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Heavy Flavor Fragmentation and Decay at SLD *

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Abstract

Results on heavy quark fragmentation obtained using the SLD detector at the SLAC Linear Collider are presented. This talk will cover the ratio of vector to pseudoscalar charmed meson production, the inclusive B hadron energy distribution, the inclusive particle production in heavy jets compared to their production in light jets, and charged and neutral B meson lifetimes.

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1 Introduction

Heavy quark fragmentation is interesting and useful in that it is very different from light quark fragmentation, perturbative QCD is able to make useful predictions, and the measurements remain relatively imprecise. Precision measures of neutral and charged B hadron decays are important to test the spectator model as well as to provide needed input for electroweak studies.

This talk will present results on:

- Production of vector and pseudoscalar charmed mesons[1],
- Inclusive B-hadron energy distribution[2],
- Production of $\pi^{\pm}, K^{\pm}, K^{o}, K^{*0}, \phi, p$, and Λ in heavy compared to light jets[3],
- Charged and Neutral B-hadron lifetimes[4].

The characteristics of the SLAC Linear Collider (SLC) and Large Detector (SLD) [5] are well known and will not be repeated here. Of particular importance for the physics discussed here, the pixel vertex detector made possible reliable and efficient identification of heavy quark events and the CRID (Cerenkov Ring Imaging Detector) provided high-quality identification of charged particles. Most of the results presented here are based on 150K events gathered by February, 1995; the B lifetime results use the 300K events gathered through December, 1997.

2 Prompt D^{+} and D^{*+} Production

In order to help understand the fragmentation of c-quarks directly into D-mesons in detail we have measured the production rates of prompt charmed pseudoscalar D^{+} and vector D^{*+} mesons[†] as a function of scaled energy x in hadronic Z^{o} decays as well as the spin alignment of D^{*+} along their flight direction.

To extract a sample of charged D and D^{*} mesons produced directly by the fragmentation of c-quarks, we proceed as follows. Charged D's are searched for using the $K^{-}\pi^{+}\pi^{+}$ decay mode. D^{*+} are found by first isolating all D^{o} decays into $K^{-}\pi^{+}$ and $K^{-}\pi^{+}\pi^{-}\pi^{+}$ and then combining with a secondary pion, π_{s}^{+}. Various cuts are made to purify the sample including $p > 1$ GeV/c for all tracks, $x_{D^{+}} > 0.2$, a decay vertex fit probability greater than 1%, and D^{+} decay length significance greater than 3 standard deviations. x_{D} is the fractional energy carried by the meson, $x_{D} = 2E_{D}/\sqrt{s}$, where E_{D} is the energy of the charmed meson and $\sqrt{s}$ is the c.m. energy.

The sample was then divided into c-rich and b-rich samples using the D^{o} or D^{+} impact parameter, the D^{o} proper decay time, and a b-tag in the opposite hemisphere based on the number of tracks with impact parameters at least three times the error. The good separation between $c\bar{c}$ and $b\bar{b}$ is apparent in Fig. 1 for the $K\pi$ mode. Similar separation was obtained

[†]The inclusion of charge-conjugate states is implied throughout this section

in the $D^+ \to K^-\pi^+\pi^+$ decay mode. These distributions are then unfolded to obtain the direct $c \to D^\pm$ and $c \to D^{*\pm}$ contributions.

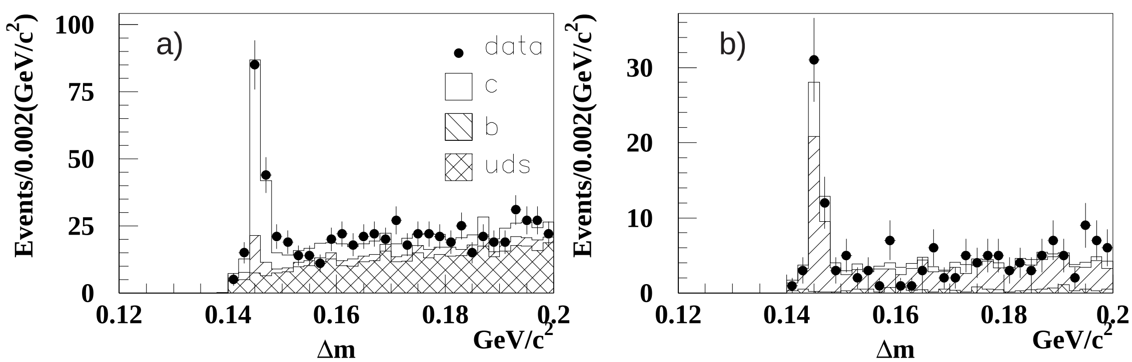

Figure 1: ΔM distributions for $D^{*+} \to D^0\pi_s^+$ in the $D^0 \to K^-\pi+$ mode. a) shows the c-rich sample and b) the b-rich. The points represent the data and the histograms represent the simulation, for which the flavor composition is indicated.

The measured numbers of D^{*+} and D^+ in $c\bar{c}$ events can be related to the number of primary $c\bar{d}$ pairs, $N_{c\bar{d}}$, via the relative vector to pseudoscalar meson production parameter $P_V = V/(P+V)$. Solving $N_{c\to D^{*+}}/N_{c\to D^+} = P_V/(1-P_V BR_*)$ where $BR_* = BR(D^{*+} \to D^o\pi^+)$ in each bin of x_D yields Fig. 2. The data are consistent with simple spin counting ($P_V = 0.75$) as well as theoretical predictions by Suzuki[6] and Braaten *et al* [7]. Averaging over $x_D > 0.4$, we obtain the preliminary result $P_V = 0.650 \pm 0.089(stat) \pm 0.032(syst) \pm 0.030(BR)$. This is consistent with LEP results[8] [9].

The D^{*+} spin alignment along its flight direction was studied by considering the angle θ^* between the momentum direction of the D^{*+} in the laboratory frame and the daughter D^0 in the D^{*+} rest frame. The events were separated into several x_{D^*} bins and then fit to $(1+\alpha\cos^2\theta^*)$ in each bin. The results for α are shown in Fig. 3 where they are compared with theoretical predictions by Suzuki [6] and Braaten *et al* [7]. There is no evidence for spin alignment of the prompt D^{*+} at any x_{D^*}. The average for $x_{D^*} > 0.4$ is $\alpha = 0.02 \pm 0.38(stat) \pm 0.02(syst.)$ (preliminary), also consistent with zero.

3 b Quark Fragmentation Function

Measurements of heavy hadron energy spectra can be used to constrain both perturbative QCD, which can predict the heavy quark spectrum, and the hadronization process which transforms the quark into a heavy hadron. We have measured the B hadron energy spectrum by reconstructing B hadron energies on an event by event basis using the $B \to DlX$ decay mode.

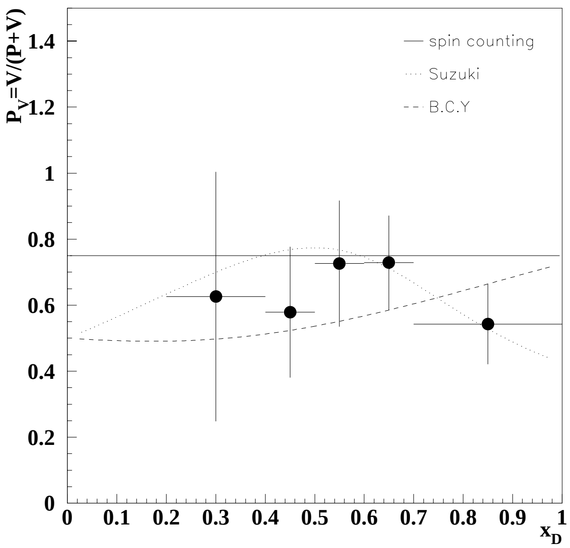

Figure 2: Preliminary measured P_V (dots) as a function of x_D

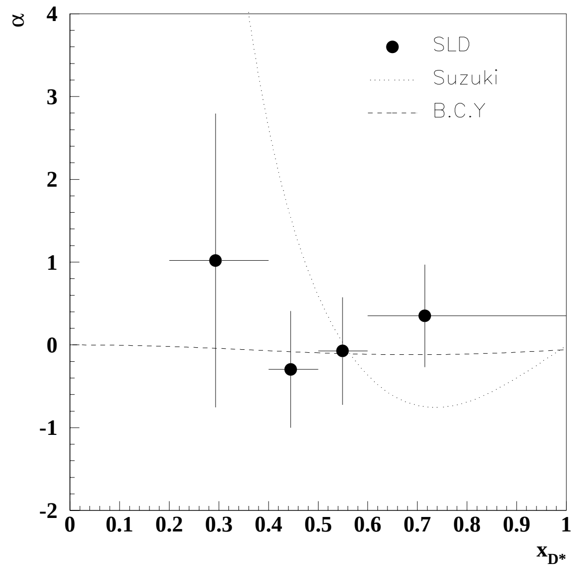

Figure 3: Preliminary fitted spin alignment parameter α for primary D^{*+} mesons as a function of x_{D^*}.

The analysis procedure consists of first selecting leptons using the Liquid Argon Calorimeter (LAC) to identify $e^{\pm}$ and the Warm Iron Calorimeter (WIC) to identify $\mu^{\pm}$. Independently all candidate D decay vertices are reconstructed using the vertex detector and drift chamber. If both an identified lepton and a reconstructed D decay vertex are present, the lepton is intersected with the D track to form the B decay vertex. Finally cuts on M_D, M_B, and the length of the D and B tracks are imposed to purify the sample. This resulted in a sample of 293 events with $\mu^{\pm}$ and 304 events with $e^{\pm}$.

The energy of the B hadron is then determined by a subtraction technique. First the energy of the jet, E_{jet}, containing the B is determined from simple kinematics (using angles only for 3 jet events). Then the charged and neutral energy, E_{chrg} and E_{neut}, in the jet not associated with the B are estimated. To calculate E_{chrg}, all the unassociated charged tracks are assigned the pion mass. E_{neut} is estimated as the sum of electromagnetic calorimeter clusters in the jet not associated with charged tracks. Then, $E_B = E_{jet} - E_{chrg} - E_{neut}$. Corrections are made for neutral tracks from the D vertex and the distribution unfolded to correct for the B energy resolution.

The resulting X_{E_B} distribution[10] is shown in Fig. 4. The average is $< X_{E_B} >= 0.718 \pm 0.011(stat) \pm 0.010(syst) \pm 0.019(unfold)$.

4 Identified Particle Production in Heavy and Light Flavor Jets

This topic depends on reliable charged particle identification which is largely provided by the CRID. Samples of events enriched in light (uds), c, and b primary flavors were selected

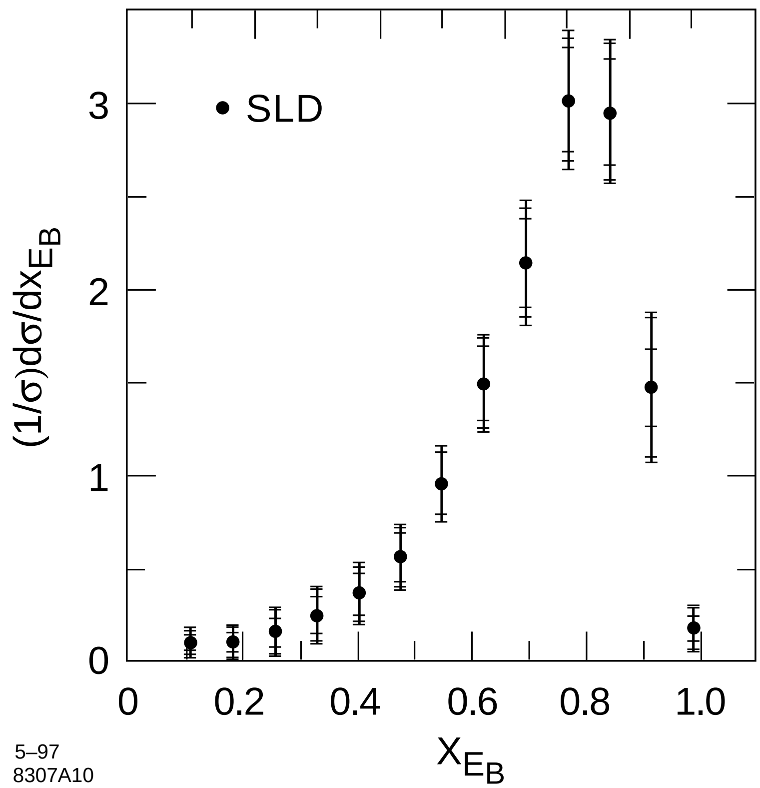

Figure 4: The distribution of reconstructed scaled energies for B hadron candidates.

based on the signed impact parameters δ of charged particles. n_{sig}, the number of tracks with $\delta > 3\sigma_\delta$ was calculated for each event. Events with $n_{sig} = 0$ were assigned to the light sample, those with $n_{sig} \geq 3$ to the b sample, and the remainder to the c sample.

Fig. 5 shows the $x_p = 2p/E_{cm}$ distribution of identified hadrons in Z^o decays into light flavors. Fig. 6 shows the ratio of the production of these particles in b and c flavor jets to their production in light flavor jets. Note that there is a large flavor dependence, which is consistent with the fragmentation and decay properties of heavy hadrons. The main features are well described by the JETSET [11] and UCLA [12] models, but HERWIG [13] has some trouble describing the $\pi^\pm$ and K features.

5 Measurement of the $B^\pm$ and B_d^0 Meson Lifetimes

We have updated our determination of the charged and neutral B lifetimes using the 300K events obtained through December, 1997. This is interesting as a test of the spectator model – are the charged and neutral lifetimes equal, unlike for the D mesons – and to generate the precise inputs needed for incisive electroweak studies including V_{cb}, R_b, A_b, and $B^o - \bar{B}^o$ mixing.

The small SLC beam spot (roughly $2 \times 1 \mu m^2$) and the close in vertex detector (first layer only 2.5 cm from the Interaction Point (IP)) give SLD a particular advantage in this

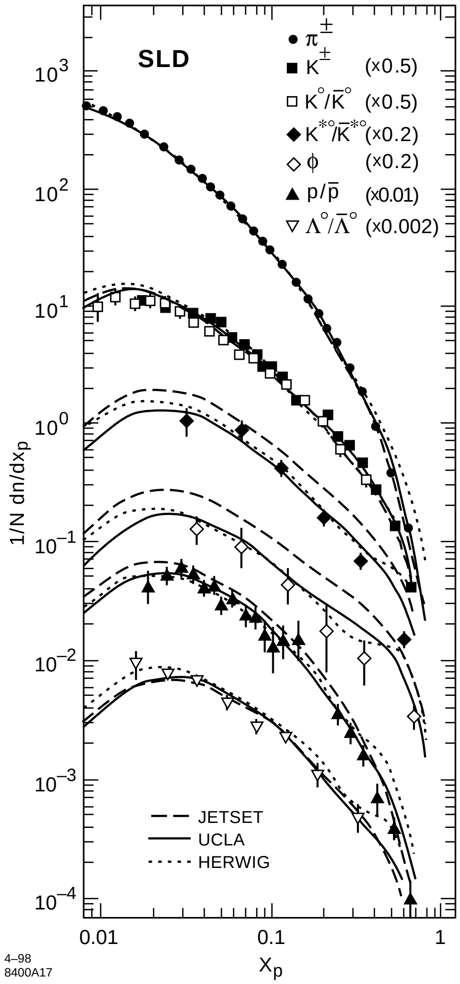

Figure 5: Identified hadron differential cross sections in light-flavor events.

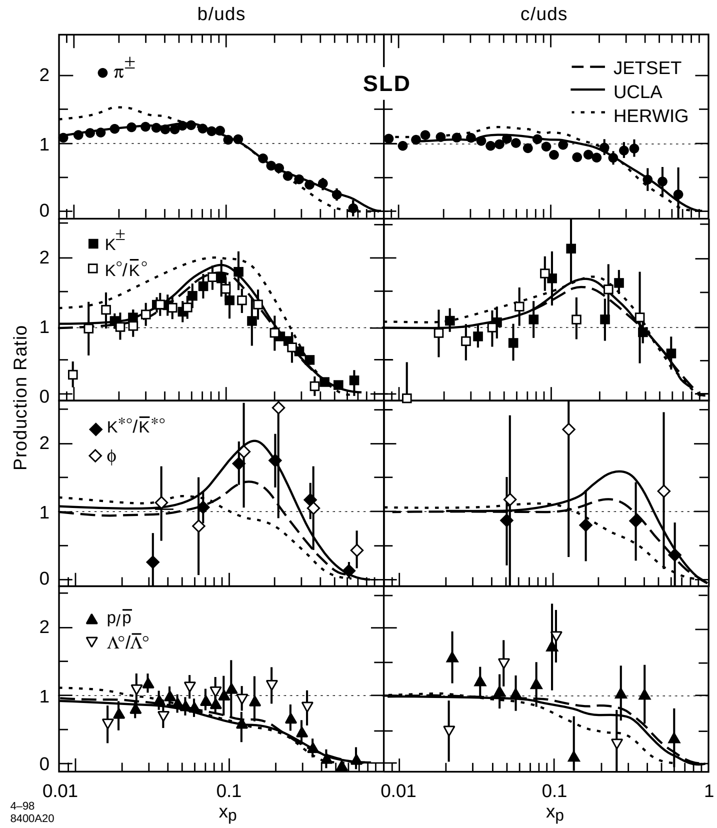

Figure 6: Ratios of the particle production in b-flavor events to that in light-flavor events (left) and in c-flavor:light-flavor (right). Also shown are the predictions of the three fragmentation models

measurement, which is exploited to the full by the topological algorithm [14] used to isolate B decays. This algorithm starts by seeking well-measured tracks which form a "seed vertex" that is displaced from the IP. Additional tracks are then attached to the seed vertex by an iterative algorithm. Finally, after correcting for missing transverse momentum, those vertices with invariant mass > 2 GeV$/c^2$ are selected, yielding 35,947 decay candidates which are 98% pure B hadrons.

An event is then classified as a $B^{\pm}$ or a B^o decay depending on whether the net charge of the tracks leaving the vertex is zero. Fig 7 shows the decay length distributions for the charged and neutral vertices. A weighted Monte Carlo fit to the data yielded: $\tau(B^{\pm}) = 1.665 \pm 0.029 \pm 0.042$ ps, $\tau(B^o) = 1.612 \pm 0.030 \pm 0.055$ ps, $\tau(B^{\pm})/\tau(B^o) = 1.030 \pm 0.035 \pm 0.027$

These SLD results are very precise and can be combined with other similar measurements. The world averages are $\tau(B^{\pm}) = 1.67 \pm 0.04$ ps and $\tau(B^{\pm})/\tau(B^o) = 1.07 \pm 0.04$. Note that the lifetime ratio is consistent with 1.0 as predicted by the spectator model and very unlike the charm meson case.

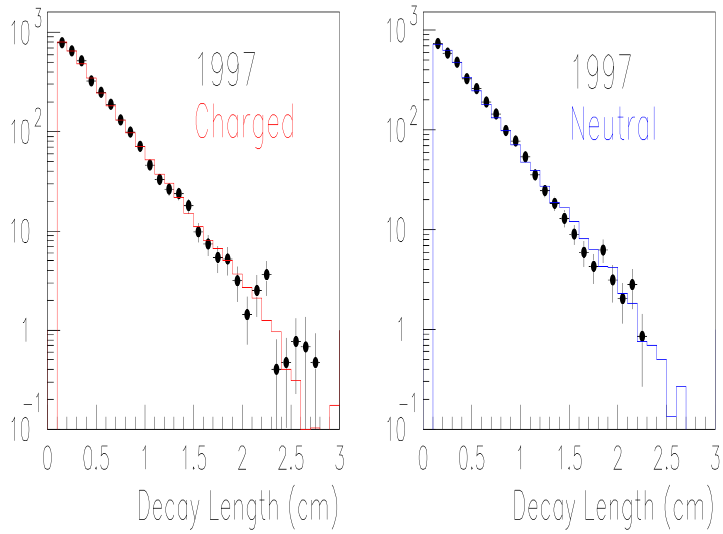

Figure 7: Decay length distribution for data (points) and best fit Monte Carlo (histogram) in the topological analysis of B lifetimes.

6 Conclusions

In summary, we have measured:

- the production of vector and pseudoscalar charmed mesons and obtained $P_V = V/(V + P) = 0.65 \pm 0.09 \pm 0.04$, consistent with simple spin counting. Further, no spin slignment of the D^{*+} was observed.

- the shape of the inclusive B-hadron energy distribution with: $< x_{E_B} > = 0.716 \pm 0.011 \pm 0.022$.

- the relative production of $\pi^{\pm}, K^{\pm}, K^0, p, \Lambda, \phi, K^{*0}$ particles. Very different production rates in heavy versus light jets were observed.

- charged and neutral B-hadron lifetimes with good accuracy. In particular, the charged to neutral lifetime ratio, $\tau_{B^+}/\tau_{B^\circ} = 1.030 \pm 0.035 \pm 0.027$ is consistent with the spectator model.

With the end of the current run in June 1998, almost 500K events are available. We plan to continue to exploit the strengths of the SLD detector, especially the Vertex Detector and the particle identification, for more and improved heavy flavor QCD measurements.

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