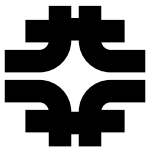

Fermi National Accelerator Laboratory

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Search for the Decay $B^0 \rightarrow \mu^+\mu^-$

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Search for the Decay[1] $B^0 \to \mu^+\mu^-$

The CDF Collaboration

Abstract

We present a search for the decays $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ using $17.8\,pb^{-1}$ of data collected with the Collider Detector at Fermilab (CDF) during 1992–1993 data taking period. We find no B_d^0 candidates in a mass window of $[5.205, 5.355]$ GeV/$c^2$and 1 B_s^0 candidate in a mass window of $[5.300, 5.450]$ GeV/c^2. Normalizing to our measured cross-section $\sigma(\mathrm{B}^+) = 2.39 \pm 0.54$ μb for $p_t(\mathrm{B}) > 6$ GeV/c and $|y(\mathrm{B})| < 1$ and assuming $\sigma(\mathrm{B}^+) = \sigma(\mathrm{B}_d^0) = 3\sigma(\mathrm{B}_s^0)$, we find

$$\mathrm{Br}(B_d^0 \to \mu^+\mu^-) < 1.6 \times 10^{-6} \text{ and } \mathrm{Br}(B_s^0 \to \mu^+\mu^-) < 8.4 \times 10^{-6}$$

at 90% confidence level. These limits are significant improvements of previous measurements.

1 Introduction

In the standard model of electroweak interactions the decay $B_{d,s}^0 \to \mu^+\mu^-$ is forbidden at tree level. This decay, however, can proceed through higher order diagrams, as shown in figure 1. Standard model predictions for the branching ratios are $\mathrm{Br}(B_s^0 \to \mu^+\mu^-) = 1.8 \times 10^{-9}$ and $\mathrm{Br}(B_d^0 \to \mu^+\mu^-) = 8.0 \times 10^{-11}$ [1], and some extensions to the standard model predict $\mathrm{Br}(B_s^0 \to \mu^+\mu^-)$ to be as large as 10^{-8} [2]. The present experimental limits (90% CL) are 5.9×10^{-6} [3] for $B_d^0 \to \mu^+\mu^-$ (the CLEO collaboration), and 8.3×10^{-6} [4] for combined $B_{d,s}^0 \to \mu^+\mu^-$ decays (the UA1 collaboration). This note presents the search for $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ using $17.8 \pm 0.6\,pb^{-1}$ of data collected during the 1992–1993 data taking period.

[1]Submitted to the Proceedings of the 17th International Symposium on Lepton Photon Interactions (LP95), Beijing, China, 1995.

2 Event Selection

At CDF [5] we measure the momentum of charged tracks using the central tracking chamber (CTC), which is immersed in an axial magnetic field. The silicon vertex detector (SVX) [6] provides us with an accurate measurement of secondary vertex position.

To reduce the background, this analysis relies primarily on the long lifetime of B mesons, and the fact that B mesons are more isolated than background.

The other selection criteria used in the analysis are either motivated by these two criteria or by the requirement that we be able to normalize our results in a reliable manner.

Precise reconstruction of the B meson proper lifetime relies on the SVX. Both muons must have at least three associated clusters in the SVX. The two muon candidates are constrained to a common vertex. The chi-square probability on this one-degree-of-freedom fit is required to be greater than 1% (i.e. $\chi^2 < 6.6$). The transverse momenta of both muons, after the vertex constrained fit, are required to be larger than 2 GeV/c (see figure 2).

The results of our search are normalized to the measured CDF B meson cross section [7]. The measurements of $\sigma(\mathrm{B}^0)$ and $\sigma(\mathrm{B}^+)$ are for $p_\mathrm{T}(B) > 6\,\mathrm{GeV}/c$ and $|y(B)| < 1$. Furthermore, the efficiency of the isolation selection criterion has only been measured for $p_\mathrm{T}(B) > 6\,\mathrm{GeV}/c$. For our search, therefore, we require that the muon pair has $p_\mathrm{T}(\mu^+\mu-) > 6\,\mathrm{GeV}/c$ (see figure 3).

To reconstruct the B meson proper lifetime $c\tau$, we use quantities measured in the plane transverse to the beamline. The proper lifetime is defined as

$$c\tau = \frac{L_{xy} \cdot m(\mu^+\mu^-)}{p_t(\mu^+\mu^-)},$$

where L_{xy} is the projection of the vector pointing from the primary vertex to the secondary vertex on the unit-vector pointing along the direction of the transverse momentum of the B meson candidate. The muon pairs are required to have $c\tau > 100\mu$m (see figure 4).

The muon pair isolation r is defined as

$$r = \frac{p_t(\mu^+\mu^-)}{p_t(\mu^+\mu^-) + \Sigma p_t},$$

where Σp_t is the sum of the transverse momenta of all tracks within a cone of radius $\Delta R < 1$ ($\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$) centered around the momentum vector of the B meson candidate (the muon tracks are not included in this sum). The muon pairs with $r < 0.7$ are rejected (see figure 5).

Finally the signal region for the B_d^0 is defined as $\pm 75\,\mathrm{MeV}/c^2$ around the measured mass $m(B_d^0) = 5279.0 \pm 2.0\,\mathrm{MeV}/c^2$ [8], and the signal region for the B_s^0 is defined as $\pm 75\,\mathrm{MeV}/c^2$around the measured mass $m(B_s^0) = 5375.0 \pm 6.0\,\mathrm{MeV}/c^2$ [8].

Figure 6 shows the mass spectrum of the data after all the cuts have been applied. Both unlike-sign (solid) and like-sign (dashed) pairs are shown.

3 Results

In the B_d^0 and B_s^0 mass windows, there are 0 and 1 candidates, respectively, that pass all the selection criteria. Treating this one candidate as signal, this implies that the 90% CL on the branching fractions corresponds to the values that yield 2.30 and 3.89 events on average, for the B_d^0 and B_s^0, respectively.

The upper limit on the branching fractions is given by

$$Br(B^0 \to \mu^+\mu^-) < \frac{N_{observed}^{90\%\ CL}}{2\sigma(B) \cdot \mathcal{L} \cdot \alpha \cdot \epsilon}.$$

For the cross section we assume that $\sigma(B^+) = \sigma(B_d^0) = 3\sigma(B_s^0)$, and $\sigma(B^+) = 2.39 \pm 0.54$ μb for $p_t(B) > 6\,\mathrm{GeV}$ and $|y(B)| < 1$ [7]. The combined acceptance and efficiency is $1.8 \pm 0.2\%$.

We have included two sources of systematic error in the limit on the branching fraction:

- the sum in quadrature of the statistical and systematic error in the cross section;
- the error in the efficiency.

These systematic errors were added in quadrature, resulting in a total error of 27.6% on $2\sigma(B) \cdot \mathcal{L} \cdot \alpha \cdot \epsilon$. This total error was treated as a Gaussian error in determining the limit.

The 90% CL limits that include systematic errors are

$$Br(B_d^0 \to \mu^+\mu^-) < 1.6 \times 10^{-6}$$

$$Br(B_s^0 \to \mu^+\mu^-) < 8.4 \times 10^{-6}.$$

The corresponding 95% CL limits are

$$Br(B_d^0 \to \mu^+\mu^-) < 2.2 \times 10^{-6}$$

$$Br(B_s^0 \to \mu^+\mu^-) < 1.1 \times 10^{-5}.$$

References

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[7] *Measurement of the B Meson Differential Cross Section, $d\sigma/dp_T$, in $p\overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV,* F. Abe et al, The CDF Collaboration, Report No. FERMILAB-Pub-95/48-E, March 1995, submitted to Phys. Rev. Lett.

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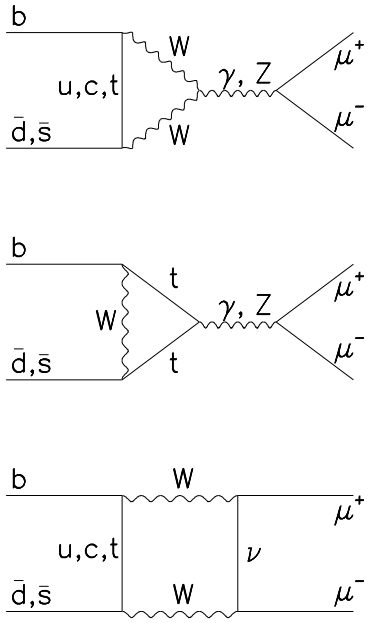

Figure 1: Some of the diagrams contributing to $B^0 \to \mu^+\mu^-$ decays.

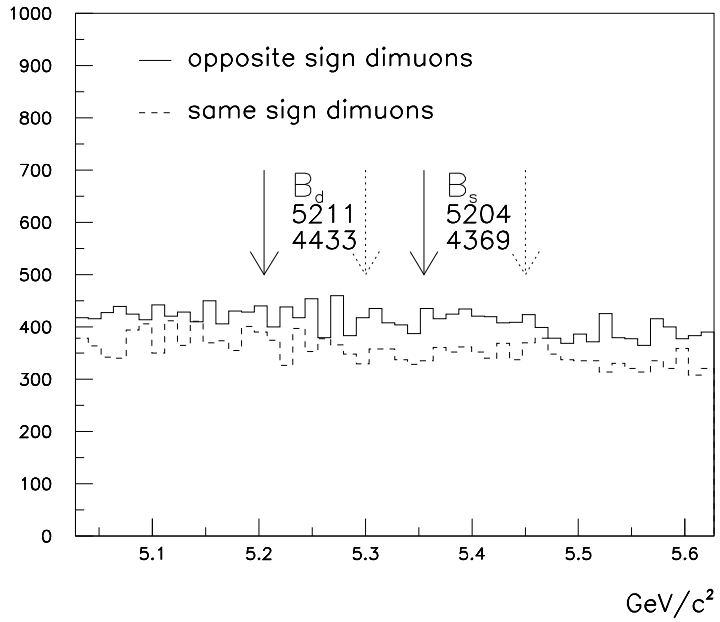

Figure 2: The mass spectrum of the data sample after preselection. The arrows mark the search regions defined later in the text. The upper number is for unlike-sign pairs and the lower number is for like-sign pairs.

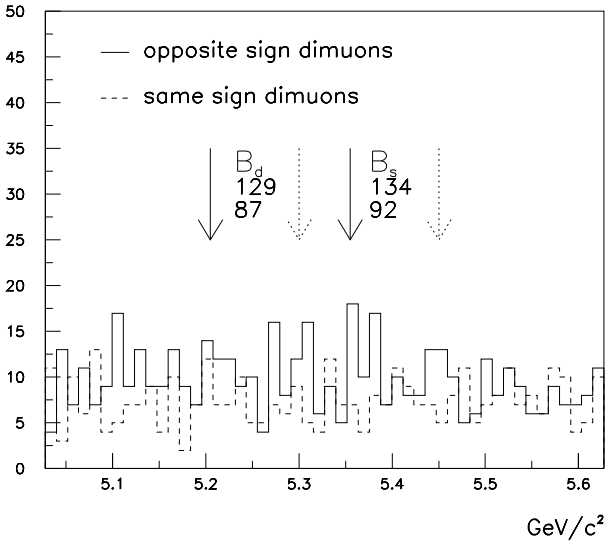

Figure 3: The mass spectrum in the data after all cuts but the proper lifetime and isolation cuts.

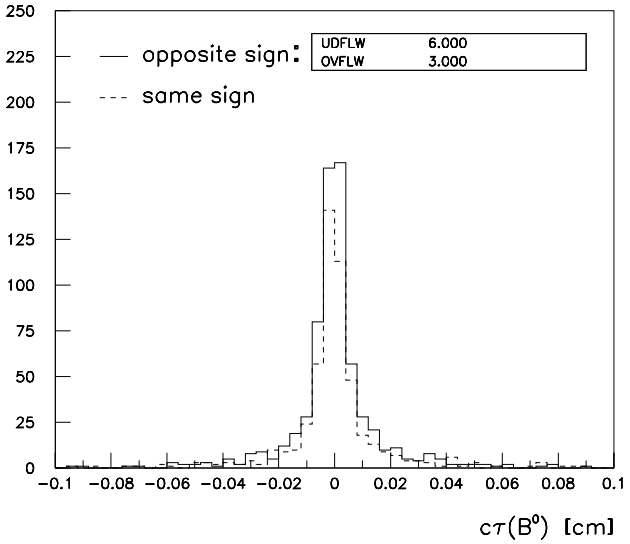

Figure 4: $c\tau$ distribution in the data.

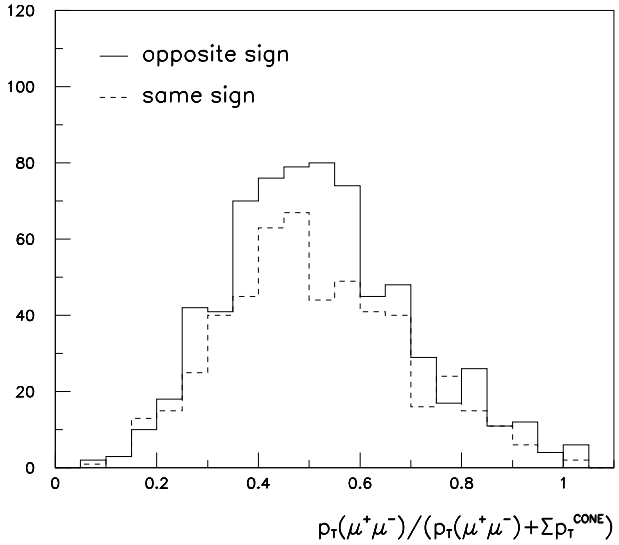

Figure 5: The isolation distribution in the data.

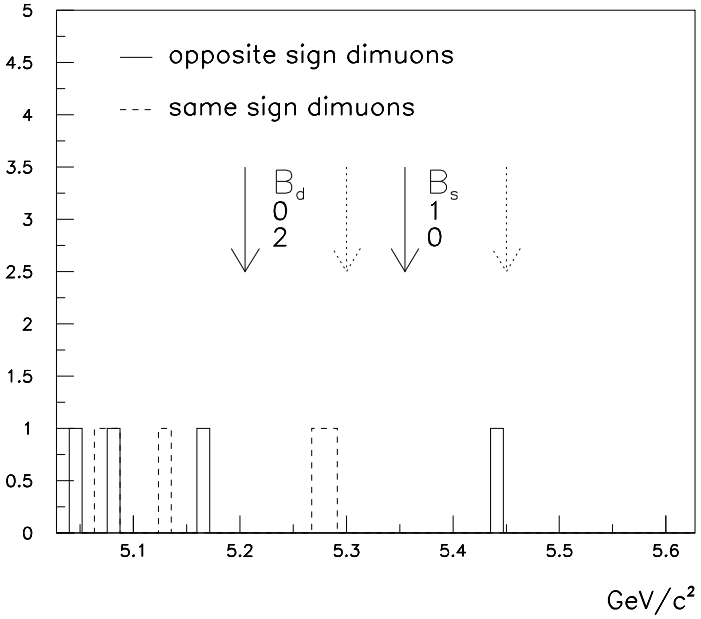

Figure 6: The mass spectrum of the data after all the cuts have been applied. Both unlike-sign (solid) and like-sign (dashed) pairs are shown.