DETERMINATION OF THE B_s LIFETIME USING HADRONIC DECAYS

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We present a measurement of the B_s^0 meson lifetime using fully and partially reconstructed hadronic decays $B_s^0 \to D_s^- \pi^+(X)$ followed by $D_s^- \to \phi\pi^-$. The data sample was recorded with the CDF II detector at the Fermilab Tevatron and corresponds to an integrated luminosity of 1.3 fb^{-1} from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

1 Introduction

For hadrons containing the heavy b quark, one might assume that the light quark is only a spectator to the decay of the b, and the lifetimes of all the b hadrons are the same regardless of the light quark's flavor. However, the spectator quarks do participate in the decay, and the hierarchy $\tau(B_c) < \tau(\Lambda_b) < \tau(B_s) \cong \tau(B_d) < \tau(B_u)$ has been both theoretically predicted and experimentally observed. The ratio of lifetimes is often quoted so some systematic uncertainties cancel. Recent theoretical calculations predict $\tau(B_u)/\tau(B_d) = 1.06 \pm 0.02$, $\tau(B_s)/\tau(B_d) = 1.00 \pm 0.01$, and $\tau(\Lambda_b)/\tau(B_d) = 0.86 \pm 0.05$. [1] The world averages for the corresponding experimental numbers are 1.071 ± 0.009, 0.939 ± 0.021, and 0.921 ± 0.036, respectively. [2] The experimental uncertainties are smaller than the theoretical uncertainties for all but the B_s ratio. As $\tau(B_d)$ is already well measured, further improvements must come from reducing the uncertainty on $\tau(B_s)$.

In this Proceeding we present the most precise flavor-specific measurement of the B_s lifetime to date. The data come from $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV produced at the Fermilab Tevatron. This analysis is based on an integrated luminosity of ~1.3 fb^{-1} collected by the CDF II detector[3] between February 2002 and November 2006. After trigger and analysis selection criteria have been applied, the sample yields more than 1100 fully reconstructed $B_s \to D_s^- \pi^+$ candidates with $D_s \to \phi\pi^-$ and $\phi \to (K^+K^-)$.[a] In addition, the sample reconstructed as $B_s \to D_s^- \pi^+$ includes a similar number of partially reconstructed B_s candidates, for example, $B_s \to D_s^- \rho^+$ followed by $\rho^+ \to \pi^+\pi^0$ where the π^0 is not reconstructed, that can contribute to the lifetime measurement and double the number of events available for analysis. The increase comes with an uncertainty due to missing particles or incorrect mass assumptions, but the uncertainty can be properly accounted for and folded into the likelihood formulation.

[a] Charge conjugation is implied throughout this Proceeding.

2 Analysis Method

A data sample rich in hadronic B decays was selected with a three-level trigger system that searches for tracks displaced from the primary vertex. The trigger level requirements preferentially select longer lived particles, shaping the proper time distribution. Thus the exponential distribution of lifetimes no longer extends down to $ct = 0$. Instead there is a visible "trigger turn-on" in the distribution, which is visible in Figure 2.

The lifetime of the B_s meson is determined from two sequential fits. The first fit is a maximum likelihood fit to the invariant mass distribution of candidates reconstructed as $D_s^-(\phi\pi^-)\pi^+$ with $m(D_s^-(\phi\pi^-)\pi^+) \in$[4.85, 6.45] GeV/$c^2$ This fit determines the relative fractions of various decay modes and backgrounds in the data sample. Using the fractions determined in the mass fit as inputs, the second fit is to the proper decay time distributions for the B_s.

The lifetime of the B_s meson is determined from an unbinned likelihood fit to the B_s candidates with invariant masses in [5.00, 5.45] GeV/c^2. We use separate probability distribution functions (PDFs) for the fully reconstructed (FR) modes, partially reconstructed (PR) modes, and the backgrounds. For the lifetime fit the variable of interest is the proper decay time, defined as $ct \equiv \frac{L_{xy} \cdot m_B^{rec}}{p_{T_B}}$ where L_{xy} is the decay length projected along the transverse momentum of the B_s, p_{T_B}. Notice that the reconstructed mass is used instead of the world average B_s mass. A salient feature of this analysis is the treatment of partially reconstructed B_s mesons as signal events that contribute to the lifetime measurement. Since in the partially reconstructed cases L_{xy}, m_B^{rec}, and p_{T_B} are extracted from candidates that are missing tracks after reconstruction or have the wrong mass assignment for a single daughter particle, a multiplicative correction factor K to the decay length is needed. K is defined as $K = \frac{1}{\cos\theta_{\rm PR}} \cdot \frac{p_T({\rm PR})}{p_T({\rm true})} \cdot \frac{m_B({\rm true})}{m_{rec}({\rm PR})}$ where θ_{PR} is the angle in the $x-y$ plane between the true momentum of the B_s and the momentum of the partially reconstructed B_s.

There are separate PDFs for the three categories of proper time distributions. How each component is treated depends on its decay structure and whether it can provide information about the B_s lifetime. The FR and PR PDFs depend on τ_B, the B_s lifetime, while the background PDFs have fixed shapes.

- **Fully Reconstructed:** The only fully reconstructed mode is the $D_s\pi$. The root functional form of the FR PDF (given in Equation 1) is an exponential with decay constant $\tau(B_s)$ convoluted with a Gaussian resolution function with width σ. A multiplicative "efficiency curve" of the form given in Equation 2 accounts for the trigger and analysis selection criteria. The shape parameters (σ, β_i, N_i and τ_i) of the PDF come from a fit to a simulated B_s sample where the lifetime used for generation is known. All the parameters for the PDF except for $\tau(B_s)$ are then fixed in the final fit to data. Note that although σ is intended to be a detector resolution, it floats along with the efficiency curve parameters during the fits to the Monte Carlo. During this process it becomes correlated with the other parameters describing the overall PDF shape and loses some of its physical meaning.

$$P_{\rm FR}(ct) = \left[\frac{1}{c\tau} e^{\frac{-ct'}{c\tau}} \otimes_{t'} \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(ct-ct')^2}{2\sigma^2}} \right] \cdot {\rm eff}(ct) \qquad (1)$$

$${\rm eff}(ct) = \begin{cases} 0 & \text{if } ct \le \beta_i \\ \sum_{i=1}^{3} N_i \cdot (ct-\beta_i)^2 \cdot e^{\frac{-ct}{\tau_i}} & \text{if } ct > \beta_i \end{cases} \qquad (2)$$

- **Partially Reconstructed:** As they also come from B_s mesons, the D_sK, $D_s\rho$, $D_s^*\pi$, and other partially reconstructed modes can contribute to the B_s lifetime measurement. However, a multiplicative correction factor K to the decay length is needed. The PR PDF

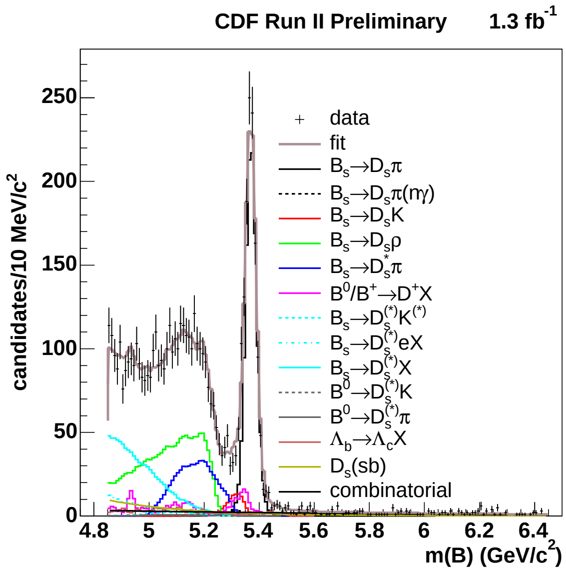

Figure 1: Mass distribution of events reconstructed as $B_s \to D_s^-(\phi\pi^-)\pi^+$ with fit projections overlaid.

given in Equation 3 is similar to the FR PDF with an additional convolution with the K factor distribution for each mode. There are separate efficiency curve parameters for each mode, again determined from fits to simulation.

$$P_{\mathrm{PR}}(ct) = \left[\frac{1}{c\tau}e^{\frac{-ct'}{c\tau}} \otimes_{t'} \frac{1}{\sqrt{2\pi}K\sigma}e^{\frac{-(K\cdot ct-ct')^2}{2K^2\sigma^2}} \otimes_K p(K)\right] \cdot \mathrm{eff}(ct) \tag{3}$$

- **Background:** The backgrounds can either come from single-B modes (*e.g.*, $B^0/B^- \to D^-X$, $B^0 \to D_sX$, and $\Lambda_b \to \Lambda_cX$), or they can be combinatorial in nature. There are two combinatorial background proxies available: the B_s upper sideband taken from the m_B interval [5.7, 6.4] GeV/c^2 and the D_s sidebands. Both proxies contains a mixture of real D_s+track and fake D_s+track events. The background PDFs come from fits to simulated samples(for b-hadron backgrounds) or from the combinatorial background proxies. All the background shape parameters are fixed in the final lifetime fit.

3 Fit Results

The fit procedure was tested extensively on three control samples: $B^0 \to D^-\pi^+$ with $D^- \to K^+\pi^-\pi^-$, $B^0 \to D^{*-}\pi^+$ with $D^{*-} \to \overline{D}^0\pi^-$ and $\overline{D}^0 \to K^+\pi^-$, and $B^+ \to \overline{D}^0\pi^+$ with $\overline{D}^0 \to K^+\pi^-$ before performing a blinded B_s fit. Good agreement with the PDG values of the B^0 and B^+ lifetimes was found.

The projection of the B_s mass fit is shown in Figure 1. The lifetime of $c\tau_{B_s} = 455.0 \pm 12.2(\mathrm{stat.})\mu$m is obtained from the full fit. The ct projection of the fit result is plotted in Figure 2.

We consider several sources of systematic uncertainty: combinatorial background fraction, modeling simulated backgrounds from single-B decays, effect of reweighting the Monte Carlo to match the data's p_T and trigger distributions, impact parameter correlation, and detector alignment. The largest contribution to the systematic uncertainty comes from the uncertainty on the total amount of combinatorial background and the relative amount of promptly-produced real-D_s background (the component with the lowest mean lifetime). The invariant mass shapes

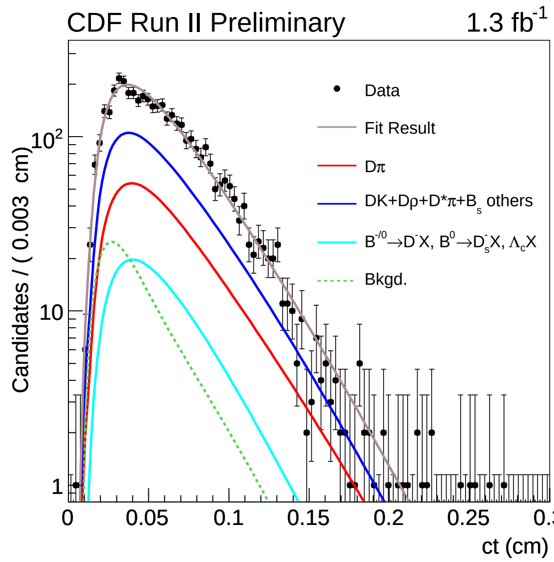

Figure 2: ct projection of lifetime fit results for events reconstructed as $B_s \to D_s^-(\phi\pi^-)\pi^+$

for the real-D_s and fake-D_s combinatorial backgrounds are very similar, and several mass fit configurations that are equally valid from first principles yield dissimilar background fractions. The variations in the fractions returned from these mass fits are used to evaluate the systematic uncertainty.

4 Conclusions

A fit for the B_s lifetime in $\sim$1.3 fb^{-1} of data reconstructed as $B_s \to D_s^-\pi^+$ is performed. The fit utilizes both fully and partially reconstructed modes. We measure

$$\begin{aligned} c\tau(B_s) &= 455.0 \pm 12.2(\text{stat.}) \pm 7.4(\text{syst.})\mu\text{m} \\ &= 1.518 \pm 0.041(\text{stat.}) \pm 0.025(\text{syst.})ps \end{aligned}$$

The ratio of this single result and the world average B^0 lifetime yields $\tau(B_s)/\tau(B_d) = 0.99 \pm 0.03$. This agrees well with the theoretical prediction of $\tau(B_s)/\tau(B_d) = 1.00 \pm 0.01$. More information about this analysis can be found on its public webpage. [4]

References

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