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Time-integrated Mixing Probability Towards an A_{SL} Measurement at CDF

Robert HARR[*†]
Wayne State University, Detroit MI 48202, USA
(for the CDF Collaboration)
E-mail: robert.harr@wayne.edu

The CDF experiment has performed a measurement of the time-integrated mixing probability $\overline{\chi}_b$ using dimuon triggered data corresponding to $1.44\,\mathrm{fb}^{-1}$ of integrated luminosity. We select events with exactly two muon candidates with an invariant mass in the range $5\,\mathrm{GeV}/c^2 < m_{\mu\mu} < 80\,\mathrm{GeV}/c^2$. Requiring that each muon track has a hit in one of the first two layers of the silicon detector further suppresses non-$b\bar{b}$ backgrounds. We fit the two dimensional distribution of muon impact parameters to separate dimuons from $b\bar{b}$ events from other sources. The time-integrated mixing is determined to be $\overline{\chi}_b = 0.126 \pm 0.008$, in good agreement with the world average. We explore the behavior of the result when the hit requirement in the inner silicon layers is relaxed as a possible explanation for the difference between past $\overline{\chi}_b$ measurements from LEP and Tevatron experiments.

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*Speaker.
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1. Introduction

The time-integrated mixing probability $\overline{\chi}_b$ measures the probability for a B hadron to mix. Only the ground-state neutral B mesons mix, so we write

$$\overline{\chi}_b = \frac{\Gamma(B^0_{d,s} \to \bar{B}^0_{d,s} \to \ell^+ X)}{\Gamma(B \to \ell^\pm X)} \tag{1.1}$$

where B represents any B hadron, and $B^0_{d,s}$ represent the neutral B mesons. This can also be expressed in terms of the fragmentations fractions for B mesons containing a d or s quark, f_d orf_s, and the time integrated mixing probabilities for the B^0 and B^0_s mesons, χ_d and χ_s, as

$$\overline{\chi}_b = f_d \chi_d + f_s \chi_s \,. \tag{1.2}$$

Before the observation of B^0_s mixing, the measurement of $\overline{\chi}_b$ was used to determine $\overline{\chi}_s$ and thereby constrain the value of Δm_s. Now that Δm_s is accurately measured, the measurement of $\overline{\chi}_b$ is used to constrain f_d and f_s, the B hadron fragmentation fractions at high energy.

It is assumed that the fragmentation of b-quark pairs should be largely independent of the source of the $b\overline{b}$ pair, be it a Z^0, γ, or gluon, but this assumption must be checked. There is a small discrepancy between $\overline{\chi}_b$ measurements from LEP and the Tevatron. As noted by HFAG [1], the LEP measurements average 0.1259 ± 0.0042 and the Tevatron measurements average 0.147 ± 0.011, a difference of 1.8σ. This difference could indicate a small effect on fragmentation arising from the difference between the leptonic and hadronic collision environments. An improved measurement of $\overline{\chi}_b$ could shed light on whether the discrepancy is an experimental artifact or a physics effect.

The recent measurement of the like-sign dimuon asymmetry, A_{SL}, by the D0 experiment [2] differs from the standard model prediction by more than 3σ. This result has garnered much attention from theorists, and deserves independent confirmation. The measurement of $\overline{\chi}_b$ uses a subset of the same data that will be used by CDF for a measurement of A_{SL}, and is therefore seen as a preparatory exercise for the A_{SL} analysis.

2. Analysis Description

This measurement uses data from $1.44\,\mathrm{fb}^{-1}$ of integrated luminosity taken with the CDF II detector at the Tevatron $p\overline{p}$ collider. The CDF II detector is described in detail elsewhere [3].

The strategy of the analysis is to determine $\overline{\chi}_b$ from the ratio of the numbers of events with like sign dimuons and opposite sign dimuons arising from $b\overline{b}$ pairs

$$R_b = \frac{N_b^{++} + N_b^{--}}{N_b^{OS}} \,. \tag{2.1}$$

In about 1% of $b\overline{b}$ events, both b hadrons decay semimuonically. The long-lived b hadrons will decay a few millimeters from the primary vertex. We separate the $b\overline{b}$ events from other sources of dimuons based on the distribution of muon impact parameters to the primary vertex. We use only the projection of the impact parameter on to the plane transverse to the beam. The silicon vertex detector provides resolution of about $30\,\mu$m in the transverse plane.

We select events that satisfy the central dimuon trigger. The events must have exactly two muon candidates, thereby removing uncertainty from the presence of additional muons. The two muons must have an invariant mass between $5\,\mathrm{GeV}/c^2 < M_{\mu\mu} < 80\,\mathrm{GeV}/c^2$, where the lower limit minimizes contributions from sequential B decays and the upper limit removes $Z^0 \to \mu^+\mu^-$ decays. The two muon candidates are required to have associated hits in one of the two innermost layers of the silicon detector. This requirement, called tight silicon, removes a class of muon candidates not well-reproduced in the simulation [4] at a cost of about a factor of 6 in the number of dimuon candidates.

We plot the impact parameter distribution of the two muons (d_1, d_2) separately for opposite sign (OS), and same sign positive $(\mu^+\mu^+)$ and same sign negative $(\mu^-\mu^-)$ muon pairs. Muons can be from semimuonic b or c hadron decays, prompt muon production, decays of light (u,d,s) hadrons, or misidentification of hadrons as muons. The sources of muon pairs are categorized as from events with a pair of b quarks (BB), a pair of charm quarks (CC), prompt production (PP), or none of these (other). The prompt category is primarily due to Υ decays and Drell-Yan production. The BB and CC categories include cases where one or both of the muons arise from hadron misidentification, primarily decay-in-flight or punchthrough. The other category includes light-flavor events with muons from strange hadron decays or misidentification.

A binned maximum likelihood fit is performed on the two dimensional impact parameter distributions. The likelihood function is

$$L = \prod_i \prod_j \left[\ell_{ij}^{n(i,j)} \frac{e^{-\ell_{ij}}}{n(i,j)!} \right] \tag{2.2}$$

where

$$\begin{aligned} \ell_{ij} = & BB^{XS} \cdot S_b^{XS}(i) \cdot S_b^{XS}(j) + BB_{FK}^{XS} \cdot S_b(i) \cdot S_b(j) + \left(CC + CC_{FK}^{XS}\right) \cdot S_c(i) \cdot S_c(j) + \\ & PP^{XS} \cdot S_p(i) \cdot S_p(j) + \frac{1}{2}\left[BP^{XS} \cdot (S_b(i) \cdot S_p(j) + S_p(i) \cdot S_b(j)) \right. \\ & \left. + CP^{XS} \cdot (S_c(i) \cdot S_p(j) + S_p(i) \cdot S_c(j)) + BC^{XS} \cdot (S_b(i) \cdot S_c(j) + S_c(i) \cdot S_b(j))\right] \end{aligned} \tag{2.3}$$

In the equations, XS indicates the dimuon sign combination, FK indicates that one of the muons is a misidentified hadron, and S_b, S_c, and S_p are the impact parameter templates for muons from b quarks, c quarks, or prompt production, respectively.

Templates for the prompt component (S_p) are derived from Υ data. Monte Carlo simulation is used to derive templates for $c\bar{c}$ (S_c) and $b\bar{b}$ (S_b) components. To both, fakes are added by applying misidentification fractions to other tracks from the b or c decays. We also generate templates for the mixture of a muon from a b or c decay with a prompt muon. The templates are combined and fit so as to maximize the likelihood defined in Eqs. 2.2 and 2.3.

3. Results

One dimensional projections of the fits are shown in Fig. 1. From the results we extract

$$R_b = 0.467 \pm 0.008 \text{ (statistical error only)}. \tag{3.1}$$

A systematic error of ± 0.007 is derived from the variation of the result for R_b when the muon fake fractions are varied within their uncertainties. Adding the systematic error in quadrature yields

$$R_b = 0.467 \pm 0.011 \tag{3.2}$$

We use the relation

$$R_b = \frac{f\left[\overline{\chi}_b^2 + (1-\overline{\chi}_b)^2\right] + 2\overline{\chi}_b(1-\overline{\chi}_b)(1-f)}{(1-f)\left[\overline{\chi}_b^2 + (1-\overline{\chi}_b)^2\right] + 2\overline{\chi}_b(1-\overline{\chi}_b)f} \tag{3.3}$$

to extract $\overline{\chi}_b$. The quantity f in Eq. 3.3 accounts for the fraction of $b\bar{b}$ events where both muons come from the same b-hadron decay, essentially guaranteeing that they are of opposite sign. We use the simulation to estimate $f = 0.176 \pm 0.011$ including systematic uncertainties due to our knowledge of b and c fragmentation and semileptonic decays. With this f we extract

$$\overline{\chi}_b = 0.126 \pm 0.008\ , \tag{3.4}$$

in excellent agreement with the average of the LEP measurements, 0.1259 ± 0.0042, and almost 2σ below the average of previous Tevatron measurements, 0.147 ± 0.011 [1].

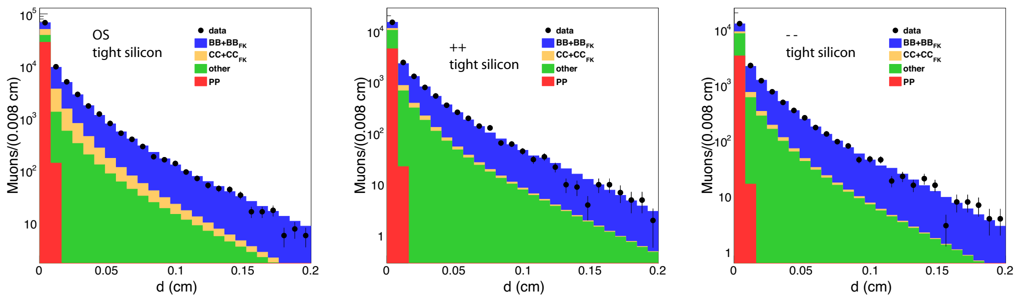

Figure 1: The one-dimensional projections of the impact parameter distributions (black points) with tight silicon requirements (see text) for opposite sign (OS), and like sign positive (+ +) and negative (- -) muons. The results of the fits are displayed as the stacked solid histograms. The two-dimensional plots are fit simultaneously.

To help understand the source of the LEP–Tevatron discrepancy, we have repeated the analysis with loose silicon requirements. The loose silicon selection requires signals in at least 3 out of 8 silicon layers, but do not demand that any of these hits be in the first two layers as required in the tight silicon selection. The fit templates are re-derived, and the fit performed exactly as before, yielding the projections shown in Fig. 2. Clearly there is a problem with many more muons in the tail of the distributions than the templates are able to accommodate.

Previous studies [4] have shown that these muons are not accurately modeled in the simulation, with about 80% coming from decays-in-flight of pions and strange particles. This background has a larger impact on the same-sign samples, resulting in somewhat higher values for R_b and $\overline{\chi}_b$.

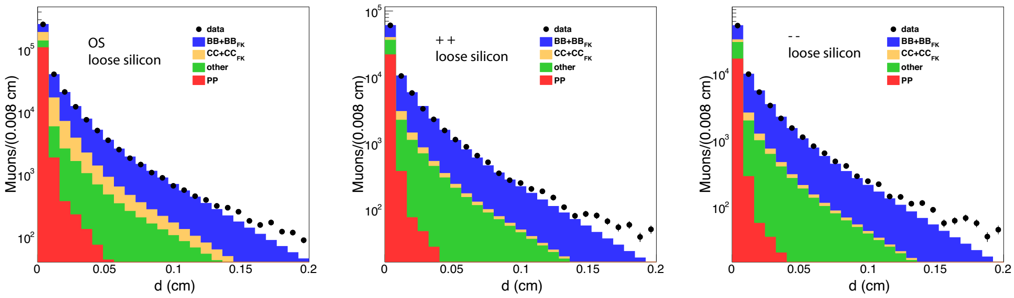

Figure 2: Like Fig. 1 but with the loose silicon requirements (see text).

4. Summary

We have measured the time integrated mixing of b hadrons and obtained the value of $\overline{\chi}_b = 0.126 \pm 0.008$ in good agreement with previous measurements. This value is in excellent agreement with the LEP average of $\overline{\chi}$ and may help explain the discrepancy between the LEP and Tevatron averages for this quantity.

References

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