A High Purity Measurement of R_b at SLD

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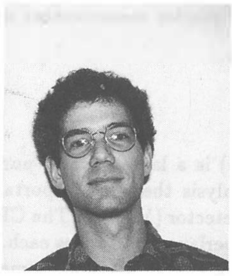

ABSTRACT

Precision measurement of R_b can provide important information about the Standard Model and beyond. SLD has developed a new method for measuring R_b with very high purity. This measurement has the lowest systematic error reported to date and future measurements using this method will likely have the lowest total uncertainty.

This paper will be divided into the five sections: introduction, hardware, topological vertexing tag method, results and conclusions. The introduction will discuss the importance of R_b and the problems with other measurement techniques. The hardware section will give a brief description of the SLC/SLD system concentrating on its advantages over LEP. An outlook towards the future of SLD R_b measurements will be included in the conclusions.

1 Introduction

The quantity R_b is defined as:

$$R_b \equiv \frac{\Gamma(Z^0 \to b\bar{b})}{\Gamma(Z^0 \to \text{hadrons})} \tag{1}$$

Most of the standard model corrections to the partial widths are common to all quarks and thus cancel in the ratio. Only the b vertex corrections (δ_b^{vert}) are significant in R_b; in essence, R_b **isolates** the b vertex corrections. The largest standard model contribution to δ_b^{vert} come from loops containing top quarks and is hence sensitive to m_{top}. Many type of new physics have similar contributions: for example, chargino/stop loops in supersymmetry or charged Higgs/top loops in the Higgs doublet model. These effects are typically 1%, so a very precise measurement of R_b along with a precise measurement of the top mass can rule out certain types of new physics.[1)]

2 Hardware

The SLAC Large Detector (SLD) is a large general-purpose detector optimized to work at the Z^0 resonance.[2)] For this analysis the most important components are the central drift chamber (CDC) and the vertex detector (VXD2). The CDC is a jet-cell drift chamber with 80 planes of wires arranged in 10 superlayers of 8 wires each. The hit resolution is approximately 100μm in the $r\phi$ direction. Using charge division, some z information is obtained, but the resolution is poor. The VXD2 is a unique design which uses charge-coupled devices (CCDs) to obtain true 3-d hits rather than using microstrips or crossed strips which can lead to hit confusion. There are over 100 million pixels in this device — arranged in two logical layers. The hit resolution is about 5μm in all three dimensions.[3)]

The SLAC Linear Collider (SLC) is a novel type of collider. Both electrons and positrons are accelerated down the same linac, but at the end they are sent into different arcs. At the end of the collider arcs the two bunches are travelling directly at one another with their center of mass at rest. The bunches collide at the center of SLD and any remnants are directed toward beam dumps. The beam spot size was (on average) $2.5\mu\text{m} \times 0.6\mu\text{m}$ during the 1994 run. The pulse-to-pulse jitter in the interaction point is significantly smaller than this size.

This small and stable beam spot allows us to use the *average* interaction point ($\langle\text{IP}\rangle$) position over several Z^0 decays to determine the transverse location of a given Z^0 decay. This method avoids the misidentification of the primary vertex that would arise if only that decay's tracks were used for the interaction point determination. It also reduces the tagging correlations due to poor IP measurements, and it makes it easier to understand and simulate the impact parameter resolutions. The uncertainty in the xy-$\langle\text{IP}\rangle$ position is 7μm for most events. The z position of the interaction point must be determined on an event-by-event basis, but we can use the xy position in this determination. The uncertainty in the z position of the IP is estimated to be 38μm.

3 Topological Vertexing Tag Method

The general method for measuring R_b involves several basic steps. First one must obtain a pure $Z^0 \to q\bar{q}$ sample. The standard method is to require a large number of charged tracks and large visible energy in the event. Next one must form a tag variable. This variable must be able to remove most non-b decays while still efficiently tagging b decays. By doing so it also removes charm and light quark modeling systematics, including correlation with R_c. There are several characteristics of B hadrons that are useful for tagging: the B–lifetime is long ($\sim$ 1.51ps), the B–mass is large ($\sim$ 5GeV/c^2) and the semi–leptonic decay spectrum is hard.

Single (or event) tag methods use the number of events and the number of tagged events to calculate R_b. In order to do this they rely on Monte Carlo estimates of the tagging efficiencies for each quark ($\epsilon_i \equiv N^i_{\text{tagged}}/N^i_{\text{true}}$). In double (or hemisphere) tag methods the most critical efficiency, ϵ_b, is measured from the data (ϵ_b^{data}) while the other efficiencies are estimated from Monte Carlo. The b–purity of the tag is often denoted as $\Pi_b \equiv N^b_{\text{tagged}}/N^{\text{all}}_{\text{tagged}}$.

3.1 Disadvantage of Lifetime Tagging Methods

All lifetime–based tagging methods share a common disadvantage: The purity is limited due to the long lifetime of primary charm events. Simply because of the exponential nature of lifetimes, it is difficult to improve the purity of a given tag without significant efficiency loss. The measurements done at the LEP experiments are already systematically limited by residual charm.[4] In addition, SLD's measurement is not more precise despite our better resolution and precision $\langle$IP$\rangle$ advantage.

3.2 Topological Vertexing

Vertices are found by forming a 3–d vertex probability from the overlap of individual track probability functions.[5] We define D as the distance from the primary vertex (PV) to the decay vertex, L is the distance along this axis from the PV to the point of closest approach (POCA) for this track, and T is the transverse distance between the track's POCA and the vertex axis. Tracks satisfying $L/D > 0.3$ & $T <$ 1mm are attached to the most distant vertex from the primary vertex. The invariant mass of the tracks forming the vertex can then be used as a tagging variable.

Since there is usually neutral energy missing we attempt to determine this and add it back to the invariant mass. If all the momentum were associated with the vertex, then the direction of the vertex axis would agree with the direction of the vertex momentum. If it does not, then we add back the missing p_t to align the two vectors. Because of tracking errors, there are many cases where the apparent missing p_t is very large. We eliminate most of these by minimizing the p_t to be consistent with both the vertex and $\langle$IP$\rangle$ errors and by limiting the total mass ($\mathcal{M} = \sqrt{M^2_{\text{raw}} + |p^v_t|^2} + |p^v_t|$) to be less than twice the raw mass. In many cases the missing p_t is consistent with zero and no mass is added to the vertex.

3.3 Event Selection

In order to separate fully–recorded hadronic events from all others (partially measured hadronic events, leptonic Z^0 events and non–Z^0 events) we require several characteristics of each event: For $Z^0 \rightarrow \ell^+\ell^-$ rejection, the event must have at least 7 good tracks in CDC and more than 18 GeV in charged tracks. Our fiducial acceptance is $|\cos(\theta_{\text{thrust}})| < 0.71$. To verify that the detector is in operating condition, we require at least 3 tracks with at least 2 vertex detector hits and at least 1 track starting at $r_{r\phi} <$ 39cm. To reduce gluon splitting events we require the number of reconstructed jets to be either two or three.

Similarly, we select quality tracks based on many criteria: For the drift chamber (CDC) segment of the track we require $|\delta_Z| <$ 1.5cm, $|\delta_{r\phi}| <$ 1.0cm, χ^2/d.o.f. < 5, $p_t >$ 0.4GeV/c, $r_0 <$ 40cm, $\geq$ 40 CDC hits, and $|\cos\theta| < 0.80$. For the combined track (CDC+VXD) we require $\sigma_{r\phi} < 250\mu$m, χ^2/d.o.f. < 5, and $|\delta_{xy}| <$ 3mm.

3.4 Determining R_b from Double Hemisphere b–Tags

From data one measures the single hemisphere tag fraction and the double tag event fraction:

$$F_S = \epsilon_b R_b + \epsilon_c R_c + \epsilon_{uds}(1 - R_b - R_c) \quad (2)$$

$$F_D = \epsilon_b{}^{\mathrm{double}} R_b + \epsilon_c{}^{\mathrm{double}} R_c + \epsilon_{uds}{}^{\mathrm{double}}(1 - R_b - R_c) \quad (3)$$

where: ϵ_i is the hemisphere tagging efficiency and $\epsilon_i{}^{\mathrm{double}}$ is the double hemisphere tagging efficiency. The two hemispheres in an event might be *correlated.* We define the correlation coefficient, λ, such that:

$$\epsilon^{\mathrm{double}} = \epsilon^2 + (\epsilon - \epsilon^2)\lambda \quad \Rightarrow \quad \lambda = \frac{\epsilon^{\mathrm{double}} - \epsilon^2}{\epsilon - \epsilon^2} \quad (4)$$

$$\Rightarrow \quad F_D = \left[\epsilon_b{}^2 + (\epsilon_b - \epsilon_b{}^2)\lambda_b\right] R_b + \epsilon_c{}^2 R_c + \epsilon_{uds}{}^2(1 - R_b - R_c) \quad (5)$$

where it is assumed that λ_c and λ_{uds} are negligible.

We can solve for ϵ_b and R_b:

$$\epsilon_b^{\mathrm{data}} = \frac{F_D - R_c\epsilon_c(\epsilon_c - \epsilon_{uds}) - F_S\epsilon_{uds} - \lambda_b R_b(\epsilon_b^{\mathrm{data}} - [\epsilon_b^{\mathrm{data}}]^2)}{F_S - R_c(\epsilon_c - \epsilon_{uds}) - \epsilon_{uds}} \quad (6)$$

$$R_b = \frac{(F_S - R_c(\epsilon_c - \epsilon_{uds}) - \epsilon_{uds})^2}{F_D - R_c(\epsilon_c - \epsilon_{uds})^2 + \epsilon_{uds}{}^2 - 2F_S\epsilon_{uds} - \lambda_b R_b(\epsilon_b^{\mathrm{data}} - [\epsilon_b^{\mathrm{data}}]^2)} \quad (7)$$

These coupled equations can then be solved by initially setting $\epsilon_b^{\mathrm{data}}$ and R_b to zero and *iterating* until both quantities converge. Note that λ_b, ϵ_c and ϵ_{uds} come from the Monte Carlo simulation while R_c comes from other measurements or the standard model value.

4 Results

Using the 1993—1995 data we find 71210 events which pass the selection criteria as hadronic events. The efficiencies and b–purity are shown in figure 1 For a mass cut of 2.0 GeV/c^2 we measure:

$$R_b = 0.2176 \quad \text{and} \quad \epsilon_b^{\mathrm{data}} = 36.9 \pm 0.6\% \quad (8)$$

assuming an $R_c = 0.171$. From the Monte Carlo we expect: $\epsilon_b = 35.9\%$, $\epsilon_c = 1.06\%$, $\epsilon_{uds} = 0.07\%$, and $\lambda_b = 0.47\%$ which implies $\Pi_b = 97.2\%$. The statistical error, $\sigma_{R_b}(\mathrm{stat.}) = 0.0033$.

The systematics are shown in figure 2. The largest physics systematic contribution comes from the b–correlation estimate. The many charm systematics also combine to give a large contribution. The double–tagging essentially eliminates the b–quark systematics. The detector systematics are dominated by the uncertainties in the impact resolution z component.

The result is therefore:

$$R_b = 0.2176 \pm 0.0033_{(\mathrm{stat})} \pm 0.0017_{(\mathrm{sys})} \pm 0.0008_{(R_c)} \quad (9)$$

5 Conclusions

SLD has successfully used a topological vertex tagging method to measure R_b. By utilizing the high mass of B mesons a very high purity can be obtained while retaining high efficiency. This mass tag method relies on the small $\langle \mathrm{IP} \rangle$ provided by the SLC and the precise resolution

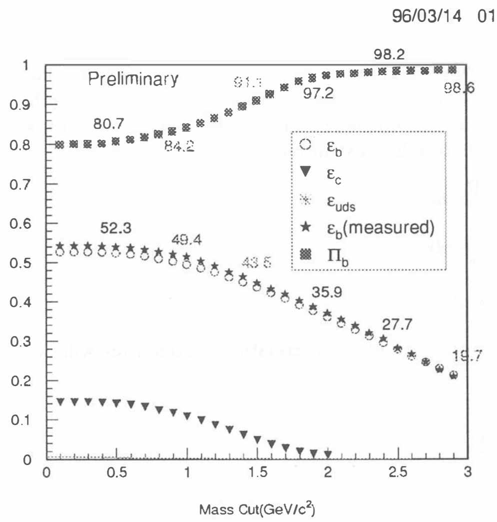

Figure 1: Performance of the mass tag as a function of mass cut.

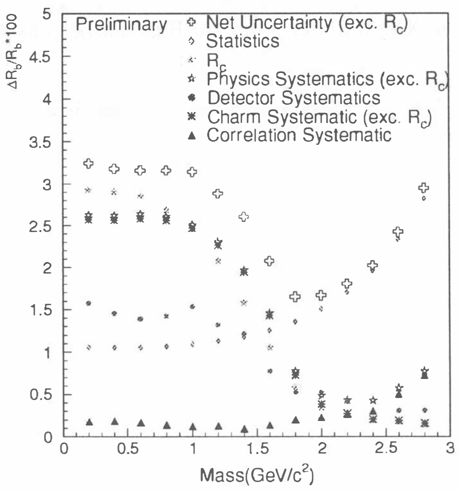

Figure 2: Net uncertainty as a function of mass cut.

of SLD's vertex detector. Other experiments may have some difficulty in using this exact method.

SLD is scheduled to run for another three years to accumulate half a million more Z^0 decays. This additional data will allow the use of harder cuts to further eliminate primary charm backgrounds. We have also installed an improved vertex detector which should enhance our b–tagging efficiency. This will assist in reducing systematics:

- ϵ_c term: $d\mathrm{R}_b \simeq (\frac{-2\mathrm{R}_c}{\epsilon_b})d\epsilon_c$
- R_c term: $d\mathrm{R}_b \simeq (\frac{-2\epsilon_c}{\epsilon_b})d\mathrm{R}_c$
- λ_b term: $d\mathrm{R}_b \simeq (\frac{\mathrm{R}_b}{\epsilon_b})d\lambda_b$

We also expect that further study of the correlation systematics will allow us to reduce that uncertainty.

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