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B MESON LIFETIMES AT CDF

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ABSTRACT

Measurements of the B_u, B_d, and B_s meson lifetime using semileptonic $B_u \to e\nu D^0 X, B_d \to e\nu D^* X, B_s \to l\nu D_s X$ events and exclusive $B_u \to \psi^{(\prime)} K^{(*)}, B_d \to \psi^{(\prime)} K^{(*)}_{(s)}, B_s \to \psi\phi$ events are presented. These results used the precise position measurements of the CDF SVX silicon vertex detector and were obtained from a 19.3 pb^{-1} sample of 1.8 TeV $\bar{p}p$ collisions collected in 1992-93 at the Fermilab Tevatron collider. Comparisons with previous measurements will be shown.

1. Introduction

During the 1992-93 Tevatron collider Run Ia, the Collider Detector at Fermilab (CDF)[1] collected a data sample of $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV with an integrated luminosity of 19.3 pb^{-1}. This data sample, in combination with improvements to the data acquisition system, the muon coverage, and most importantly, the installation of the CDF SVX silicon vertex detector,[2] has allowed the first measurements of inclusive and exclusive B meson lifetimes at a hadron collider. In this paper we report results on the B_u, B_d, and B_s meson lifetime using semileptonic $B_u \to e\nu D^0 X, B_d \to e\nu D^* X, B_s \to l\nu D_s X$ events and exclusive $B_u \to \psi^{(\prime)} K^{(*)}, B_d \to \psi^{(\prime)} K^{(*)}_{(s)}, B_s \to \psi\phi$ events.

2. Charged and Neutral B Meson Lifetimes

Measuring the lifetime differences of the individual B mesons is a direct probe to possible non-spectator contributions in B meson decay. Only small lifetime differences are expected among the different B mesons (possibly as low as $\sim 5\%$[3]) and experiments are now approaching this precision.

At CDF, the measurement of the charged and neutral B meson lifetimes was performed using fully reconstructed B decays in the following modes[4]:

$$
\begin{array}{llllll}
B^+ & \to J/\psi K^+ & \to \mu^+\mu^- K^+; & B^+ & \to J/\psi K^{*+} & \to \mu^+\mu^- K^0_s \pi^+ \\
B^+ & \to \psi(2S) K^+ & \to \mu^+\mu^-\pi^+\pi^- K^+; & B^+ & \to \psi(2S) K^{*+} & \to \mu^+\mu^-\pi^+\pi^- K^0_s \pi^+ \\
B^0 & \to \psi K^0_s & \to \mu^+\mu^- K^0_s; & B^0 & \to \psi K^{*0} & \to \mu^+\mu^- K^+\pi^- \\
B^0 & \to \psi(2S) K^0_s & \to \mu^+\mu^-\pi^+\pi^- K^0_s; & B^0 & \to \psi(2S) K^{*0} & \to \mu^+\mu^-\pi^+\pi^- K^+\pi^-
\end{array}
$$

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These measurements using exclusive decay modes are rather unique, provide a statistical precision of 10 – 12%, and are now published.[5] We quote only the results here:

$$\begin{aligned} \tau^+_{exc} &= 1.61 \pm 0.16(\text{stat}) \pm 0.05(\text{syst})\text{ps} \\ \tau^0_{exc} &= 1.57 \pm 0.18(\text{stat}) \pm 0.08(\text{syst})\text{ps} \\ \tau^+_{exc}/\tau^0_{exc} &= 1.02 \pm 0.16(\text{stat}) \pm 0.05(\text{syst}) \end{aligned}$$

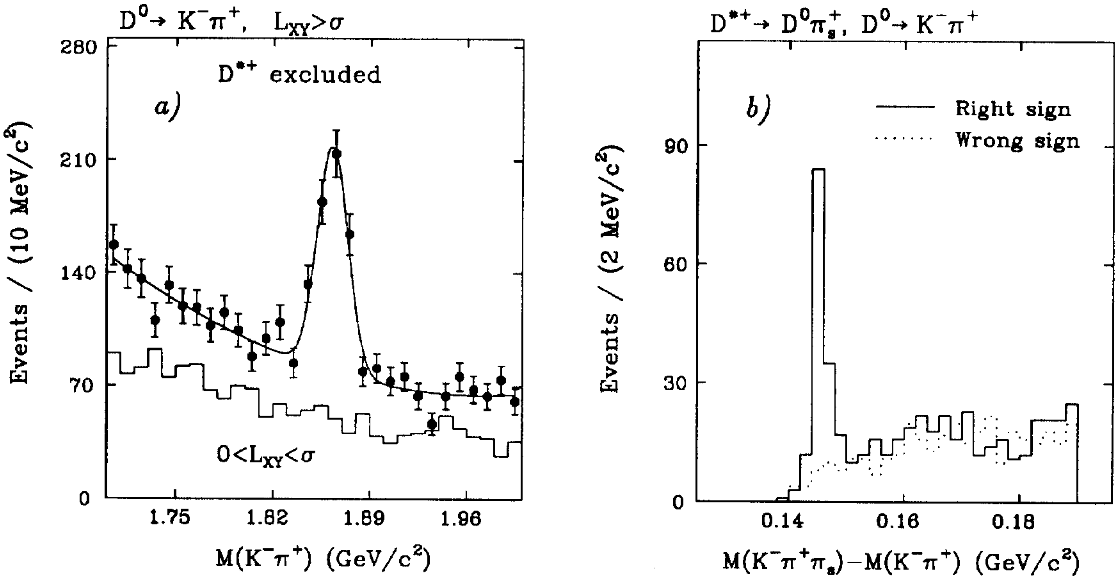

Fig. 1: a) The $K^-\pi^+$ invariant mass distribution in the electron sample. Events from D^{*+} decay are excluded. b) The distribution of the mass difference, $\Delta m = m(K^-\pi^+\pi_s) - m(K^-\pi^+)$, for $D^{*+} \to D^0\pi_s^+, D^0 \to K^-\pi^+$ candidates.

We now turn to a new, preliminary measurement of the charged and neutral B meson lifetimes using semileptonic decays,[6] as have been previously done by the LEP experiments.[7] Partially reconstructed semileptonic decays of B mesons, namely a lepton in association with a charm D^0 or D^{*+} meson will provide *nearly orthogonal* samples of charged and neutral B mesons and thus enable a determination of their individual lifetimes.

The present measurement uses only the single electron sample and makes electron identification cuts which have been described previously.[8] After applying these cuts, approximately 400,000 electron candidates remain. The next step is the reconstruction of the D^0 meson in the decay mode $D^0 \to K^-\pi^+$. This is done by using all oppositely charged track pairs, assigning kaon and pion masses, and considering only tracks within a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.7$ around the electron. In addition, the momentum of the kaon and pion are required to satisfy $p(K) > 1.0$ GeV/c, $p(\pi) > 0.5$ GeV/c and all three tracks, the electron, kaon, and pion candidates must be well reconstructed within the SVX detector. Three sources of D^0 mesons are considered in this analysis: 1) $B^- \to e^-\overline{\nu}D^0X, D^0 \to K^-\pi^+$, where the D^0 is *not* from

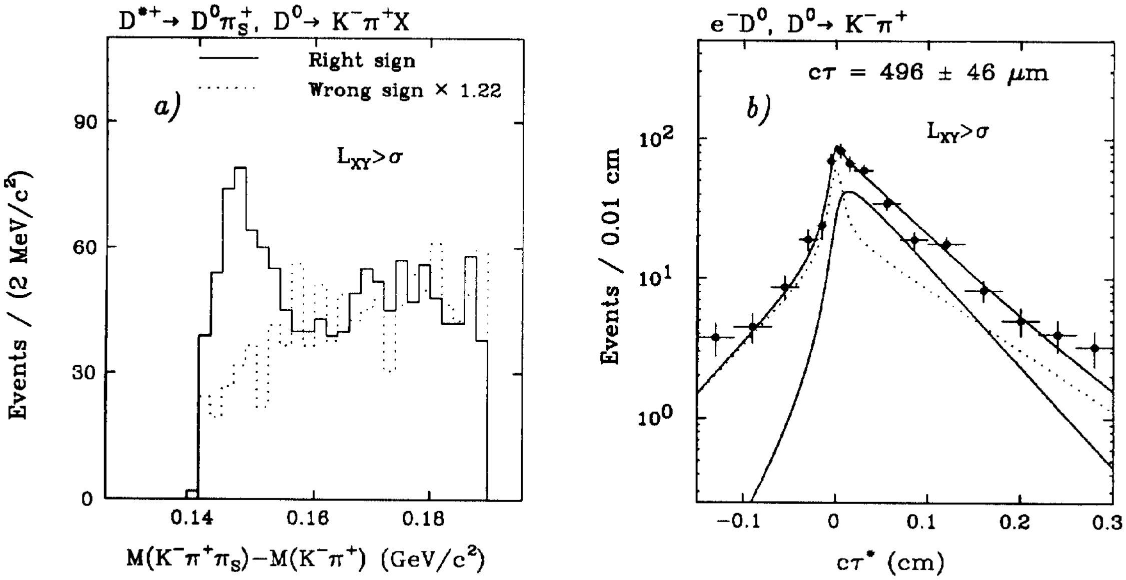

Fig. 2: a) The mass difference distribution for $D^0 \to K^-\pi^+\pi^0$ candidates. b) The combined, signal, and background $c\tau^*$ distributions in the D^0 signal sample.

$D^{*+} \to D^0\pi_s^+$ ("D^0 sample"); 2) $\overline{B}^0 \to e^-\overline{\nu}D^{*+}X, D^{*+} \to D^0\pi_s^+, D^0 \to K^-\pi^+$ ("D^{*+} sample"); and 3) $\overline{B}^0 \to e^-\overline{\nu}D^{*+}X, D^{*+} \to D^0\pi_s^+, D^0 \to K^-\pi^+\pi^0$ ("satellite sample") . The decay length of the D^0 in the plane transverse to the colliding beams, L_{XY}, must satisfy $L_{XY} > \sigma(L_{XY})$, where $\sigma(L_{XY})$ is the calculated error on the transverse decay length, for the D^0 and satellite samples. Figure 1a shows the resulting $K^-\pi^+$ mass distribution, containing 389 ± 31 events in the D^0 peak, for the D^0 sample. Figure 1b gives the mass difference distribution for the D^{*+} sample, and Fig. 2a gives the Δm distribution for the satellite sample where a cut is made at $\Delta m < 0.155$ GeV/c^2. These figures show the production of $e - D^0$ combinations in the expected ("right sign") charge combinations and little evidence above combinatoric background in the "wrong sign" combinations.

The electron and D^0 tracks are then intersected to determine the B decay vertex position and decay length from the primary vertex. Since the B is only partially reconstructed, the $e - D^0$ system transverse momentum can be used to determine a "pseudo-$c\tau$" value $c\tau^* = L_B m_B / p_T(e + D^0) = c\tau/K$, where K is a momentum correction factor determined from Monte Carlo. It is determined separately for each D^0 signal sample.

The signal $c\tau^*$ distributions are fit with an exponential lifetime term convoluted with a Gaussian resolution function and the momentum correction distribution. The lifetime of the background under the signal peak is determined from the wrong sign and signal sideband distributions and is modeled by a Gaussian resolution function plus two exponential tails. Figure 2b shows the result of the lifetime fit for the D^0 signal sample. The fit quality and results for the D^{*+} and satellite samples are similar. The fraction of B^- and $\overline{B^0}$ contributing to each of the D^0, D^{*+}, and satellite samples is determined and includes the effects of cross-talk due to: 1) the π_s^+ reconstruction efficiency, $\epsilon(\pi_s^+) = 0.93 \pm 0.21$. A missed spectator pion from D^{*+} decay can cause a D^0 to be associated with B^- rather than $\overline{B}^0$; 2) the D^{**} fraction, $f^{**} = \mathrm{BR}(\overline{B} \to l^-\overline{\nu}D^{**})/\mathrm{BR}(\overline{B} \to l^-\overline{\nu}X) = 0.36 \pm 0.12$[9]; 3) the fraction of D^{**} decaying to D^*, from the QQ Monte Carlo is found to be $\mathrm{BR}(D^{**} \to D^*\pi)/(\mathrm{BR}(D^{**} \to D^*\pi) + \mathrm{BR}(D^{**} \to D\pi)) = 0.78$; and 4) the charged-to-neutral lifetime ratio can affect the event mixture, $\mathrm{BR}(B^- \to l^-\overline{\nu}X)/\mathrm{BR}(\overline{B^0} \to l^-\overline{\nu}X) = \tau(B^-)/\tau(\overline{B^0})$. In spite of these effects, we find that the D^0 and D^{*+} signals provide *nearly orthogonal* samples of B^- and $\overline{B^0}$ mesons. A combined likelihood function is used to simultaneously fit the signal samples for the B^- and $\overline{B^0}$ meson lifetimes. Variations in the sample composition due to the above effects are included in the systematic uncertainty. The results are:

$$\begin{aligned} \tau^+_{semi} &= 1.63 \pm 0.20(\mathrm{stat})^{+0.15}_{-0.16}(\mathrm{syst})\mathrm{ps} \\ \tau^0_{semi} &= 1.62 \pm 0.16(\mathrm{stat})^{+0.14}_{-0.15}(\mathrm{syst})\mathrm{ps} \\ \tau^+_{semi}/\tau^0_{semi} &= 1.01 \pm 0.19(\mathrm{stat}) \pm 0.17(\mathrm{syst}) \end{aligned}$$

Tables 1 and 2 show a comparison of the latest[10] τ^+, τ^0, and τ^+/τ^0 values from CDF, LEP, and CLEO. Averaging asymmetric errors and computing a weighted average, we find that the error on the world value for τ^+ and τ^0 is at 5% and the lifetime ratio has an uncertainty of 7%. Clearly, with some additional statistics and work on systematic errors, non-spectator contributions to B meson decay will soon be tested.

Table 1: Comparison of charged and neutral B meson lifetime measurements.

Experiment	τ^+ (ps)	τ^0 (ps)	Reference
Delphi	1.30 ± 0.35	1.17 ± 0.31	Z. Phys. C57, 181 (1993)
Delphi	1.72 ± 0.10	1.68 ± 0.21	DELPHI 94-97 PHYS 414
Opal	1.53 ± 0.18	1.62 ± 0.14	OPAL Note PN149
Aleph	1.47 ± 0.25	1.52 ± 0.21	Phys. Lett. B307, 194 (1993)
Aleph	1.30 ± 0.23	1.17 ± 0.22	ALEPH Note 94-100
CDF	1.61 ± 0.17	1.57 ± 0.20	PRL 72, 3456 (1994)
CDF	1.63 ± 0.26	1.62 ± 0.22	CDF Note 2598
World Ave.	1.60 ± 0.07	1.53 ± 0.08	DPF 1994

3. B_s Meson Lifetime

A similar technique has been used to measure the B_s meson lifetime using semileptonic $B_s \to l\overline{\nu}D_s, D_s \to \phi\pi, \phi \to K^+K^-$ decays.[12] Figure 3a shows the $K^+K^-\pi^+$ invariant mass spectrum after all cuts for the combined electron and muon samples. Some 76 ± 8 events are found in the right-sign mass peak and a hint of the Cabbibo

Table 2: Comparison of charged-to-neutral B meson lifetime ratio results.

Experiment	τ^+/τ^0	Reference
Delphi	1.11 ± 0.46	Z. Phys. C57, 181 (1993)
Delphi	1.02 ± 0.16	DELPHI 94-97 PHYS 414
Opal	0.94 ± 0.14	OPAL Note PN149
Aleph	0.96 ± 0.23	Phys. Lett. B307, 194 (1993)
Cleo	0.93 ± 0.22	CLNS 94/1286[11]
CDF	1.02 ± 0.17	PRL 72, 3456 (1994)
CDF	1.01 ± 0.25	CDF Note 2598
World Ave.	0.98 ± 0.07	DPF 1994

Table 3: B_s meson lifetime results from CDF and LEP.

Experiment	τ_s (ps)	Reference
Delphi	1.42 ± 0.24	Z. Phys. C61, 407 (1994)
Opal	1.33 ± 0.24	OPAL Note PN113
Aleph	1.75 ± 0.36	ALEPH Note 94-044
Aleph	1.92 ± 0.40	Phys. Lett. B322, 275 (1994)
CDF	1.42 ± 0.27	CDF Note 2472
CDF	1.74 ± 0.75	CDF Note 2515
World Ave.	1.49 ± 0.12	DPF 1994

suppressed $D^+ \rightarrow \phi\pi^+$ decay is seen. Following the same procedure as above, the B_s lifetime from semileptonic $B_s \rightarrow l\bar{\nu}D_s$ is measured to be (Fig. 3b):

$$\tau_s^{semi} = 1.42^{+0.27}_{-0.23}(\text{stat}) \pm 0.11(\text{syst})\text{ps}$$

Finally, there is a new low-statistics measurement of the B_s lifetime using fully reconstructed $B_s \rightarrow J/\psi\phi, J/\psi \rightarrow \mu^+\mu^-, \phi \rightarrow K^+K^-$ decays.[13] At least two of the four daughter tracks are required to be reconstructed in the SVX. Based on a sample of 10 events, the B_s lifetime using exclusive $B_s \rightarrow J/\psi\phi$ is measured to be:

$$\tau_s^{exc} = 1.74^{+0.90}_{-0.60}(\text{stat}) \pm 0.07(\text{syst})\text{ps} \tag{1}$$

Table 3 shows a comparison of the latest B_s lifetime measurements at CDF and LEP.[14] Calculated similar to above, the world average value has only an 8% uncertainty.

4. Conclusions

The first measurements of the B_u, B_d, B_s meson lifetimes and the B_u/B_d lifetime ratio by CDF are comparable to the latest results from other experiments. With the installation of a rad-hard SVX and possibly x5 more data from the present Run Ib, the prospects for precision measurements of the B meson lifetimes in both inclusive and exclusive modes in the near future is very promising.

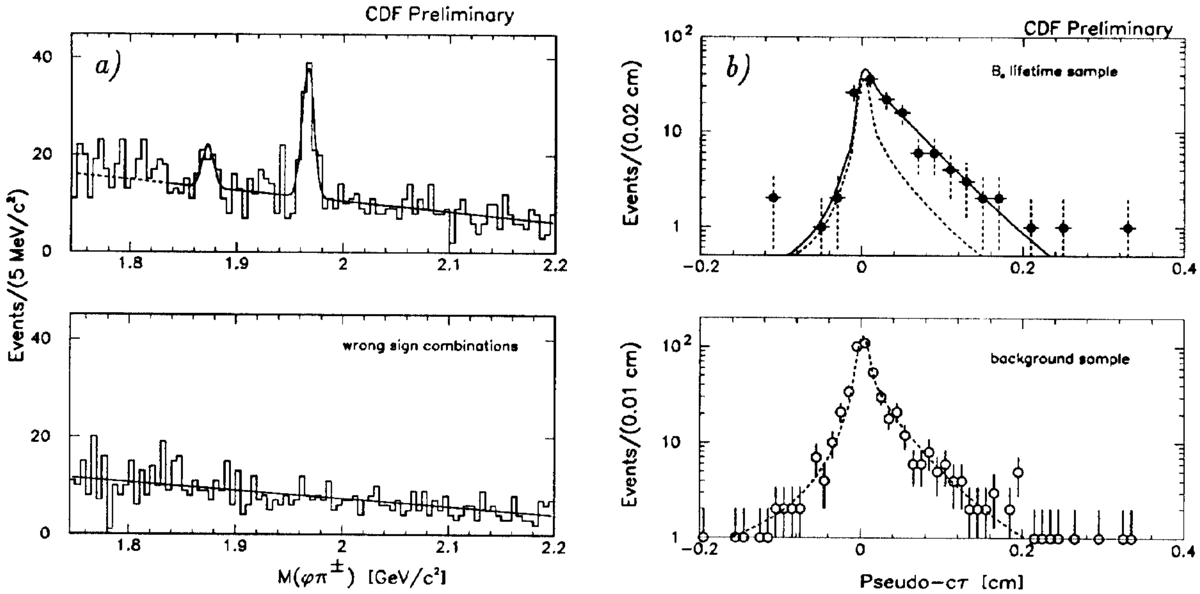

Fig. 3: a) The $\phi\pi^-$ mass distribution for "right sign" and "wrong sign" lepton-D_s combinations. b) Pseudo-$c\tau$ distribution of the $l^- D_s^+$ signal sample showing the lifetime fits of the combined (signal plus background) and background distributions separately.

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