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MEASUREMENT OF THE B HADRON LIFETIME AT THE SLC*

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ABSTRACT

We have measured the average B hadron lifetime from $Z^0 \to b\bar{b}$ events using the Mark II detector at the SLC. We use an impact parameter tag, requiring two or more tracks with significant impact parameter (δ) in a hemisphere, to obtain a 40% efficiency and an 80% B-purity. The $\Sigma\delta$ distribution from charged tracks in the hemisphere opposite the tag is used to fit for τ_b. From 53 tagged B decays we find $\tau_b = 1.63^{+0.54}_{-0.40}(\text{stat}) \pm 0.16(\text{syst})$ psec (preliminary), consistent with the world average. This method can be competitive with τ_b measurements using high P_T leptons and has a different sensitivity to $\tau(B^+)/\tau(B^0)$.

1. Introduction

In this paper we report a measurement of the bottom hadron lifetime from $Z^0 \to b\bar{b}$ events using 10.1 ± 0.7 nb^{-1} of data collected by the MARK II detector at the SLC. Our method uses hadronic tracks to tag $b\bar{b}$ events and to measure the B lifetime.

2. Detector Performance and Impact Parameter Resolution

The MARK II detector measures charged tracks precisely using a 72 layer Central Drift Chamber (CDC), a 38 layer Drift Chamber Vertex Detector (DCVD), and a three layer Silicon Strip Vertex Detector (SSVD) with the first measurement at 28 mm from the interaction point. The DCVD has achieved spatial resolutions in hadronic Z^0 decays of $\sigma^2 = (28\ \mu m)^2 + (43\ \mu m)^2$ D(cm), where D is the drift distance to the sense wire. The average position resolution in the SSVD is 7 μm.

The signed impact parameter of tracks (δ) is measured with respect to an average beam position in the plane perpendicular to the beam axis. The sign is positive if the intersection of the track and the reconstructed jet axis corresponds to a positive decay length. This will occur for tracks from B decays. Tracks with the opposite sign ($\delta < 0$) can result from multiple coulomb scattering, K_s^0 decays, or jet axes that poorly reproduce the true B hadron direction. The impact parameter resolution is $\sigma_\delta^2 = \sigma_{trk}^2 + \sigma_{extra}^2$, where σ_{trk} is the detector and multiple scattering contribution, and $\sigma_{extra} = 30\ \mu m$ is from a 25 μm beam motion and uncertainties in the alignment of the SSVD. The resolution is approximately $\sigma_\delta^2 = (29\ \mu m)^2 + (70\ \mu m)^2/(P_T^2 \sin\theta)$.

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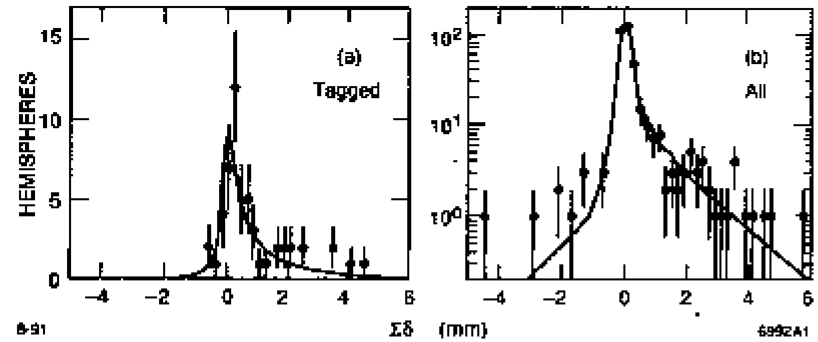

Fig. 1. $\Sigma\delta$ distribution for (a) the hemispheres opposite the tagged sample, and (b) all hemispheres.

Hadronic events are required to have at least seven charged tracks in the fiducial volume, visible energy $E_{vis} \geq \frac{1}{2}E_{cm}$, thrust ≥ 0.7, and $|\cos\theta_T| \leq 0.8$ where θ_T is the angle between the thrust axis and the beam axis. From an integrated luminosity of 10.1 nb^{-1} we are left with 208 hadronic events.

Only well measured tracks are used in the lifetime analysis. Tracks must have at least 20 CDC, 15 DCVD, and 1 SSVD position measurements. Tracks that pass through inoperative DCVD cells but are assigned at least 2 SSVD hits are also allowed. In addition, we require $|\cos\theta| \leq 0.8$, $P_T\sqrt{\sin\theta} \geq 0.5$ GeV/c, $|z| \leq 30$ mm, and $|\delta| \leq 5$ mm. The charged multiplicity after cuts is 9.9 ± 0.3 tracks.

3. B Hadron Tag and B Lifetime Measurement

The tracks are divided into two thrust hemispheres. We enrich the $b\bar{b}$ sample with a hemisphere tag that requires two or more tracks with significant impact parameter ($\delta/\sigma_\delta \geq +3.0$) and $|\delta| \leq 2$ mm to reduce the light quark contribution. This method finds B hadrons with 40% efficiency and 80% purity. We tag 53 hemispheres and double tag 11 events. This agrees well with the Lund 6.3 Monte Carlo (MC) with parton showers.

The hemispheres opposite the tag are a relatively unbiased sample of B hadrons. We compute τ_b from the sum of impact parameter distribution ($\Sigma\delta$) using all good tracks in that hemisphere (Fig. 1a). The $\Sigma\delta$ distribution has properties that are advantageous to that of an inclusive δ distribution. The $\Sigma\delta$ is relatively insensitive to beam motion and to tracks from the Z^0 primary vertex. We extract τ_b from a one-parameter maximum likelihood fit to the $\Sigma\delta$ distribution using the $\Sigma\delta$ probability distributions from the individual quark flavors and the purity as prescribed by the MC. The shape of the B quark $\Sigma\delta$ distribution has a complex dependence on the MC generated τ_b, but it roughly resembles an exponential decay function convoluted with a resolution function. The resolution function approximates the uds distribution and displays a core Gaussian with a symmetric exponential tail that is due to Λ_b^0 decays and tails in the multiple scattering. We find the lifetime to be $\tau_b = 1.63^{+0.64}_{-0.40}$ psec, where the error is statistical only.

4. Systematic Uncertainties

As a consistency check, we obtain a measurement of $\tau_b = 1.77^{+0.68}_{-0.36}$ psec by fitting the $\Sigma\delta$ distribution for all 416 hemispheres, where the quark branching fractions are set to the Standard Model values (Fig. 1b).

The largest source of systematic error comes from uncertainties in the tails of the track resolution function. The region $\delta < 0$ of the inclusive δ distribution is the least sensitive to charm and bottom lifetime effects and is used to place limits on the additional amounts of symmetric track smearing in the MC, gaussian with exponential tails, that is allowed by the data ($\delta_{\tau_b} = ^{+4}_{-1}$ %). The B decay multiplicity and momentum spectrum were allowed to vary within the uncertainties of the CLEO[1] and ARGUS[2] measurements ($\delta_{\tau_b} = \pm 4.5\%$). The LEP experiments[3] have measured the B fragmentation to be $\langle x_E \rangle_b = 0.68 \pm 0.03$ ($\delta_{\tau_b} = \pm 3.2\%$), and the B branching fraction to be $f_b = 0.22 \pm 0.02$ ($\delta_{\tau_b} = \pm 1.8\%$). Beam-associated backgrounds were simulated by mixing MC events with random beam events recorded at the time of the Z^0 events. The uncertainty in the tracking efficiency is 2% ($\delta_{\tau_b} = \pm 2.1\%$) due to imperfect knowledge of the CDC performance, uncertainties in the efficiency of linking vertex hits to CDC tracks, and uncertainties in the two track resolution. Charge multiplicity errors have a negligible effect on τ_b ($\delta_{\tau_b} =< \pm 1\%$). The total systematic error from all sources added in quadrature is 10% of τ_b.

5. Conclusions

We have measured the B lifetime from an enriched sample of $Z^0 \to b\bar{b}$ events using an impact parameter hemisphere tag that is both efficient (40%) and pure (80%). Our preliminary result $\tau_b = 1.63^{+0.64}_{-0.40}(\text{stat}) \pm 0.16(\text{syst})$ psec is consistent with the world average of $\tau_b = 1.24 \pm 0.12$ psec.[4] With more statistics this method can have systematic errors under 6% and holds considerable promise for future τ_b measurements. Further, this method has a different sensitivity to $\tau(B^+)/\tau(B^0)$ than does a lifetime measurement using high P_T leptons since the semi-leptonic branching fraction is larger in the longer lived B species.

References

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