MEASUREMENT OF R_b AT SLD

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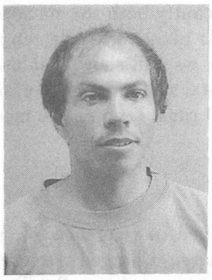

ABSTRACT

We report a new measurement of $R_b = \Gamma_{Z^0\to b\bar{b}}/\Gamma_{Z^0\to hadrons}$ using a double tag technique where the b selection is based on topological reconstruction of the mass of the B-decay vertex. The measurement was performed using a sample of 150k hadronic Z^0 events collected with the SLD at the SLAC Linear Collider during the years 1993-1995. The method utilizes the 3-D vertexing abilities of the SLD CCD pixel vertex detector and the small stable SLC beams to obtain a high b tagging efficiency of 37% for a purity of 97.2%. The high purity reduces the systematics introduced by charm contamination and correlations with R_c. We obtain a result of $R_b = 0.2176 \pm 0.0033_{stat.} \pm 0.0017_{syst.} \pm 0.0008_{R_c}$.

1 Introduction

The fraction R_b of $Z^0 \to b\bar{b}$ events in the hadronic Z^0 decays is of special interest in the Standard Model (SM). Since this is a ratio between two hadronic rates, uncertainties from the unknown oblique or QCD corrections mostly cancel. Therefore given the mass of the top (measured by CDF and D0 [2]) it provides through the Zbb vertex radiative corrections a sensitive environment to detect a signal for physics beyond the SM. The LEP and SLD measurements on variety of Z^0 coupling parameters have provided precise confirmations of the SM predictions. Hence the current average value of R_b measurements [1], which is more than 3σ higher than the SM expectation, is very valuable window in the electroweak tests of the SM.

Our $b\bar{b}$ event selection utilizes a double tag technique where one attempts to identify separately the two B hadrons in the event. It allows measurement of both the R_b value and the efficiency for identifying a b decay directly from the data. Most recent precise LEP [3] and SLD [4, 5] R_b measurements have exploited the long lifetime of the B-hadrons to distinguish between the b and the charm or lighter quark events. The elimination of charm is critical in obtaining precision R_b measurements due to the dominance of charm decay modeling uncertainties in the overall R_b uncertainty. LEP measurement are already systematically limited mainly by the charm contamination. Hence a new b tag technology is required to improve the current level of precision. To increase significantly both the efficiency and the purity of $b\bar{b}$ identification our new measurement uses the CCD pixel vertex detector (VXD) to reconstruct the mass of the secondary vertex. In this paper we will show that using this mass tag we have obtained an R_b measurement with the best total systematic uncertainty of all current R_b measurements, and will, with data from future SLD runs, become the most precise single measurement of R_b.

2 SLD Detector

The SLD detector has been described in reference [6], and only components important to this analysis are briefly reviewed here. Charged particle tracking was performed using the Central Drift Chamber (CDC) [7] surrounded by a 0.6 T solenoidal magnetic field. The vertex detector(VXD [8]) is of special importance for this measurement. It consists of 480 charged coupled devices (CCDs) with 2 hits in the angular region of $\cos\theta < 0.74$ and 1 hit within $\cos\theta < 0.8$. Each CCD is an array of 385×578 square pixels of size $22\mu m \times 22\mu m$. The CCDs are arranged in four concentric layers at a radii from 29.5 mm to $41.5mm$ from the beam line. A typical tracks produces hits in two or three of these layers. SLC provides SLD with a small and very stable interaction point (IP) ($< rms >_{xyz} \approx 2.4 \times 0.8 \times 700\ \mu m^3$). σ^{IP}_{xy} measured with reconstructed tracks from $\sim$30 sequential hadronic Z^0 events is $7 \pm 2\ \mu m$ and the z position measured on event-by-event basis is $\sigma^{IP}_z = 38\ \mu m$. The impact parameter resolution in plane perpendicular to (containing) the beam axis is $\sigma_{r\phi}[\mu m] = 11 \oplus 70/p\sin^{3/2}\theta$ ($\sigma_{rz}[\mu m] = 37 \oplus 70/p\sin^{3/2}\theta$) where p is in GeV/c. The energy deposition in the Liquid Argon Calorimeter (LAC) [9] was used in the event trigger and in the calculation of the event thrust axis.

3 Analysis Method

3.1 Topological Vertexing

SLD has already presented a measurement of R_b using the now standard lifetime double tag methods [5]. The current analysis is performed in a similar manner except the b-tag on the track impact parameter to the interaction point is replaced by a b-tag using the reconstructed mass of the secondary vertex.

The identification of the vertices is performed using a topological vertexing procedure [10]. It searches for 3-D high track overlapping density location from the single track probability (resolution) function. An event is divided in to two hemispheres with the axis defined by the highest momentum jet. The vertex finding for a hemisphere is done using only tracks within the hemisphere, and the measured IP. A secondary (+tertiary) vertex is found in 45% (5%) of the b hemispheres. The *seed vertex* (SV) is defined as the most significant non-primary vertex [10]. Hence, a SV is identified in 50% of the b hemispheres (and in 15% and 2% of the charm and the light quark hemispheres respectively). The tracks from a b decay chain do not originate from a common vertex and will not necessarily be associated with the SV. All unassociated tracks are checked for consistency with the SV, looking at the point of closest approach with respect to the vertex flight direction.

To obtain the vertex mass, all tracks associated with the SV and consistent with it are assigned the mass of a pion and used to calculate the invariant vertex mass. The mass distribution in our data compared to Monte Carlo (MC) is shown in Fig. 1a.

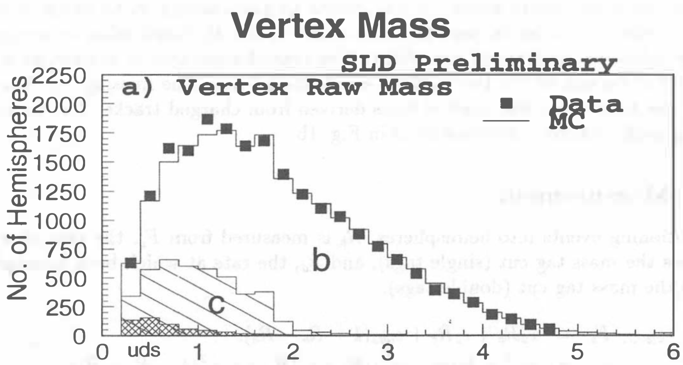

Figure 1: Vertex mass distribution (a), and the P_t corrected mass distribution (b). The data is plotted with boxes where MC b, c, and uds are represented by the open, hatched and cross hatched histograms respectively.

3.2 The Mass Tag

The MC reconstructed mass distributions show that a sharp cut-off just above the charm mass exists, beyond which almost only b decays are found (see Fig. 1a). However since we are using charged track information to reconstruct the B mass, only half of the reconstructed b masses are beyond the natural charm edge. One can still improve the b tagging performance by including additional kinematic information to compensate for the loss of neutral particles energy information. Comparison between the direction of the SV displacement from the *primary vertex* (PV) and the direction of the sum of momenta of the associated charged tracks results in the missing transverse momentum. Including the transverse momentum P_t as the minimum missing momentum we can define our tagging parameter $\mathcal{M}$ to be:

$$\mathcal{M} \equiv \sqrt{P_t^2 + M(tracks)^2} + |P_t| \leq M_B \tag{1}$$

This procedure increases mass for the b hemispheres significantly, especially affects those Bs with small charged tracks invariant mass, while charm decays close to the full charm mass will gain relatively little. However, the errors in the derivation of either the PV or the SV may cause some low mass charm events or uds events to gain enough P_t to enter to the selected sample. Therefore, in order to prevent fluctuations in the P_t distribution to contaminate our sample the following constraints are added: The contribution that is consistent with coming from the errors on one of the two vertices is subtracted from the missing P_t. The new $\mathcal{M}$ is limited to less than twice the original mass derived from charged tracks. The improvement of the tagging performance is demonstrated in Fig. 1b.

3.3 R_b Measurement

After partitioning events into hemispheres, R_b is measured from F_s, the rate at which hemispheres pass the mass tag cut (single tags), and F_d, the rate at which both hemispheres in an event pass the mass tag cut (double tags).

$$\begin{aligned} F_s &= \epsilon_b R_b + \epsilon_c R_c + \epsilon_{uds}(1 - R_b - R_c), \\ F_d &= ({\epsilon_b}^2 + \lambda_b(\epsilon_b - {\epsilon_b}^2))R_b + {\epsilon_c}^2 R_c + {\epsilon_{uds}}^2(1 - R_c - R_b). \end{aligned} \tag{2}$$

Estimations for the light quarks and charm tagging rates ($\epsilon_{uds}, \epsilon_c$) and the hemisphere b-tagging efficiency correlation (λ_b) are derived from our Monte Carlo, where for R_c we assume the SM value. Measuring the two tagging rates allows ϵ_b, the hemisphere b-tagging efficiency, to be calculated directly from data simultaneously with R_b itself:

$$\begin{aligned} R_b &= \frac{(F_s - R_c(\epsilon_c - \epsilon_{uds}) - \epsilon_{uds})^2}{F_d - R_c(\epsilon_c - \epsilon_{uds})^2 + {\epsilon_{uds}}^2 - 2F_s\epsilon_{uds}\lambda_b R_b(\epsilon_b - {\epsilon_b}^2)}, \\ \epsilon_b &= \frac{F_d - R_c\epsilon_c(\epsilon_c - \epsilon_{uds}) - F_s\epsilon_{uds} - \lambda_b R_b(\epsilon_b - {\epsilon_b}^2)}{F_s - R_c(\epsilon_c - \epsilon_{uds}) - \epsilon_{uds}}, \end{aligned} \tag{3}$$

thus eliminating the influence of uncertainties in b decay modeling except in the correlation term λ_b. The correlation which expresses the difference between the efficiency of tagging the two hemispheres in b event (${\epsilon_b}^{double}$) and ${\epsilon_b}^2$ is given by:

$$\lambda_b = \frac{{\epsilon_b}^{double} - {\epsilon_b}^2}{\epsilon_b - {\epsilon_b}^2}. \tag{4}$$

3.4 b Tag Performance

The b hemisphere tagging efficiency and purity as a function of the cut on $\mathcal{M}$ are shown in Fig. 2 along with the efficiencies estimated for charm and uds hemispheres. At a mass cut of 2 GeV a b-tag efficiency of 37% and a b purity of 97.2% is achieved. The measured ϵ_b from the data agrees with the MC estimate reasonably well. This far exceeds the performance we previously obtained using the impact parameter double tag ($\epsilon_b{}^{lifetime} = 31\%$, $\Pi_b{}^{lifetime} = 94\%$) [5].

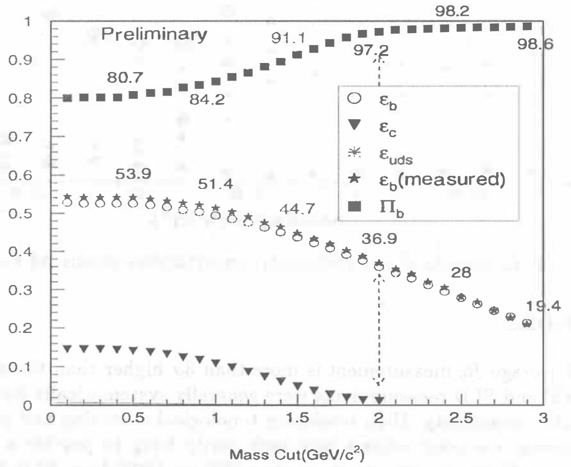

Figure 2: As a function of the $\mathcal{M}$ cut the purity of the b sample (Π_b) and the efficiency for tagging light flavours (ϵ_c, ϵ_{uds}) are shown together with the b-tag efficiency (ϵ_b) as measured in the data (black stars) and as estimated from MC (open circles).

From the single and double hemisphere b tagging efficiencies we obtain the b hemisphere efficiency correlation $\lambda_b = 0.47\%$.

A total of 71000 events passing the standard SLD hadronic events selection (see e.g. [5]) were included in this analysis to obtain $R_b = 0.2176 \pm 0.0033_{stat.}$ The R_b measurement is performed also with different mass cut values and the variation in R_b is found to be consistent with statitics.

3.5 Systematic Uncertainties

The systematic uncertainty is a combination of detector related effects such as tracking efficiency and resolution, as well as physics effect while the effect of R_c uncertainty is treated separately. The physics systematic studies are similar to those of previous R_b measurements at LEP and SLD [3, 5] and the error is a combination of uncertainties from the estimation of the correlations and the modeling of the charm and uds. The curves in Fig. 3 show all the detector, physics and R_c systematic and the statistical uncertainties versus the $\mathcal{M}$ cut. It demonstrates how charm systematics dominate for a loose $\mathcal{M}$ cut, while after the natural charm mass cut-off the statistical uncertainty is the primary limitation. The contributions to the systematic uncertainty at the optimal cut are summarized in Table 1. At this cut the combined uncertainty from all systematic sources including detector, physics and R_c is $\delta R_b/R_b = 0.83\%$.

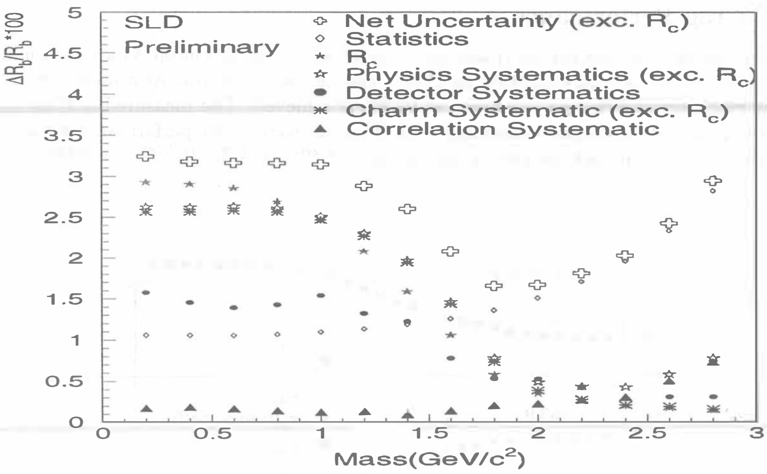

Figure 3: R_b statistical and systematic uncertainties versus $\mathcal{M}$ cut.

4 Conclusions

The current world average R_b measurement is more than 3σ higher than the SM expectation value. Previous LEP and SLD measurements were generally systematically limited mainly by the charm systematic uncertainty. High resolution topological vertexing and precision knowledge of the SLD interaction point allow a new high purity b-tag to provide a low systematic approach for precision R_b measurement. Analyzing 1993 to 1995 data, SLD has measured a new preliminary R_b value:

$$R_b = 0.2176 \pm 0.0033_{stat.} \pm 0.0017_{syst.} \pm 0.0008_{R_c}$$

This value supersedes our previous R_b measurement. With a new vertex detector and more data SLD is expected to perform a measurement of R_b to a precision of $< 1\%$.

Detector Systematics			
Systematic	$\delta R_b/R_b$	Systematic	$\delta R_b/R_b$
Efficiency Corrections	0.21%		
Z Impact Resolutions	0.48%	Beam Position Tails	0.08%
Total Detector Systematics 0.53%			
Physics Systematics			
Systematic	$\delta R_b/R_b$	Systematic	$\delta R_b/R_b$
Correlation Systematics	0.37%	Charm Systematics	0.36%
Light Quark Systematics	0.19%	$R_c = 0.171 \pm 0.014$	0.34%
Total Physics (excluding R_c) Systematics 0.55%			

Table 1: Summary of contributions to the systematic error at $\mathcal{M}_{cut} = 2.0\ GeV$

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