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B lifetimes and flavour tagging at CDF Run II

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Abstract. Data samples of $\sim 140\text{pb}^{-1}$ gathered with CDF Run II's displaced vertex trigger and J/Ψ trigger have led to measurements of B hadron lifetimes in exclusive and semileptonic modes which are presented here. Also discussed are evaluations of flavour tagging techniques in Run II data.

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1 Introduction

$p\overline{p}$ collisions produce a wide spectrum of B hadrons in a challenging environment. CDF Run II has specialised triggers for the collection of B events, in particular a displaced vertex trigger. Individual data samples of about 140pb^{-1} have been collected to date. This surpasses the CDF Run I integrated luminosity and has already led to accurate lifetime measurements of B hadrons in J/Ψ and semileptonic channels which are presented here. Also presented are preliminary flavour tagging studies which utilise high statistics semileptonic samples.

2 B triggers

The collection of B mesons at CDF Run II benefits greatly from the Silicon Vertex Trigger (SVT) [1] which allows triggering on a track's impact parameter at Level 2. SVT requirements are that a track must have $p_T > 2\text{GeV/c}$ and impact parameter $> 120\mu\text{m}$. This ability is currently utilised in two types of trigger at CDF. Firstly, a trigger requiring one SVT track and a lepton (μ or e) with $p_T > 4\text{GeV/c}$ provides samples rich in the semileptonic decays of B hadrons. This sample is used for very accurate lifetime measurements and flavour tagging studies. With the displaced trigger, the semileptonic B yields are three times those of Run I. In a second trigger implementation, two tracks are required to pass the SVT, resulting in samples which are rich in hadronic decays of bottom and charm hadrons [2]. Both samples will be used for a B^0_s mixing measurement. In addition to these two novel triggers, CDF Run II also has an improved dimuon (J/Ψ) trigger, in which the p_T of each μ must be $> 1.5\text{GeV/c}$, which gathers J/Ψ decay modes of B hadrons at low transverse momentum. In fact, CDF now gathers J/Ψ's with $p_T \geq 0\text{GeV/c}$ allowing the J/Ψ cross section to be measured down to $p_T = 0$ [3].

3 B lifetimes

According to the spectator model, all B hadrons have equal lifetimes but experiment proves otherwise. The current best theoretical model for lifetime predictions is HQET which still has discrepancies with the observed lifetimes. Therefore one of the prime motivations for measuring B hadron lifetimes is to give an accurate reference for theoretical predictions of the pattern of B hadron lifetimes. Measurement of lifetimes at this point in Run II also serves as a check of the detector and triggers, and in the case of B^0_s begins the path to measuring $\Delta\Gamma_s/\Gamma_s$ and Δm_s.

The lifetime analyses presented here fall into two categories: exclusive and semileptonic. The former are of the type $B \to J/\Psi X$. The J/Ψ trigger provides us with clean fully reconstructable B's whose lifetimes are unbiased by the trigger. The latter come from the lepton plus SVT trigger and are of the type $B \to \ell\nu D$. These also give clean signals but in this case the decay is only partially reconstructed, owing to the ν, and the lifetime is biased. Monte Carlo information is used to deal with these complications. In both exclusive and semileptonic lifetime analyses the ideology is to reconstruct the decay length by vertexing decay products to calculate the B transverse decay length, L_{xy}, and measuring their transverse momentum, p_T. The lifetime is then $c\tau = \frac{L_{xy} m(B)}{p_T}$.

3.1 Exclusive lifetimes

The fit methodology for exclusive B decays is a simultaneous unbinned maximum likelihood fit to the candidate B hadron mass and lifetime distributions. The fit to the mass distribution is used to determine the fraction of background in the signal region. The mass peak is modelled as a Gaussian and the background as a first order polynomial. Fig. 1 shows the B^0_s invariant mass distribution in

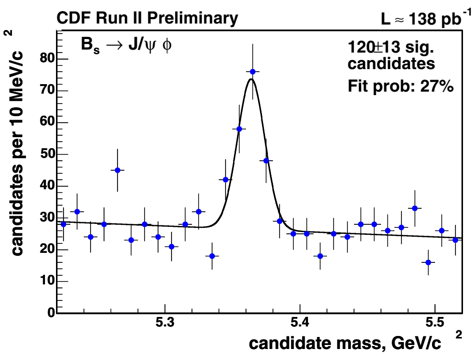

Fig. 1. Invariant mass of B_s^0 meson in the decay $B_s^0 \to J/\Psi\phi$

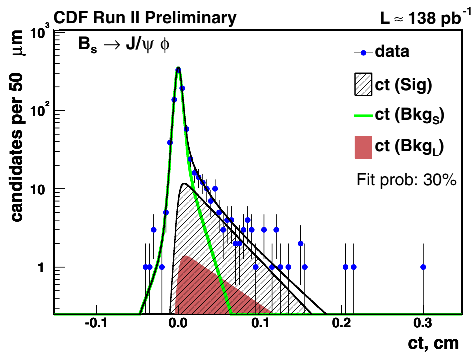

Fig. 2. Lifetime fit to $B_s^0 \to J/\Psi\phi$ decays' lifetime distribution

Table 1. CDF Run II preliminary B hadron lifetimes in exclusive channels. The first error is statistical and the second is systematic. The integrated luminosity is $\approx 138\text{pb}^{-1}$

CDF Run II Preliminary	
$B^+ \to J/\Psi K^+$	1.63±0.05±0.04 ps
$B_d^0 \to J/\Psi K^{0*}$	1.51±0.06±0.02 ps
$B_s^0 \to J/\Psi\phi$	1.33±0.14±0.02 ps
$\Lambda_b \to J/\Psi\Lambda$	1.25±0.26±0.10 ps

the decay $B_s^0 \to J/\Psi\phi$. The fit to the lifetime distribution is shown in Fig. 2. The signal component is an exponential decay convoluted with a Gaussian whose width is defined by the error on the decay vertex multiplied by a scale factor, which is allowed to float in the fit. The background parameterisation is a δ function to model the prompt component, one negative exponential and two positive exponential components. The lifetime results for B^+, B_d^0, B_s^0 and Λ_b are shown in Table 1. This is the first measurement of the Λ_b lifetime in a fully reconstructed decay. Since this is a statistically limited sample, much of the Λ_b analysis was optimised using $B_d^0 \to J/\Psi K_s^0$.

3.2 Semileptonic lifetimes

As discussed in Sect. 2, a lepton plus SVT track trigger has been implemented successfully for the first time giv-

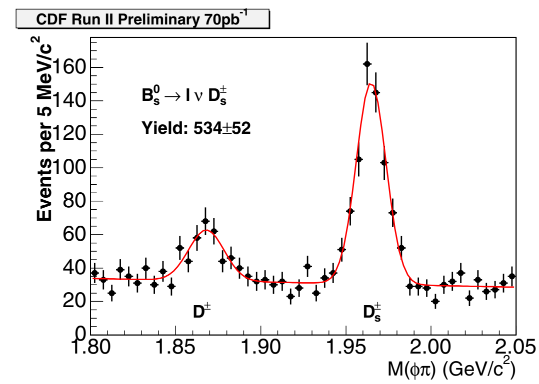

Fig. 3. Invariant mass of $D_s^\pm$ meson in the decay $D_s^\pm \to \phi\pi$. Also visible is the Cabibbo suppressed $D^\pm \to \phi\pi$

ing CDF the capability to accumulate samples which are rich in B hadron semileptonic decays, $B \to \ell\nu D$. To measure lifetimes in the semileptonic channels, the standard methodology [4] is followed. The D meson is reconstructed and required to be in proximity to the lepton, by means of a cone ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$) cut. The invariant mass distribution of the $D_s^\pm \to \phi\pi$ which pass the proximity and vertexing requirements is shown in Fig. 3. From such plots, signal and sideband regions are defined. Then, since the B is not fully reconstructed owing to the ν, the $\beta\gamma$ factor is extracted from Monte Carlo, and the lifetime formula given earlier becomes $c\tau = \frac{L_{xy} m(B)}{p_t(B)} = \frac{L_{xy} m(B)}{p_t(\ell D)} K$ where K is the correction factor: $K = \frac{p_t(\ell D)}{p_t(B)}$. There is, however, one significant complication to this usual methodology. The displaced vertex trigger introduces a bias to the lifetime. To correct for this, Monte Carlo emulations of the trigger are deployed to model the lifetime bias which is factored into the fit function. The fit methodology is an unbinned maximum likelihood fit to the B lifetime distribution. The signal is fit with an exponential decay convoluted with a Gaussian resolution function, the K factor distribution, P(K), and the lifetime bias function ϵ in the following form :

$$F_{sig} = N\frac{K}{c\tau}\exp\left(\frac{-Kt}{\tau}\right)\epsilon(Kt) \otimes G(t, s\sigma) \otimes P(K)$$

The background is parameterised by a δ function and positive exponential which are convoluted with a Gaussian resolution with width equal to the error on the displaced vertex multiplied by a scale factor. Unlike the exclusive lifetime Gaussian width, here the scale factor is determined separately in a control sample which does not have a lifetime bias. Fig. 4 shows the lifetime fit for the Λ_b baryon. At present the control sample lifetime measurements (B^+, B_d^0) show a discrepancy with the world average. Work is ongoing with cross checks and further studies of the trigger bias, semileptonic decay kinematics and possible contamination from combinations of real D's with real or fake leptons. The statistical errors evaluated for 140pb^{-1} are shown in Table 2.

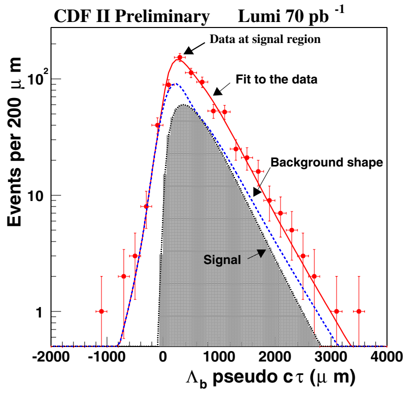

Fig. 4. Lifetime fit to $\Lambda_b \to \ell\nu\Lambda_c$ decays' lifetime distribution

Table 2. CDF Run II B semileptonic lifetime statistical error projections based on an integrated luminosity of 140 pb^{-1}

Lifetime statistical error projections	
$B^+ \to \ell\nu D^0$	±0.04 ps
$B_d^0 \to \ell\nu D^{(*)-}$	±0.06 ps
$B_s^0 \to \ell\nu D_s^-$	±0.07 ps
$\Lambda_b \to \ell\nu\Lambda_c$	±0.09 ps

4 Flavour tagging studies

CDF Run II will have the ability to measure B_d^0 mixing and B_s^0 mixing if it occurs at the value predicted by the Standard Model. For this purpose, a battery of flavour tagging techniques is being developed. These can be divided into "same side" (K/π tag) and "opposite side" (soft lepton, opposite side K, jet charge) tags. Two of these have so far been evaluated using Run II data.

The same side π tag has been evaluated in samples where a B^+ meson, which cannot mix, is reconstructed. A π is sought close to the B^+ and the power of its charge to tag the B flavour at production is evaluated. The time dependent raw asymmetry, $(N_R(t) - N_W(t))/(N_R(t) + N_W(t))$, has been measured in samples of $B^+ \to \ell^+\nu D^0$ and $B^+ \to J/\Psi K^+$ decays. The raw asymmetry in the former is 0.165 ±0.013 and in the latter is 0.209±0.039. The errors are statistical only. A version of this tag, seeking a K rather than π, will be applied to B_s^0 events.

The lepton plus SVT track trigger provides a high statistics sample of semileptonic b and c decays which is ideal for optimising opposite side tags. The sign of the trigger lepton gives an estimate of the flavour of one B in the event allowing the power of a tag to be optimised and measured on the other B. The bottom component can be isolated by a mass cut on the invariant mass of the lepton and SVT track and by subtracting the prompt background using the signed impact parameter of the SVT track. The result is that in a sample of 60pb^{-1}, of order 150k semileptonic B decays are isolated, which is sufficient to allow the sample to be subdivided into several categories, as will be discussed later for the soft muon tag. The unbiased optimisation and evaluation of dilutions in the large generic semileptonic samples can then be cross-checked with partially reconstructed decays, $B_{d,u}^{0,+} \to \ell^+ D^{+,0}$ and, if the results are consistent, this gives credibility to the determination of dilution in $B_s^0 \to \ell^-\nu D_s^+$.

This methodology has been applied to the soft muon tag which involves identifying a muon on the opposite side from the trigger lepton and SVT track. Its charge tags the flavour of the B on the opposite side and so the efficiency and dilution of the tag can be measured. ϵD^2 is found to be 0.660±0.093%. This can be compared with the Run I result ϵD^2=0.584±0.082%. Owing to the large statistics available, the parameterisation of the dilution can be determined as a function of variables such as the transverse momentum of the tag muon with respect to the opposite jet, p_T^{rel}, as shown in Fig. 5. The parameterisation has also been examined as a function of the muon subsystem in which the muon was detected.

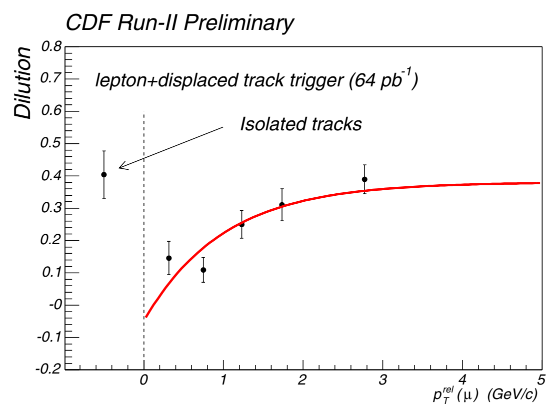

Fig. 5. Dilution as a function of p_T^{rel} of the tag muon with respect to the opposite side jet. The data points with $p_T^{rel} < 0$ correspond to tracks not associated with a jet

5 Summary

Lifetime measurements have been made in the clean $B \to J/\Psi X$ channels with the results shown in Table 1. In addition, a lepton plus displaced vertex trigger has been implemented at CDF for the first time. The lifetime measurements from this sample are ongoing and they will give the world best statistical accuracy for the B_s^0 and Λ_b lifetimes. A procedure has been established for flavour tagging in Run II and two taggers have been optimised and evaluated in an unbiased way. These measurements pave the way for a determination of $\Delta\Gamma_s/\Gamma_s$ and the first steps towards observing B_s^0 mixing have taken place.

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