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A Measurement of $R_b=\Gamma(Z^0\to b\bar{b})/\Gamma(Z^0\to \text{hadrons})$ at SLD*

THE SLD COLLABORATION
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ABSTRACT

A measurement of the ratio $R_b=\Gamma(Z^0\to b\bar{b})/\Gamma(Z^0\to \text{hadrons})$ is reported. This measurement is made using the CCD-based vertex detector of the SLD detector at the SLAC Linear Collider. Efficient tagging of the $b\bar{b}$ events is performed with an impact parameter technique that takes advantage of the small and stable interaction point of the SLC and all charged tracks in Z^0 decays. In a sample of 27K Z^0 events collected in 1992 & 1993, a value $R_b=0.235\pm0.006\pm0.018$ is obtained.

The branching ratio $R_b=\Gamma(Z^0\to b\bar{b})/\Gamma(Z^0\to \text{hadrons})$ measures the coupling of the b-quark to the Z^0 gauge boson. Of all hadronic decays of the Z^0, only $Z^0\to b\bar{b}$ receives a large vertex radiative correction due to direct coupling of the b to the t-quark. We present herein a measurement of R_b from a sample of 27K Z^0 events collected in 1992 and 1993 at $\sqrt{s}$=91GeV in the SLD detector at the SLC.

Due to the long B-hadron lifetime and large boost, $Z^0\to b\bar{b}$ events produce tracks with large displacements from the interaction point. In addition, because of the large b-quark mass, tracks from b-decays have large transverse momentum relative to the initial quark direction making an impact analysis appropriate. The process $Z^0\to b\bar{b}$ is identified by requiring a large number of charged tracks with large positive impact parameters with respect to the e^+e^- interaction point. A precise measurement of the impact parameter for both hadron and lepton tracks, and an independent determination of the IP position for each event, allows a high b-tagging efficiency and purity to be obtained.

For this analysis, a subset of the elements of the SLD are utilized: the vertex detector(VXD), covering 76% of 4π sr, the drift chamber (CDC), covering 85% of 4π sr, and the calorimeter (LAC), covering 95% of 4π sr. The VXD contains 480CCD chips of 20μm thick EPI silicon, starting at 29mm and extending to 41mm from the beam line. Each CCD contains 375x578, 22μm square pixels. The total material before the first CCD layer is 0.71% rl; each CCD-layer add ~1% rl. The 2.1m long cylindrical CDC extends radially from 0.2m to 1.0m. The central tracking detector lies in a 0.6T axial B-field and has an average spatial resolution of 70μm.

Charged tracks found in the CDC are linked with pixel clusters in the VXD. The angular errors of the CDC combined with the local $\langle\delta\phi\rangle$ and $\langle\delta z\rangle$ of the VXD clusters of 6μm and 7μm respectively, lead to xy (orthogonal to the e^- beam) and rz (plane containing the beam axis) impact resolutions of $(\alpha,\beta)_{xy}$=(15μm,80μm)[1] and $(\alpha,\beta)_{rz}$=(43μm,70μm)[1], respectively. Hadronic Z^0 events are reconstructed and selected for analysis by requiring a large visible energy in ≥7 charged tracks (E_{vis}>18GeV). The thrust axis, reconstructed from charged tracks, is required to lie well within the VXD acceptance ($|\cos\theta_T|<0.71$). We also require events to come from periods where the VXD was fully operational, and we require at least three tracks with two or more VXD hits. From 13.5K (13.4K) triggers in 1992 (1993) data, 5641 (6147) Z^0 events are retained. The flavor bias potentially introduced by this selection for b-quarks relative to all hadronic Z^0 events is found from Monte Carlo to be less than 0.7%. The average IP x and y positions are tracked using hadronic Z^0 events. An independent test of the IP position determination using the impact parameter of each track from a $\mu^+\mu^-$ event relative to the other track in the event, and relative to the previously determined average IP positions, gives $\sigma_{x^{IP}}\approx\sigma_{y^{IP}}\approx 8\mu m$.

The b-tagging algorithm proceeds as follows. CDC tracks are selected which start r<0.4m, have >40 hits, extrapolate to the IP within 1.0cm in xy, and 1.5cm in z, and have good fit quality ($\chi^2_{/df}<5$). At least one good VXD hit is required, and the combined CDC/VXD fit must satisfy ($\chi^2_{/df}<10$). The xy impact parameter of the track relative to the IP (δ), and its error matrix are calculated. Poorly measured tracks (those with σ_δ>250μm), and tracks with $|\delta|$>3mm are removed. Track impact parameters are signed with respect to jet axes found using the JADE algorithm with y_{cut}=0.02. For each track, $|\delta|$ is signed +(-) if it crosses its jet axis in front (back) of the IP. A signed and normalized impact parameter (δ_{norm}) is formed from $\pm|\delta|$ divided by σ_δ added in quadrature with σ_{IP}. Secondary decay tracks preferentially populate $+|\delta_{norm}|$, while $-|\delta_{norm}|$ tracks largely reflect errors in the jet assignment and direction, tracking resolution, and IP position. Fig. 1 shows δ_{norm} for the data, and for Monte Carlo (MC) events with simulation of the detector.

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[1] $\sigma_\delta \approx \alpha \oplus \frac{\beta}{P_{xy}\sqrt{\sin\theta}}$

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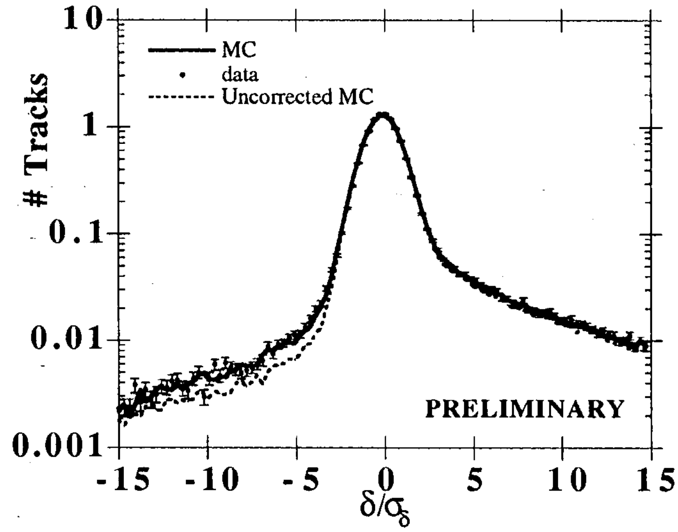

Fig. 1

An event is b-tagged by requiring a minimum number of tracks (N_{track}) with large normalized impact parameter ($\delta_{norm}>N_{sig}$), where N_{sig} is the number of standard deviations. For this analysis we choose $N_{sig}=3$ and require at least three tracks passing the δ_{norm} cut. This tag selects 1056 of 5641 events from 1992 data and 1114 of 6147 events from 1993 data. The MC and Standard Model cross-sections for $Z^0\rightarrow q\bar{q}$ are used to estimate the purity of the sample, $\Pi_b=0.80$. Using MC efficiency estimates $\varepsilon_b=0.64$, $\varepsilon_c=0.13$, and $\varepsilon_{uds}=0.02$, we obtain a value of $R_b=0.235\pm0.006$ (stat. error only), after combining the two sets of data.

Some MC tracks are adjusted after reconstruction to make the impact parameter in the MC agree more closely with the data over a range of δ_{norm} from -15.0 to 0.0. A fit is performed, to make the corrections. While no degradation of resolution is required to get the cores ($|\delta_{norm}|<2$) of the distribution to match, we find 4% of all linked tracks require position smearing as large as 500μm. Differences in track finding efficiency between the data and the MC are corrected for as a function of momentum, cosθ, φ, and angle to jet direction, by randomly removing MC tracks. About 10% of the MC tracks passing CDC and VXD cuts are removed. After these corrections, good agreement between the MC and the data in both shape and normalization is seen in Fig. 1 over the entire distribution.

Table I summarizes the fractional systematic errors in the R_b measurement; they are divided into detector and physics modeling sources. The uncertainty from tracking efficiency is estimated by averaging out the dependencies on each of the tracking correction variables. The uncertainty from tracking resolution is estimated by examining the variation in R_b with reasonable variations of the impact parameter tail smearing parameters. An upper limit on the amount of non-Gaussian tail which could be present in the IP distribution is derived from the hadronic and leptonic Z^0 decays and used as an estimator for the effect of the IP position systematics on R_b. The combined detector and IP modeling error is 5.9%.

The physics modeling systematics are dominated by uncertainties in heavy quark fragmentation, lifetime, and multiplicities. The average B-hadron lifetime is varied about the world average of 1.45±0.10ps. The effect of fragmentation has been studied with the LUND MC, using Peterson functions with ($\langle x_e\rangle$,e)= (0.494±0.025, 0.06) and (0.700±0.021, 0.006) for c and b quarks respectively. The total charged multiplicity in B-hadron decays has been allowed to vary by ±0.5 tracks to assign an error which properly reflects present experimental uncertainties on B decay multiplicities. Exclusive models of the hadronic and semileptonic decays of B and C hadrons have been incorporated into LUND and adjusted to reflect present knowledge of their decays. A second model attempting to preserve the weak matrix elements using the factorization hypothesis, provides a test of the sensitivity to induced momentum and charge correlations. A ±20% variation of both the ratios $\Gamma(B\rightarrow D^+X)/\Gamma(B\rightarrow all)$ and $\Gamma(c\rightarrow D^+X)/\Gamma(c\rightarrow all)$ were found to contribute less than 1% each to the systematic error on R_b. The present uncertainty in the charm branching fraction of the Z^0, $\Gamma(Z^0\rightarrow c\bar{c})$ / $\Gamma(Z^0\rightarrow hadrons)$ = 0.170±0.017, contributes 1.6%. The jet axis algorithm has been studied by varying the JADE algorithm parameter y_{cut} from 0.02 to 0.1. The overall physics modeling systematic error is estimated to be 5.0%.

DETECTOR MODELING	ERROR (%)	PHYSICS MODELING	ERROR (%)
Tracking Resolution	3.5	Jet Axis Modeling	<1.0
Tracking Efficiency	4.5	B-Lifetimes	2.2
IP Position Tails	1.6	b-fragmentation	2.4
Subtotal	5.9	B-Decay to D^+	<1.0
		B-Multiplicity	2.9
		B-Model	1.0
		$\Gamma(Z^0\rightarrow c\bar{c})$	1.6
		c-Fragmentation	<1.0
		c-Decay to D^+	0.9
		Subtotal	5.0
		TOTAL	7.7

Table I

In conclusion, we have measured R_b using a technique which relies on the counting of all charged tracks with large 2D normalized impact parameters relative to the beam interaction point. Tagged b-samples with high efficiency (64%) and purity (80%) are obtained. Combining our 1992 data with our preliminary data from 1993 we find

$$R_b=0.235\pm 0.006_{stat}\pm 0.014_{detector}\pm 0.012_{physics}.$$

This result is consistent with the prediction of $R_b\approx 0.22$ in the standard model.