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b Decay Charm Counting Via Topological Vertexing*

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Abstract

We present a new and unique measurement of the branching fractions of b hadrons to states with 0, 1, and 2 open charm hadrons, using a sample of 350,000 Z's collected during the SLD/SLC 97-98 run. The analysis takes advantage of the excellent vertexing resolution of the VXD3, a pixel- based CCD vertex detector, which allows the separation of B and cascade D decay vertices. Analysis of the decay length distributions for each of the 1-, 2-, and 3-vertex topologies allows the extraction of the inclusive branching fractions. We measure: $BR(b \to 0D) = 5.6\% \pm 1.1\%(stat.) \pm 2.0\%(syst.)$, $BR(b \to 2D) = 24.6\% \pm 1.4\%(stat.) \pm 4.0\%(syst.)$ (preliminary), where b and D represent mixtures of open b and open c hadrons.

1. Introduction

An outstanding puzzle in b decay physics is that the theoretical prediction for the semileptonic branching ratio is somewhat larger than the currently measured values. A simple resolution of this puzzle is for the non-semileptonic decay amplitude to be larger than expected, thus enhancing the total decay cross section and reducing the predicted semileptonic decay rate. The total b decay cross section may be separated into three components: those containing 0,1, or 2 open charm mesons, ($0D$, $1D$, $2D$). The majority of semi-leptonic decays are in the $1D$ category with only a small fraction in the $0D$ category. Measurements of these 3 inclusive branching fractions therefore have the potential to resolve the b decay puzzle.

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2. The Analysis Technique

In our analysis, we take advantage of the characteristic vertex multiplicity and separation distributions for each of the inclusive decay modes. If all vertices were detectable, we would find exactly one vertex in a $0D$ decay, two in a $1D$ decay, and three in a $2D$ decay. However, finite vertexing resolution and a population of invisible neutral vertices cause these categories to be mixed together. Estimating the vertex separation distributions requires a careful modelling of the decay kinematics leading to the true distributions and of the vertexing resolution. The data distributions can be fit to a linear combination of the smeared distributions predicted by the MC in order to extract the desired branching fractions.

Separation of distinct vertices is possible when the vertex resolution scale is smaller than the length scale set by the typical heavy flavor decay lengths. At the Z pole, these typical decay lengths are $\sim$1.7 mm for $Z \to c$, $\sim$2.8 mm for $Z \to b$, and $\sim$1.0 mm for $b \to D$. In a $b \to 2D$ decay, there are two chances for a D to decay at any given b-D separation. Hence the effective decay length for the first D decay may be estimated as $\sim$0.5 mm, half that of the D in the $b \to 1D$ case. The second D should decay one decay length away from the first D decay and so its effective decay length is $\sim$1.5 mm from the b.

The VXD3 vertex detector has an excellent 4 μm single hit resolution which yields impact parameter resolutions of $8 \oplus 33/p(\sin\theta)^{3/2}$ [μm] in $r - \phi$ and $10 \oplus 33/p(\sin\theta)^{3/2}$ [μm] in $r - z$. The corresponding 1-sigma vertexing resolution for $Z \to b$ kinematics is $\sim$175 μm, more than adequate for resolving the mm scale vertex separations of interest. However, tails in the track error distributions may cause tracks to be placed in the wrong vertex (causing a lower vertex count) or to form new fake 1-prong vertices (causing a higher vertex count). Hence, a more conservative $\sim$3-sigma vertexing resolution of $\sim$500 μm is used. The contributions of fake vertices to the vertex count are also controlled by fitting the vertex separation distributions rather than just the vertex count distribution. Fake vertices will naturally occur at the shorter resolution scale rather than at the longer decay length scale.

3. The Analysis Procedure

First, an unbiased sample of b decay hemispheres was obtained by requiring an opposite vertex mass tag. [1] A topological vertexing algorithm is used to reconstruct vertices in our sample hemispheres. [2] This algorithm first approximates the b decay axis by threading a virtual 'ghost' track through all of the quality tracks in the hemisphere. The tracks are then ordered according to their points of closest approach to the ghost track. Attempts are then made to put neighboring tracks into common vertices using a confidence level requirement of 0.005. 1-prong vertices may be formed by vertexing the track with the ghost axis.

The number of secondary vertices (N_{vtx}) found in each hemisphere is counted, and the hemisphere sample is divided into sub-samples of N_{vtx} = 0,1,2,$\geq$ 3. The nearest-neighbor vertex separation distributions are then histogrammed separately for each sub-sample. The same procedure is used for the data and for the MC. To get the predicted shapes, the MC histograms are further separated into their contributions from the various b decay topologies and the $udsc$ background in the b tag. These histograms are roughly exponential in character and exhibit the various decay distance scales estimated above as well as the resolution cut-off. The collection of histogrammed predictions is then normalized by the total number of MC hemispheres of each corresponding type.

The vertex separation distributions in the data are simultaneously fitted using an unconstrained χ^2 fit to the following function derived from the MC distributions:

$$F^i_{data} = R_n \cdot [(1-R_{bkgd}) \cdot [BR_{0D} \cdot F^i_{0D} + (1-BR_{0D}-BR_{2D}) \cdot F^i_{1D} + BR_{2D} \cdot F^i_{2D}] + R_{bkgd} \cdot F^i_{bkgd}]$$

where $F_{0D}, F_{1D}, F_{2d}, F_{bkgd}$ are the four MC distributions, and i is the bin number. The parameters extracted from the fit are a normalization R_n, the $udsc$ background R_{bkgd} in the b tag and the branching ratios BR_{0D}, BR_{2D}. BR_{1D} has been eliminated to impose the constraint that the branching fractions sum to unity.

The results of the fit are shown in figure 1. The χ^2 is $\sim$1.5/d.o.f. and both the vertex count distribution and the vertex separation distributions match very well. The measured branching fractions are:

$$BR(b \to 0D) = 5.6\% \pm 1.1\%(stat.) \pm 2.0\%(syst.) \text{ (preliminary)}$$

$$BR(b \to 2D) = 24.6\% \pm 1.4\%(stat.) \pm 4.0\%(syst.) \text{ (preliminary)}$$

with the correlations: $+0.42(stat.), -0.44(syst.)$. Using the formula:

$$N_c = 1 - BR_{0D} + BR_{2D} + 2 \times BR_{charmonia}$$

and assuming the branching fraction $BR_{charmonia} = 2.4\% \pm 0.3\%$ we calculate:

$$N_c = 1.238 \pm 0.027(stat) \pm 0.048(syst) \pm 0.006(charmonia)$$

This value should pull the N_c world average higher, bringing it into the theoretically preferred region for resolving the b decay puzzle.

References

1. K. Abe *et al.*, *Direct Measurement of A_b using Charged Vertices*, SLAC-PUB-8542, July 2000.
2. K. Abe *et al.*, *Time Dependent $B^0_s - \overline{B^0_s}$ Mixing Using Inclusive and Semileptonic B Decays at SLD*, SLAC-PUB-8568, August 2000.

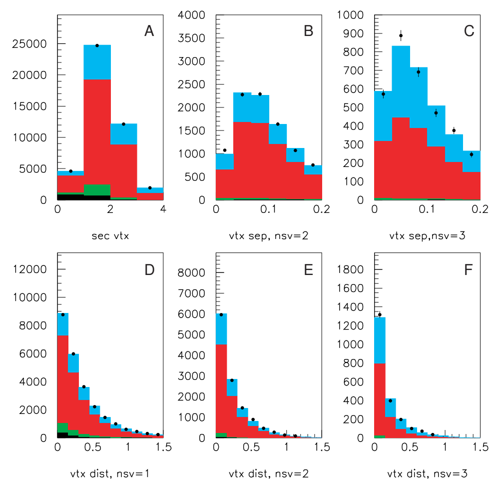

Fig. 1. Results of the fit: 1A) number of found secondary vertices; 1B,1C) Measured $b - D$ separation in the 2,3 vertex cases; 1D,1E,1F) Measured b decay length in the 1,2,3 vertex cases. The contributions to each histogram are (bottom to top): $udsc$, $0D$, $1D$, $2D$.