rate into $b\bar{b}$ events; the branching fractions, BR_D, in the three decay modes $\mathrm{BR}(D^0 \to K^-\pi^+) = 0.0385 \pm 0.0009$, $\mathrm{BR}(D^+ \to K^-\pi^+\pi^+) = 0.090 \pm 0.006$ and $\mathrm{BR}(D^{*+} \to D^0\pi^+_*) = 0.683 \pm 0.014$ are used [1]. $\epsilon_{D\ell}$ and ϵ_{**} are respectively the efficiencies to reconstruct and select the $D\ell^-$ and π_{**} candidates from $\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell$ decays. They were obtained from the simulation and corrected by the factor f_{cor}, taking into account the various efficiencies as for track and vertex reconstruction and for particle identification. $f_{\tau,c\to\ell}$ and $\mathcal{F}_{\mathcal{H}}$ account for the "$\tau, c \to \ell$" and "hadronic" backgrounds; $\mathcal{F}_{\mathcal{D}^*}$ is the background due to residual $D^{*+}\pi^-\ell^-$ which applies to the "wrong" sign $D^0\pi^-\ell^-$ and $D^0K^-\ell^-$ samples only.

2.5. Systematics

The main systematic uncertainty for all the channels was induced by the fake Dl background (5–7%). Detector resolution discrepancies between data and simulation were the second systematic error source ($\sim$ 5%). Particle identification (pion, kaon and lepton) has also i uced a $\sim$4% systematic error.

3. Results

From the previous study, the b semileptonic branching fraction can be computed in each $D\pi\ell^-$ final state:

BR($b \to D^{**}\ell^-\bar{\nu}_\ell$) ($\times 10^{-3}$)			
$D^0h\ell^-$	$D^0\pi\ell^-$	$D^+\pi\ell^-$	$D^{*+}\pi\ell^-$
"right" sign			
$11.64 \pm 2.41 \pm 1.11$	$10.66 \pm 2.51 \pm 1.01$	$4.92 \pm 1.77 \pm 0.64$	$4.80 \pm 0.91 \pm 0.49$
"wrong" sign			
$1.89 \pm 1.40 \pm 0.42$	$2.31 \pm 1.46 \pm 0.38$	$2.63 \pm 1.48 \pm 0.41$	$0.59 \pm 0.67 \pm 0.15$

The "wrong" sign results are at less than 2 standard deviations from zero, thus $D\pi\pi$ final states will be neglected in the following. Using the production fraction BR($b \to \bar{B}^0$) =BR($b \to B^-$) $= 0.395 \pm 0.014$, the branching fractions:

$$\begin{aligned} \mathrm{BR}(\bar{B}^0 \to D^0\pi^+\ell^-\bar{\nu}_\ell) + \mathrm{BR}(\bar{B}^0 \to D^{*0}\pi^+\ell^-\bar{\nu}_\ell) &= (2.70 \pm 0.64\ (stat) \pm 0.27\ (syst))\% \\ \mathrm{BR}(B^- \to D^+\pi^-\ell^-\bar{\nu}_\ell) + \mathrm{BR}(B^- \to D^{*+}\pi^-\ell^-\bar{\nu}_\ell) &= (2.08 \pm 0.47\ (stat) \pm 0.20\ (syst))\% \end{aligned}$$

are measured. According to isospin conservation rules, the ratio of final states:

$$\frac{D^0\pi^+ + D^{*0}\pi^+}{D^+\pi^0 + D^{*+}\pi^0} = \frac{D^+\pi^- + D^{*+}\pi^-}{D^0\pi^0 + D^{*0}\pi^0} = 2$$

can be assumed, allowing to infer the branching fractions:

$$\begin{aligned} \mathrm{BR}(\bar{B}^0 \to D\pi\ell^-\bar{\nu}_\ell) + \mathrm{BR}(\bar{B}^0 \to D^*\pi\ell^-\bar{\nu}_\ell) &= (4.05 \pm 0.96\ (stat) \pm 0.41\ (syst))\% \\ \mathrm{BR}(B^- \to D\pi\ell^-\bar{\nu}_\ell) + \mathrm{BR}(B^- \to D^*\pi\ell^-\bar{\nu}_\ell) &= (3.12 \pm 0.71\ (stat) \pm 0.30\ (syst))\%. \end{aligned}$$

4. Summary and conclusion

The previous values are found in good agreement between each other. Thus, using DELPHI data recorded from 1992 to 1995, the average B meson semileptonic branching fraction into any excited D meson is computed to be:

$$\mathrm{BR}(\bar{B} \to D\pi\ell^-\bar{\nu}_\ell) + \mathrm{BR}(\bar{B} \to D^*\pi\ell^-\bar{\nu}_\ell) = (3.40 \pm 0.52\ (stat) \pm 0.31\ (syst))\%\ .$$

in good agreement with the expectation from the difference[1]:

$$\mathrm{BR}(\bar{B} \to \ell^-\bar{\nu}_\ell X) - \mathrm{BR}(\bar{B}^0 \to D^+\ell^-\bar{\nu}_\ell) - \mathrm{BR}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}_\ell) = (3.85 \pm 0.42)\%$$

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