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Observation of the semileptonic decays of B_s and Λ_b hadrons at LEP

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In 450000 hadronic Z decays recorded with the ALEPH detector at LEP, the yields of $D_s^-\ell^+$ and $\Lambda_c^+\ell^-$ combinations have been measured. 16.0 ± 4.3 $D_s^-\ell^+$ combinations were observed in the $D_s^- \to \phi\pi^-$ channel and 17.0 ± 4.5 combinations were observed in the $D_s^- \to K^{*0}K^-$ channel. 21.0 ± 5.0 $\Lambda_c^+\ell^-$ combinations were observed, with the Λ_c^+ reconstructed in the decay mode $\Lambda_c^+ \to pK^-\pi^+$. These events provide evidence for the decays $B_s \to D_s^- X\ell^+\nu$ and $\Lambda_b \to \Lambda_c^+ X\ell^-\bar{\nu}$. Assuming that the B_s and Λ_b semileptonic decays are dominantly three-body, these observed yields, after background subtraction, translate into the following product branching ratios: $\mathrm{Br}(\bar{b} \to B_s)\mathrm{Br}(B_s \to D_s^- X\ell^+\nu) = 0.040 \pm 0.011\,^{+0.010}_{-0.012}$, $\mathrm{Br}(b \to \Lambda_b)\mathrm{Br}(\Lambda_b \to \Lambda_c^+ X\ell^-\bar{\nu}) = 0.030 \pm 0.007 \pm 0.009$.

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1. Introduction

In the recent past, significant progress has been made in the study of the spectroscopy and weak decay dynamics of the B^0 and B^+ mesons [1]. The experimental information on the production and decay of the B_s and the Λ_b hadrons, however, is relatively modest[#1] [3,4]. Z decays provide an abundant source of a variety of b hadrons with a large boost, but to date only inclusive b samples have been used to measure B^0–$\overline{B}^0$ mixing and the inclusive b lifetime. It is of clear interest to isolate a sample of B_s and Λ_b decays as a first step towards measuring their production and decay properties.

Previous letters [4] presented evidence for b baryons in Z decays via correlation between a Λ and a high transverse momentum prompt lepton. In this letter, an observation of the semileptonic decays of the B_s and Λ_b[#2] hadrons via a study of opposite sign $D_s^- \ell^+$ and $\Lambda_c^+ \ell^-$ combinations, respectively, is reported. This study is based on a sample of 450 000 hadronic Z decays recorded with the ALEPH detector at centre-of-mass energies near 91.2 GeV during the 1990 and 1991 running of LEP.

As a result of the hard fragmentation of b hadrons, the decay products of the semileptonic decays of b hadrons emerge with high momenta. Due to the large mass of the b hadrons, their semileptonic decays are characterized by the large invariant mass of the charm hadron–lepton system. These two features of the b decay are used to distinguish the $D_s^- \ell^+$ and $\Lambda_c^+ \ell^-$ combinations that result from the semileptonic decays of the B_s and Λ_b, respectively, from other possible sources of such combinations. Throughout this paper charge conjugate reactions are implied, and unless stated otherwise, "B" and "D" refer to any weakly decaying beauty and charm mesons, respectively. In this letter a reference to a lepton always implies an electron or a muon and all branching ratios quoted are summed over these two particles.

2. The ALEPH detector

The ALEPH detector has been described in detail elsewhere [7]. Charged tracks are measured over the range $|\cos\theta| < 0.95$, where θ is the polar angle, by an inner cylindrical drift chamber (ITC) and a large cylindrical time projection chamber (TPC). These chambers are immersed in a magnetic field of 1.5 Tesla and together measure the momentum of charged particles with a resolution of $\delta p/p = 0.0008p\ (\mathrm{GeV}/c)^{-1} \oplus 0.003$ [7,8]. During the 1991 data-taking period, a double-sided silicon vertex detector, consisting of 96 silicon wafers arranged in two concentric cylinders with 6.4 and 11.5 cm average radii, was commissioned. It covers a solid angle $|\cos\theta| < 0.76$ and provides two three-dimensional measurements of charged tracks with a resolution of approximately 15 μm. The TPC provides up to 330 measurements of the specific ionization ($\mathrm{d}E/\mathrm{d}x$) of each charged track. For electrons in hadronic events, the $\mathrm{d}E/\mathrm{d}x$ resolution is 4.6% for 330 ionization samples. The electromagnetic calorimeter (ECAL), which surrounds the TPC and is inside the coil of the superconducting solenoid, is used to measure electromagnetic energy and, together with the TPC, to identify electrons. The hadron calorimeter (HCAL) is composed of the iron of the magnet return yoke interleaved with 23 layers of streamer tubes, and is surrounded by the muon chambers, an additional two layers of streamer tubes that cover the same angular range as the HCAL. The muon chambers are read out by cathode strips both parallel and perpendicular to the tubes. Therefore each layer provides a three-dimensional coordinate for charged tracks which penetrate the 7.5 interaction lengths of material between the interaction point and the muon chambers.

The selection of hadronic events is based on charged tracks and has been described elsewhere [9]. Leptons are identified in the ALEPH detector by matching a charged track measured in the TPC and ITC with either an energy deposit consistent with an electron in the ECAL, or a pattern of hits in the HCAL and muon

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[#1] The observed rate of like sign lepton pairs in $p\bar{p}$ and e^+e^- collisions is circumstantial evidence for the existence of B_s meson [2].

[#2] The Λ_b is expected to be the lightest [5,6] and most copiously produced b baryon. The Σ_b is expected to be heavier than the Λ_b by more than a pion mass; consequently it is expected to decay to the Λ_b. This study is also sensitive to semileptonic decays of the Ξ_b and Ω_b involving a Λ_c^+ in the final state. However, since the Ξ_b and Ω_b contain one or more strange quark, their production rates compared to that of the Λ_b are expected to be suppressed.

chambers consistent with being from a muon. In addition, the specific ionization of the electron candidate in the TPC is required to be within 2.5 standard deviations of the hypothesis provided at least 50 ionization samples are available. For momenta greater than 3 GeV, the electron identification efficiency is about 72% and the hadron misidentification probability varies with momentum from 0.8% to 0.1%. Muons with momenta greater than 3 GeV have an average identification efficiency of 78% and the hadron fake probability is typically 0.5%. The details of lepton identification have been discussed in previous publications [10,11].

3. The decay $B_s \rightarrow D_s^- X \ell^+ \nu$

While the semileptonic decay $B_s \rightarrow D_s^- X \ell^+ \nu$ leads to a $D_s^- \ell^+$ combination on the same side of an event, there are other processes which can also result in $D_s^- \ell^+$ combinations. The four sources of $D_s^- \ell^+$ combinations in Z decays are listed below:

$$B_s \rightarrow D_s^- X \ell^+ \nu, \qquad (1)$$

$$\bar{B} \rightarrow D_s^- D X, \quad D \rightarrow X \ell^+ \nu, \qquad (2)$$

$$B \rightarrow D_s^- \text{“K”}\, W^{*+}, \quad W^{*+} \rightarrow \ell^+ \nu, \qquad (3)$$

accidental correlations. (4)

The first three processes are illustrated in fig. 1. The first process represents the signal of interest while processes (2)–(4) constitute the background in this analysis; their production rates are discussed in the following paragraphs.

The features of D_s production in the decay of $B^-, \bar{B}^0$ mesons have been studied [12–15] near the $\Upsilon(4S)$ resonance. The inclusive rate $B \rightarrow D_s X$ is 11.1 ± 2.6%[#3]. The D_s production rate in $B^-, \bar{B}^0$ decay is consistent with the theoretical expectation [17–20] that all D_s are produced during the hadronization of $W^- \rightarrow \bar{c}s$. Attributing the entire D_s meson production rate in $B^-, \bar{B}^0$ decay to two-body or multi-body double-charm decay gives a product branching ratio for the process ($\bar{B} \rightarrow D_s^-$“D”X)(“D” $\rightarrow X \ell^+ \nu$) of 2.2 ± 0.5 %[#4].

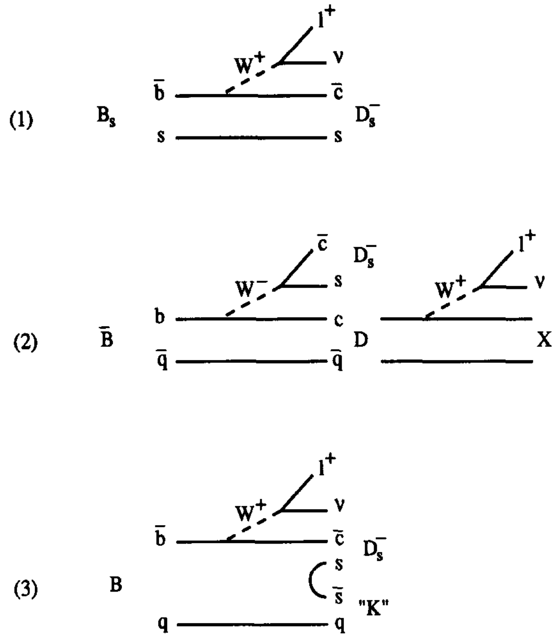

Fig. 1. Processes leading to $D_s^- \ell^+$ combinations.

To date, there exists no evidence for the process $B \rightarrow D_s^-$“K”W^{*+}. While such a process may occur, its rate is expected to be suppressed due to the required $s\bar{s}$ production from the sea. The semileptonic decays of $B^-, \bar{B}^0$ mesons have been measured [21,22] and are dominated by three-body decays. These measurements imply that the four-body semileptonic decay of B mesons is less than 7.8% at 95% confidence level. Assuming an $s\bar{s}$ production probability of 0.14 constrains the rate for the process $B \rightarrow D_s^-$“K”$\ell^+ \nu$ to be less than 1.1% at 95% confidence level. A less model-dependent 90% confidence level upper limit of $\mathrm{Br}(B \rightarrow D_s^- \text{“K”}\, W^{*+}) \leqslant 0.32 \cdot \mathrm{Br}(B \rightarrow D_s X)$ has been set by a study [23] of $D_s^- \ell^-$ correlations at the $\Upsilon(4S)$ where the signature of a negative lepton from a $\bar{B}^0$ (B^-) ensures that the D_s^- parent was a B^0 (B^+). Assuming that the rate for the virtual $W^{*+} \rightarrow \ell^+ \nu$

[#3] Here and throughout this paper $\mathrm{Br}(D_s^+ \rightarrow \phi\pi^+) = 2.7 \pm 0.7$ [16] has been used.

[#4] “D” here refers to an admixture of D^0 and D^+ and the appropriate fraction of these species is obtained from the observed occurrence of these mesons in two-body double-charm decays.

is[#5] 40%, a 90% confidence level upper limit on the rate for the process B → D_s^-"K"$\ell^+\nu$ of 1.4% is obtained.

The fourth process represents the possibility that a D_s^- produced in the decay of b hadron or directly from hadronization of a charm quark pairs up with a misidentified hadron or non-prompt lepton. The contribution of the accidental correlations can be estimated from the measured hadron misidentification probability, the non-prompt lepton rate and the observed inclusive yield of D_s^-. Since these probabilities are very small, this contribution to the $D_s^-\ell^+$ combinations is expected to be small and will be quantified later in this letter.

In order to differentiate among these sources of $D_s^-\ell^+$ combinations and isolate a sample of semileptonic B_s decays, advantage is taken of certain kinematic features of processes (1)–(3). In analogy with the $B^-, \overline{B}^0$ system, the semileptonic decays of the B_s are expected to be dominated by three-body decays. In the three-body semileptonic decay $B_s \to D_s^{(*)-}\ell^+\nu$, the D_s^- and the lepton emerge with high momentum, and the reconstructed invariant mass of the $D_s^-\ell^+$ system is large, on average, since only a neutrino and sometimes a low-energy photon (from D_s^{*-}) are missing. In contrast, process (2) is characterized by a much softer lepton momentum since it originates from the semileptonic D decay, and in addition the $D_s^-\ell^+$ invariant mass from this process is relatively smaller. Such features are also true for the process B → D_s^-"K"$\ell^+\nu$ which is a four-body decay.

In this analysis, D_s^- were identified in the channels $D_s^- \to \phi\pi^-$ and $D_s^- \to K^{*0}K^-$. The ϕ and the K^{*0}, identified by their decays $\phi \to K^+K^-$ and $K^{*0} \to K^+\pi^-$, were required to have momentum greater than 5.0 GeV in order to decrease the combinatorial background. Whenever TPC dE/dx information was available, the measured specific ionization of the kaon and the pion candidates were required to be within two standard deviations of the hypothesis. The resulting K^+K^- and $K^+\pi^-$ invariant-mass spectra are shown in fig. 2a and fig. 2b, respectively. In total, 6022 ± 321 ϕ and 55 858 ± 880 K^{*0} signal candidates were observed in the data sample, with masses and widths consistent with expectation from detector simulation and the natural widths of these resonances.

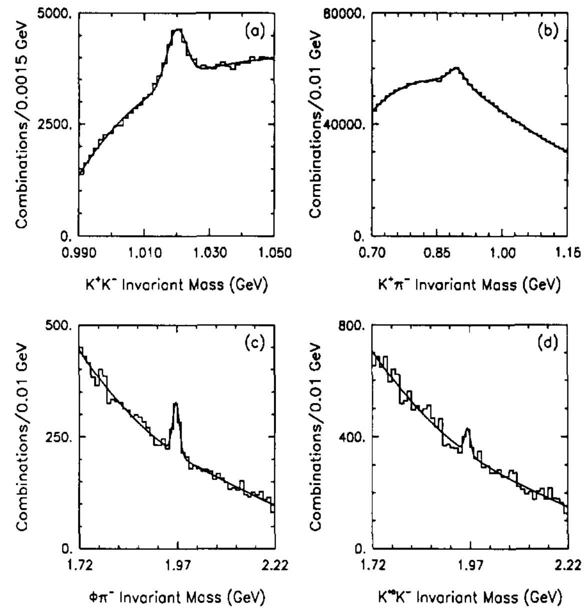

Fig. 2. (a) The invariant-mass spectrum of K^+K^- combinations with momenta greater than 5.0 GeV. (b) The invariant-mass spectrum of $K^+\pi^-$ candidates with momenta greater than 5.0 GeV. (c) The invariant-mass spectrum of $\phi\pi^-$ combinations with momenta greater than 8.0 GeV and cuts described in the text. (d) The invariant-mass spectrum of $K^{*0}K^-$ combinations with momenta greater than 8.0 GeV and cuts described in the text.

To reconstruct D_s^- candidates in the $\phi\pi^-$ channel, all K^+K^- candidates within ±0.009 GeV of the nominal ϕ mass were taken as ϕ candidates and were combined with all π^- candidates with momentum greater than 3.0 GeV. Similarly, D_s^- candidates were reconstructed in the $K^{*0}K^-$ channel by pairing all $K^+\pi^-$ candidates within ±0.05 GeV of the K^{*0} mass with charged tracks, under the kaon hypothesis, with momentum greater than 3.0 GeV. The specific ionization of these kaon ("bachelor" kaon) candidates was always required to be available and within two standard deviations of the kaon hypothesis. This requirement rejects 60% of true pions in the momentum range of interest. In both decay modes, the three tracks forming the D_s^- were fitted to a common vertex in three dimensions. In the $K^{*0}K^-$ channel, which suffers from large combinatorial background, the fitted vertex was required to be in front of the average fill-by-fill beam

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[#5] This is calculated assuming that $W^{*+} \to c\bar{s}$ is completely suppressed due to limited phase-space.

spot. In these decay modes of the D_s^-, the ϕ (K^{*0}) has zero helicity in the D_s^- rest frame; hence the angular distribution θ_K of the K^+ in the ϕ (K^{*0}) rest frame, with respect to the π^- (K^-), is of the form $\cos^2\theta_K$. In contrast, the combinatorial background has a flat distribution in $|\cos\theta_K|$. To suppress the combinatorial background, the D_s^- candidates were required to have $|\cos\theta_K|$ greater than 0.4. Figs. 2c and 2d show the invariant-mass distributions of all $\phi\pi^-$ and $K^{*0}K^-$ candidates, respectively, with momenta greater than 8.0 GeV. A fit to these distributions with a gaussian representing the signal and a second-order polynomial parameterizing the combinatorial background yielded 240 ± 38 reconstructed D_s^- in the $\phi\pi^-$ mode and 170 ± 45 in the $K^{*0}K^-$ mode.

These D_s^- candidates were then paired with electron and muon candidates with momenta greater than 3.0 GeV. The opening angle between the lepton and D_s^- candidates was required to be less than 45° to ensure that they came from the decay of the same b hadron. Furthermore, to be sensitive to semileptonic decay of B_s meson and minimize the contribution of processes (2) and (3) as well as the combinatorial background, the $D_s^-\ell^+$ invariant-mass was required to be greater than 3.0 GeV. This requirement eliminates 62% of the contribution from process (2) and 53% from process (3), while retaining 92% of $D_s^-\ell^+$ combinations from semileptonic decays of the B_s. To further reduce the combinatorial background in the $K^{*0}K^-$ channel for the 1991 data sample, for which the vertex detector was operational, the fitted D_s^- vertex was required to be displaced by 0.08 cm transverse to the beam direction with respect to the average fill-by-fill beam spot.

The $\phi\pi^-$ and $K^{*0}K^-$ invariant-mass distributions for the $D_s^-\ell^+$ combinations after the requirements mentioned above are shown in fig. 3a and fig. 4a. A clear signal at the D_s^- is evident in each case. These mass distributions were fitted with a gaussian at the D_s^- mass and a flat background. The fitted D_s^- mass of 1.966 ± 0.003 and RMS width of 0.008 ± 0.001 GeV for the $\phi\pi^-$ mode and 1.972 ± 0.003 and 0.0078 ± 0.001 GeV for the $K^{*0}K^-$ mode are in agreement with the expectation based on a Monte Carlo simulation of process (1). In the $\phi\pi^-$ mode 16.0 ± 4.3 $D_s^-\ell^+$ combinations were observed, and 17.0 ± 4.5 combinations were observed in the $K^{*0}K^-$ mode. From the known hadron–lepton misidentification probabilities, the contribution of the accidental combinations in the $D_s^-\ell^+$ sample was estimated to be 0.53 ± 0.30 and 0.45 ± 0.25 for the $\phi\pi^-$ and $K^{*0}K^-$ modes, respectively. Figs. 3b and 4b show the mass distributions of $\phi\pi^-$ and $K^{*0}K^-$ candidates, respectively, forming the (wrong-sign) $D_s^-\ell^-$ combinations. No enhancement is observed at the D_s^- mass, consistent with the low level of estimated accidental background. The background subtracted excess of $D_s^-\ell^+$ is 15.5 ± 4.3 in the $\phi\pi^-$ mode and 16.5 ± 4.5 in the $K^{*0}K^-$ mode.

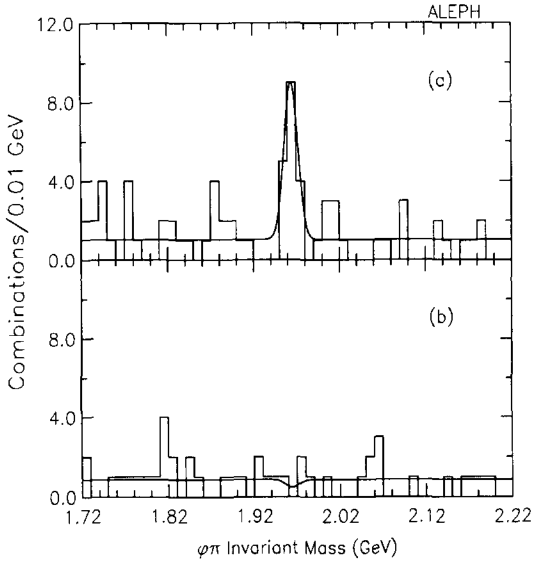

Fig. 3. The invariant-mass spectrum of the $\phi\pi^-$ combinations is shown in (a) for the "right sign" $D_s^-\ell^+$ and (b) the "wrong sign" $D_s^-\ell^-$ combinations. The mass range near the nominal D^- mass was excluded from the fit.

To establish that the observed $D_s^-\ell^+$ combinations come from the semileptonic decay of the B_s, the contributions from background processes (2) and (3) were estimated. In the $\phi\pi^-$ channel, the detection efficiency for the $D_s^-\ell^+$ combinations, passing the requirements enumerated earlier in the text, from process (2) is $1.52 \pm 0.15\%$, and for process (3), using a simulation of the decay $B \to D_s^-$"K" $\ell^+\nu$, is $2.84 \pm 0.39\%$. The background from process (2) is well known and expected; consequently its contribution of 1.8 ± 0.6 to the observed $D_s^-\ell^+$ combinations was subtracted. The contribution of process (3) could be as large as 2.0 ± 0.6 based on the 90% confidence level upper limit of $\mathrm{Br}(B \to D_s^-$"K" $W^{*+}) \leqslant 0.32 \cdot \mathrm{Br}(B \to D_s^-X)$ cited earlier in the text. Since

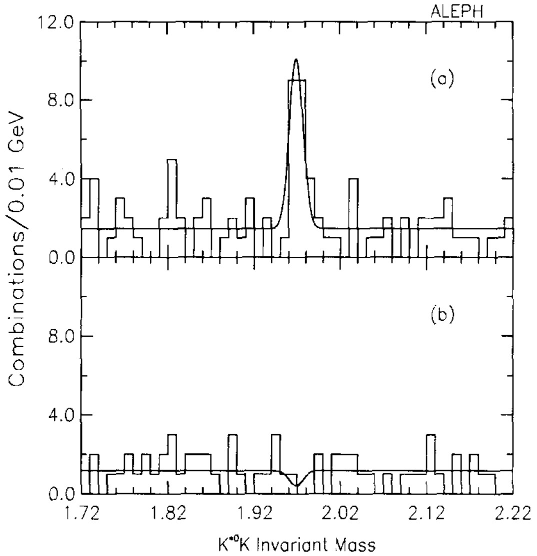

Fig. 4. The invariant-mass spectrum of the $K^{*0}K^-$ combinations is shown in (a) for the "right sign" $D_s^-\ell^+$ and the (b) "wrong sign" $D_s^-\ell^-$ combinations. The mass range near the nominal D^- mass was excluded from the fit.

the existence of this process is, at present, hypothetical, the possible contribution from this process was considered as a systematic error on the measurement of the Br($B_s \rightarrow D_s^- X\ell^+\nu$). The resulting number of $D_s^-\ell^+$ combinations from the process $B_s \rightarrow D_s^- X\ell^+\nu$ in this channel is $13.7 \pm 4.4^{+0.0}_{-2.0}$.

In the $D_s^- \rightarrow K^{*0}K^-$ channel, the estimated contribution of process (2) is 1.6 ± 0.6 and the 90% confidence level upper limit for process (3) is 1.8 ± 0.6 $D_s^-\ell^+$ combinations. In addition, a possible background contribution to the $D_s^-\ell^+$ combinations for this channel comes from the decay $B \rightarrow D^- X\ell^+\nu$ followed by $D^- \rightarrow K^{*0}\pi^-$. Misinterpretation of the "bachelor" pion as a kaon produces a sharp enhancement (reflection) [#6] near the D_s^- mass when the pion carries a large fraction of the D_s^- momentum. In general the "reflected" mass is quite broad, but about 37% of the $D^- \rightarrow K^{*0}\pi^-$ produced in the semileptonic decays of b hadrons can contribute to an enhancement near (±0.024 GeV) the D_s^- mass. As previously stated, requiring the dE/dx of the "bachelor" kaon to be within two standard deviations of the kaon hypothesis eliminates 60% of the remaining D^- background.

The π–K dE/dx separation was also used to obtain an estimate of the $D^-\ell^+$ contamination from data. The invariant-mass distribution of all $K^{*0}K^-$ combinations where the specific ionization of the K^- candidate was consistent with the pion hypothesis but inconsistent (at two standard deviations) with the kaon hypothesis was examined. No enhancement was observed at the D_s^- mass. A fit to this distribution yielded 2.2 ± 3.0 combinations, which translates into a $D^-\ell^+$ contribution to the observed $D_s^-\ell^+$ sample of 1.8 ± 2.4, which was subtracted. An estimate of this background contribution from Monte Carlo simulation was 1.0 ± 0.8, consistent with the estimate from data. Hence, in this channel, the number of $D_s^-\ell^+$ combinations originating from the process $B_s \rightarrow D_s^- X\ell^+\nu$ is $13.1 \pm 5.5^{+0.0}_{-1.8}$.

Assuming that the semileptonic decay of the B_s is dominated by the three-body decays $B_s \rightarrow D_s^{(*)-}\ell^+\nu$, reconstruction efficiencies of 6.71 ± 0.55 % and $5.4 \pm 0.54 \pm 0.6$% were estimated for the $\phi\pi^-$ and the $K^{*0}K^-$ channels, respectively, using the JETSET 7.2 Monte Carlo program [24] and ALEPH detector simulation. In the $K^{*0}K^-$ channel, the error on the reconstruction efficiency of 0.6% corresponds to a $^{+50}_{-20}$% variation in the B_s lifetime from the average b lifetime. With these efficiencies and the measured [9,25] rate for the process $Z \rightarrow b\bar{b}$, the observed yields translate into product branching ratios of $\mathrm{Br}(\bar{b} \rightarrow B_s) \cdot \mathrm{Br}(B_s \rightarrow D_s^- X\ell^+\nu) = 0.038 \pm 0.0120 \pm 0.010^{+0.000}_{-0.005}$ for the $\phi\pi^-$ channel and $\mathrm{Br}(\bar{b} \rightarrow B_s) \cdot \mathrm{Br}(B_s \rightarrow D_s^- X\ell^+\nu) = 0.047 \pm 0.020 \pm 0.013\ ^{+0.000}_{-0.006}$ for the $K^{*0}K^-$ channel. In each case, the first error is statistical, the second is the systematic error largely due to the poor knowledge of D_s^- branching ratios and the third error reflects the possible overestimation due to the process $B \rightarrow D_s^-$"K"$\ell^+\nu$. The weighted average of these two measurements, taking into account the common systematic errors, is $\mathrm{Br}(\bar{b} \rightarrow B_s) \cdot \mathrm{Br}(B_s \rightarrow D_s^- X\ell^+\nu) = 0.040 \pm 0.011 \pm 0.010\ ^{+0.000}_{-0.006}$.

4. The decay $\Lambda_b \rightarrow \Lambda_c^+ X\ell^-\bar{\nu}$

Previous letters have [4] reported evidence for semileptonic decay of b baryons via an inclusive

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[#6] The reflection is symmetric. If the kaon from the decay $D_s^- \rightarrow K^{*0}K^-$ were misinterpreted as a pion, a similar enhancement would occur near the D^- mass.

study of the $\Lambda\ell^-$ correlations in Z decays. In those analysis only the Λ from the decay of the charm baryon and the lepton from the b-baryon decay were reconstructed. In the following analysis a more direct study of the Λ_b semileptonic decay with a completely reconstructed Λ_c^+ is reported.

The five sources of $\Lambda_c^+\ell^-$ combinations in Z decays are

$$\Lambda_b \to \Lambda_c^+ X \ell^- \bar{\nu}, \tag{5}$$

$$B \to \Lambda_c^- X \ell^+ \nu, \tag{6}$$

$$B \to \Lambda_c^- D_s^+ X, D_s^+ \to X \ell^+ \nu, \tag{7}$$

$$\Lambda_b \to \Lambda_c^+ D_s^-, D_s^- \to X \ell^- \bar{\nu}, \tag{8}$$

accidental correlations. (9)

Unlike process (5), which is the signal of interest in this analysis, $\Lambda_c^+\ell^-$ combinations from processes (6)–(8) are characterized by relatively low invariant masses, largely (for processes (6) and (7)) as a consequence of the baryon-number conservation in the final state and also (for process (8)) due to missing energy in the cascade decay of the D_s^+. Furthermore, the leptons from processes (6)–(8) have a soft momentum spectrum, either due to phase-space suppression or due to their origin in the cascade decay $b \to c \to \ell$.

No experimental evidence exists for processes (6) and (7). The ARGUS Collaboration has searched for the process $\bar{B} \to pe^-X$ and placed an upper limit of $\mathrm{Br}(\bar{B} \to pe^-X) \leqslant 0.16\%$ at 90% confidence level [26]. Assuming that at least half of the Λ_c^+ decays produce a proton in the final state, this implies that the process $\bar{B} \to \Lambda_c^+ X \ell^- \bar{\nu}$ occurs with a rate less than 0.32% at 90% confidence level. The rates for the processes (7) and (8) are estimated to be less than 0.1% and 1.2%, respectively, using the measured rates [28,16] for $B \to \Lambda_c^+ X$ and $D_s^+ \to X\ell^+\nu$.

The Λ_c^+ candidates were identified in this analysis via the decay $\Lambda_c^+ \to pK^-\pi^+$. This is the most prolific observed decay mode of the Λ_c^+ but offers very few favourable kinematic features. To suppress the combinatorial background, the proton, the kaon and the pion candidates, with the appropriate charge combination, were required to have momenta greater than 4, 2 and 1 GeV, respectively. The specific ionization in the TPC of the proton candidate was required to be inconsistent (2 standard deviations) with that expected for a pion of similar momentum. This requirement removes approximately 96% of all pion tracks from consideration as a proton while retaining 50% of all protons. The kaon candidate was required to have its specific ionization within 3 standard deviations of the expectation for a kaon when $\mathrm{d}E/\mathrm{d}x$ information was available for the track. The three tracks were fitted to a common vertex in three dimensions, which was required to be in front of the average fill-by-fill beam spot.

Surviving Λ_c^+ candidates with momenta greater than 8.0 GeV were then paired with identified leptons, with momenta greater that 3 GeV, within a 45° cone of the Λ_c^+ direction. The momentum sum of the $\Lambda_c^+\ell$ system was required to be greater than 20 GeV and the invariant mass of the pair was required to exceed 3.5 GeV. These requirements remove approximately 90% of all surviving combinatorial background and practically eliminate the $\Lambda_c^+\ell^-$ contributions from processes (6)–(8). From a JETSET 7.2 based simulation, less than 1.2 $\Lambda_c^+\ell^-$ combinations were expected from processes (6)–(8) in the data sample.

The invariant-mass distribution of the $pK^-\pi^+$ candidates for the surviving $\Lambda_c^+\ell^-$ combinations is displayed in fig. 5a. A fit to this mass distribution using a gaussian to parameterize the signal and a flat background yielded 21.0 ± 5.0 events. The contribution of the accidental combinations to this sample was estimated to be 0.4 ± 0.3. The observed Λ_c^+ mass of 2.283 ± 0.002 and resolution of 0.008 ± 0.001 GeV are consistent with the expectation. The $pK^-\pi^+$ invariant-mass distribution for the "wrong-sign" $\Lambda_c^+\ell^+$ combinations is shown in fig. 5b.

From a simulation of the three-body decay $\Lambda_b \to \Lambda_c^+\ell^-\bar{\nu}$ using the JETSET prescription, a reconstruction efficiency for this process of $8.0 \pm 1.0 \pm 1.0$ % was obtained. The second error on the efficiency estimate reflects the possible consequences of Λ_b polarization [27] and the uncertainty in the modeling of this process. Using the measured partial width of the process $Z \to b\bar{b}$, the measured rate [28] $\mathrm{Br}(\Lambda_c^+ \to pK^-\pi^+) = 4.3 \pm 1.1\%$ and the efficiency quoted above, a product branching ratio of $\mathrm{Br}(b \to \Lambda_b) \cdot \mathrm{Br}(\Lambda_b \to \Lambda_c^+ X \ell \bar{\nu}) = 0.030 \pm 0.007 \pm 0.009$ was obtained. The first error is statistical and the second error largely reflects the error on the measurement of

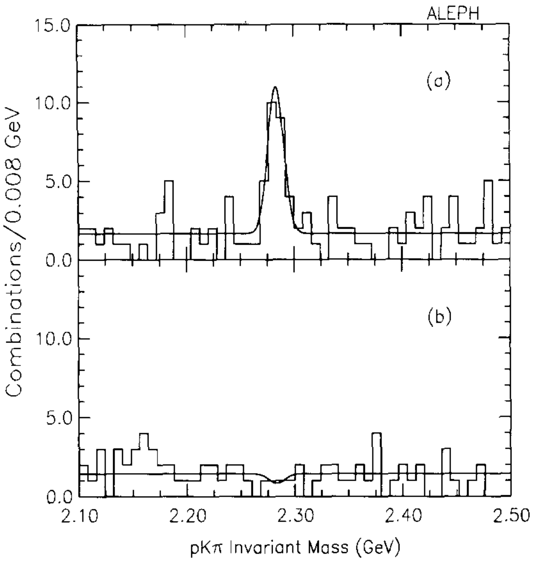

Fig. 5. The invariant-mass spectrum of the $pK^-\pi^+$ combinations is shown in (a) for the "right sign" $\Lambda_c^+\ell^-$ and (b) the "wrong sign" $\Lambda_c^+\ell^+$ combinations.

the rate for the process $\Lambda_c^+ \to pK^-\pi^+$ and model dependence in the estimation of the reconstruction efficiency. This result is consistent with the previous measurements [4] assuming that the Λ_b is the dominantly produced b baryon at the Z resonance.

5. Conclusion

In 450000 hadronic Z decays recorded with the ALEPH detector at LEP, the yields of $D_s^-\ell^+$ and $\Lambda_c^+\ell^-$ combinations have been measured. These events provide evidence for the decays $B_s \to D_s^- X\ell^+\nu$ and $\Lambda_b \to \Lambda_c^+ X\ell^-\bar{\nu}$.

16.0 ± 4.3 $D_s^-\ell^+$ combinations in the $D_s^- \to \phi\pi^-$ channel and 17.0 ± 4.5 combinations in the $D_s^- \to K^{*0}K^-$ channel were observed. The probability that these $D_s^-\ell^+$ combinations are explained by non-B_s background is less than 0.01%. The product branching ratio for semileptonic B_s decay is

$$\mathrm{Br}(\bar{b} \to B_s) \cdot \mathrm{Br}(B_s \to D_s^- X\ell^+\nu)$$

$$= 0.040 \pm 0.011^{+0.010}_{-0.012} .$$

Similar results using the $D_s^- \to \phi\pi^-$ and $K^{*0}K^-$ decay modes were presented by the DELPHI Collaboration at the 1992 LaThuile and Moriond Spring meetings [29,30]. These measurements at LEP represent clear evidence for the existence of the B_s meson and provide the first measurement of its semileptonic decay rate.

21.0 ± 5.0 $\Lambda_c^+\ell^-$ combinations were observed in the $\Lambda_c^+ \to pK^-\pi^+$ channel. This is the first observation of semileptonic Λ_b decay with exclusively reconstructed charm baryons. The product branching ratio for semileptonic Λ_b decay is

$$\mathrm{Br}(b \to \Lambda_b) \cdot \mathrm{Br}(\Lambda_b \to \Lambda_c^+ X\ell\bar{\nu})$$

$$= 0.030 \pm 0.007 \pm 0.009.$$

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