Recent B physics results from D0

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The D0 detector as collected over 3.7 fb^{-1} of high quality data. With this large data set, D0 is able to perform a number of precision B lifetime and CP asymmetry measurements. Additionally D0 is measuring a number of properties of B hadrons (B_s and B_c) which are currently only accessible at the Tevatron.

1. $B_s \to J/\psi\phi$

The CP violating mixing phase ϕ_s is predicted to be small, -0.04 ± 0.01, however, new phenomenon may modify this phase and a large value of ϕ_s may be an indication of new physics. B_s decays are reconstructed in the mode $B_s \to J/\psi\phi$. Using 2.8 fb^{-1} of data, 1967 ± 65 (stat) events are reconstructed. The flavor of the initial B_s is determined by flavor tagging using both "same-side" and "opposite-side" tagging. The decay amplitude of the B_s is separated into three independent components. These components are either longitudinal or transverse to their direction and parallel or perpendicular to each other. There is a high degree of correlation between Δm_s, ϕ_s and the two CP-conserving phases. This makes it difficult to obtain a stable fit if all parameters are allowed to vary independently. To obtain a stable fit, Δm_s is fixed to the measured value of 17.77 ± 0.12 ps^{-1} [1]. The two CP-conserving phases are allowed to vary around the world averages under a Gaussian constraint with width $\pi/5$.

After applying the above constraints an unbinned likelihood fit returns $\phi_s = -0.57^{+0.24}_{0.30}$ and $\Delta\Gamma_s = 0.19 \pm 0.07$ ps^{-1}. Fig. 1 shows the confidence contours in the $\Delta\Gamma_s$-ϕ_s plane.

In addition, the average lifetime of the $(B_s, \bar{B}_s)$ system is measured to be $\bar{\tau}_s$= 1.52 ± 0.05 (stat) ± 0.01 (syst) ps (see Fig. 2).

2. $B_s \to D_s^{(*)} D_s^{(*)}$

In the Standard Model, the mixing phase ϕ_s can be ignored when discussing $\Delta\Gamma_s$. In this case,

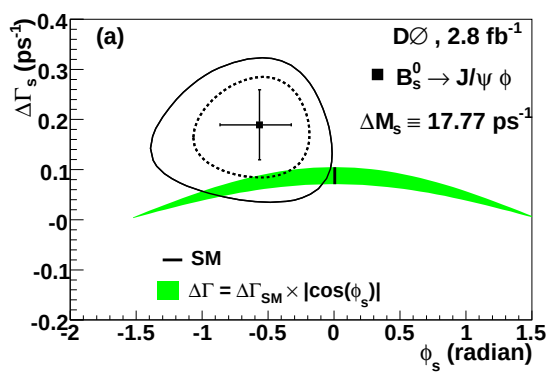

Figure 1. The confidence-level contours in the $\Delta\Gamma_s$ - ϕ_s plane. The dashed curve is the 68.3% CL and the solid is the 90% CL.

the mass eigenstates are the CP eigenstates and any $b \to c\bar{c}s$ decay into a CP even ground state arises only from the CP even component. Under certain theoretical assumptions [3] the decay $B_s \to D_s^* D_s^*$ is CP-even to within 5% and therefore this branching ratio is related to $\Delta\Gamma_s$ as:

$$2Br(B_s \to D_s^* D_s^*) \approx \Delta\Gamma_s^{CP}[\frac{1+cos\phi_s}{2\Gamma_L} + \frac{1-cos\phi_s}{2\Gamma_H}]$$

This analysis is based on 2.8 fb^{-1} and studies B_s decays into two $D_s^{(*)}$ mesons. The notation $D_s^{(*)}$ refers to either a D_s or D_s^* since it is not possible to distinguish between them due to the undetected particles in $D_s^* \to D_s\gamma/\pi^0$ decays.

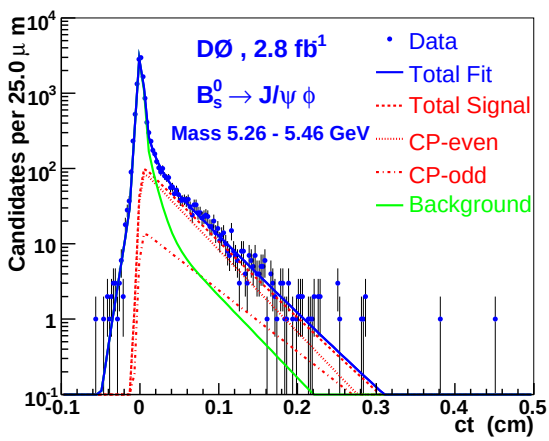

Figure 2. Lifetime distribution for $B_s \to J/\psi\phi$.

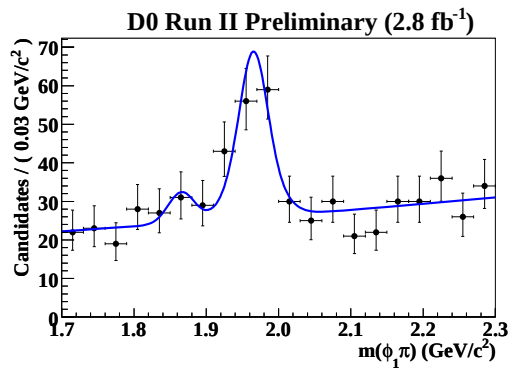

Figure 3. Invariant mass distribution $m(\phi_1\pi)$ for the $D_s\phi_2\mu$ sample

In this analysis, one $D_s^{(*)}$ decays into $\phi_1\pi$ and the other into $\phi_2\mu\nu$. The branching ratio measurement is made by normalizing the $B_s \to D_s^{(*)}D_s^{(*)}$ decay to $B_s \to D_s^{(*)}\mu\nu$.

The correlation between $D_s(\phi_1\pi)$ candidates and $\phi_2(KK)$ candidates is exploited using a two-dimensional unbinned likelihood fit. Fig. 3 shows the result of the fit, where the fit yields N($D_s\phi_2\mu$)= 31.0 $\pm$ 9.4. The signal fraction of $B_s \to D_s^{(*)}D_s^{(*)}$ is determined by assuming the background is dominated by two processes: $B^{\pm,0} \to D_s^{(*)}D_s^{(*)}KX$ and $B_s \to D_s^{(*)}\mu\nu\phi$. Fig 4 shows the two-dimensional mass distributions for signal and background. The plot is divided into nine regions and Monte Carlo is to determine the fraction of events in each region occupied by signal and background. The data are then fit to determine the number of signal events. The main systematic uncertainty in the measurement of the branching ratio is the uncertainties of the branching ratios found in the PDG [2]. A final branching ratio measurement of Br($B_s \to D_s^{(*)}D_s^{(*)}$) = $0.042 \pm 0.015(stat) \pm 0.017(syst)$ is obtained giving $\frac{\Delta\Gamma_s}{\Gamma_s} = 0.088 \pm 0.030(stat) \pm 0.036$(syst).

3. B_c mass and lifetime

The B_c is unique in that it is a bound state of two heavy quarks of different flavor. By studying the B_c, various theoretical models can be tested against the measured mass and lifetime. The B_c is most easily reconstructed when it decays into a J/ψ such as $B_c \to J/\psi\ell\nu$ (for lifetime measurements due to the high statistics) and $B_c \to J/\psi\pi$ (for mass measurements, since there is no undetected neutrino).

Using approximately 1.3 fb^{-1} of data, the decay $B_c \to J/\psi\pi$ is reconstructed and is shown in Fig. 5. An unbinned likelihood fit is performed resulting in a signal yield of 54 $\pm$ 12 events, a signal significance of 5.2 σ and a B_c mass of 6300.7 $\pm$ 13.6 MeV/c^2

Using approximately 1.3 fb^{-1} of data, the lifetime of the B_c meson is also measured. B_c candidates are formed by combining a J/ψ with a muon. The mass of the $J/\psi + \mu$ candidate is required to be between 3 and 10 GeV. The mass can be used to separate out the signal from the five major backgrounds. A signal mass template is determined using MC and background templates are measured using data. Fig. 6 shows the fit to the mass distribution after subtracting the backgrounds due to B^+ and the J/ψ sidebands.

A fit to the data consisting of a mass shape tem-

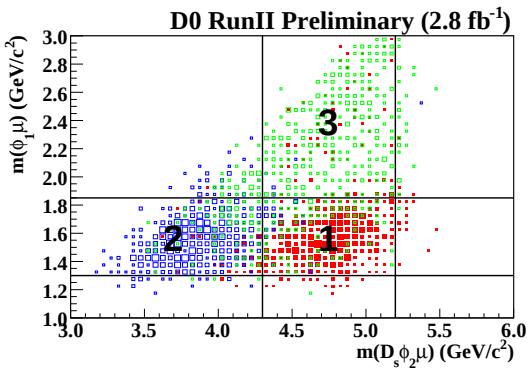

Figure 4. Two dimensional plot of $m(\phi_2\mu)$ versus $m(D_s\phi_2\mu)$. The signal region is dominant in region 1 while the background, $B^{\pm,0} \to D_s^* D_s^* KX$ is dominant in region 2 and $B_s \to D_s^* \mu\nu\phi$ is dominant in region 3.

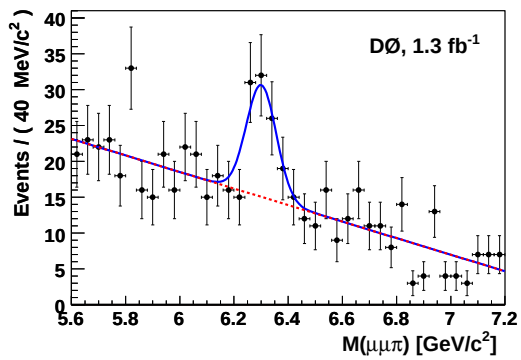

Figure 5. $J/\psi\pi$ invariant mass distribution. A projection of the unbinned fit is overlaid on the plot.

plate and a lifetime model is performed. Since the p_T of the B_c is not known due to the presence of the neutrino, the p_T of the $J/\psi + \mu$ is used as an approximation. The visible proper decay length is measured and defined as $L_{xy}\frac{m(B_c)}{p_T(J/\psi\mu)}$ where L_{xy} is the transverse decay length. A correction factor based on MC is then applied to estimate the p_T of the B_c to determine the proper time. Fig 7 shows the visible proper decay length for the $J/\psi{+}\mu$ sample with projections of the fit superimposed. A lifetime of $\tau(B_c) = 0.448^{+0.038}_{-0.036}$ stat $\pm$ 0.032(sys) ps is obtained, currently making this measurement the most precise measurement of the B_c lifetime.

4. B_s mixing

A measurement of the $B_s - \bar{B}_s$ oscillation frequency is a powerful test for the CKM formulism of the Standard Model. The CDF experiment has reported the oscillation frequency Δm_s to be 17.77 $\pm$ 0.10 (stat) $\pm$ 0.07 (sys) [4].

Using 2.8 fb^{-1} of data, we have updated our oscillation frequency measurement. This measurement combines all of our semileptonic decay modes as well as the hadronic mode.

The data are fit using the amplitude fit method [5]. The values of Δm_s are varied from 0 to 30 ps^{-1} in step sizes of 0.5 ps^{-1}.The fitted value of the amplitude A is plotted as function of Δm_s. Fig. 8 shows the amplitude as function of Δm_s.

We plot the difference $\Delta logL(\Delta m_s)= logL_{\Delta m_s}(A = 1) - log(L_\infty)$, see Fig. 9. The points are fitted to a parabolic function and a value of Δm_s=18.56 $\pm$ 0.87 is obtained. The statistical significance of the minimum is 3.1 σ.

5. $B^+ \to J/\psi K^+$

The Standard Model predicts a very small charge asymmetry for $B^\pm \to J/\psi K^\pm$ decays, where the charge asymmetry is defined as

$$A_{CP}(B^+ \to J/\psi K^+) =$$

$$\frac{N(B^- \to J/\psi K^-) - N(B^+ \to J/\psi K^+)}{N(B^- \to J/\psi K^-) + N(B^+ \to J/\psi K^+)}$$

A measurement of the charge asymmetry can therefore constrain those models which predict large asymmetries for $B^\pm \to J/\psi K^\pm$ decays.

B^+ decaying to $J/\psi K^+$ events are reconstructed and shown in Fig. 10. This distribution is a combination of $B \to J/\psi K, B \to J/\psi\pi$, and $B \to J/\psi K^*$. Using an unbinned likelihood fit,

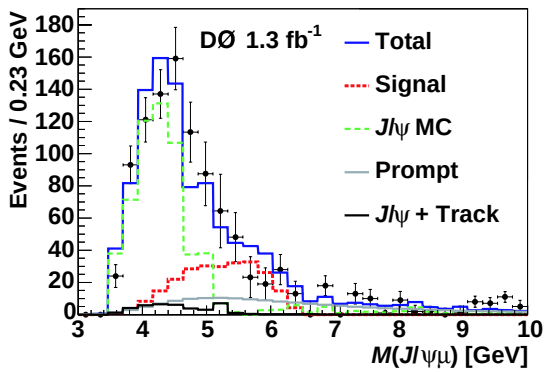

Figure 6. Fit to the $J/\psi + \mu$ mass with the J/ψ mass sideband and B^+ background subtracted. A decay length significance of greater than 4 has been applied.

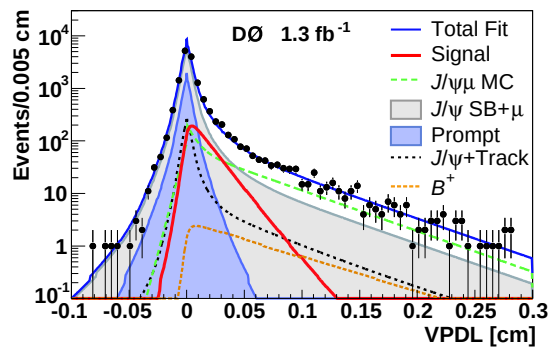

Figure 7. Visible proper decay length of the $J/\psi\mu$ sample with the fit projections overlaid.

the fraction of each decay is determined. The asymmetry due to physics and detector effects must be removed. In order to measure these asymmetries, the data are subdivided into eight samples with different solenoid and toroid polarities and different pseudorapidity of the J/ψ K system and charge of the kaon candidate. Fitting these eight samples allows an extraction of the true asymmetry. The direct CP-violating charge asymmetry is measured to be $A_{CP}(B^+ \to J/\psi K^+) = +0.0075 \pm 0.0061(stat) \pm 0.0030(syst)$, making this the most precise measurement of this asymmetry.

6. Upsilon polarization

Non-relativistic QCD (NRQCD) is able to predict both the production and decay of quarkonium [6]. One of the predictions from NRQCD for quarkonium produced at the Tevatron is that the S-wave should be transversely polarized at high p_T. By measuring the polarization of the $\Upsilon(1S)$ and $\Upsilon(2S)$ at D0, this prediction can be tested.

One measure of the polarization is

$$\alpha = (\sigma_T - 2\sigma_L)/(\sigma_T + 2\sigma_L)$$

where σ_T and σ_L are the transversely and longitudinally polarized components of the production cross section. The angular distribution of quarkonium decaying into two muons is given by

$$\frac{dN}{d(cos(\theta^*))} \propto 1 + \alpha cos^2(\theta^*)$$

where θ^* is the angle of the positively charge muon in the quarkonium center-of-mass frame with respect to the momentum of the Υ in the lab frame.

The dimuon invariant mass spectrum is fitted in bins of $|cos(\theta^*)|$. Fig. 11 shows a fit to the invariant mass distribution for a particular $|cos(\theta^*)|$ bin. The Monte Carlo does not accurately describe the data, so the MC was weighted so that both p_T^Υ and p^Υ agree. After this reweighting, there is good agreement between data and Monte Carlo, see Fig. 12.

Fig. 13 compares the measured values from D0 (circles) of α for the $\Upsilon(1S)$ as a function of p_T^Υ. Also shown in Fig. 13 are the prediction of NRQCD (grey band), and the two limits of the k_t factorization model [7] (lower curve: quark-spin conservation hypothesis) (upper curve: full quark-spin depolarization hypothesis). Also shown (triangles) is the previous measurement from CDF [8]. Fig 14 compares the measured values from D0 (circles) of α for the $\Upsilon(2S)$ as a function of p_T^Υ along with the predic-

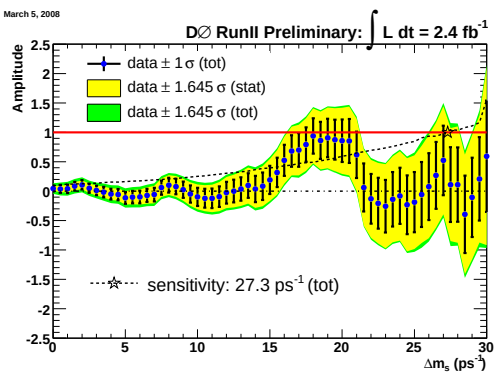

Figure 8. Combined B_s oscillation amplitude as a function of Δm_s

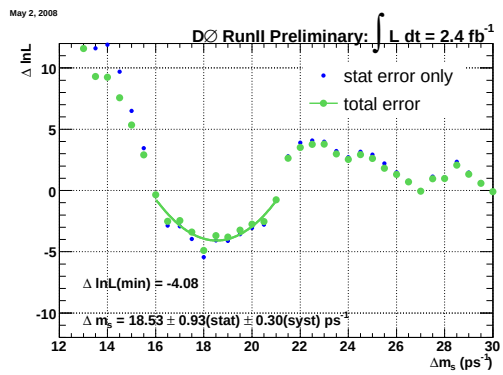

Figure 9. Combined dependence of $\Delta(logL)$ on Δm_s.

tion of NRQCD (grey band).

Significant p_T dependence is seen in the longitudinal polarization for the $\Upsilon(1S)$ which is not seen in the NRQCD prediction.

REFERENCES

1. D. Acosta, *et al.* (CDF collaboration), Phys. Rev. Lett. 97, 242003 (2006)
2. W.-M. Yao *et al.*, Journal of Physics G **33**, 1 (2006).
3. R. Aleksan *et. al.,* Phys. Lett. B, **316**, 567 (1993).
4. A. Abulencia, *et. al.,* Phys. Rev. Lett. **97** (2006) 242003.
5. H.G Moser, A. Roussarie, Nucl. Instrum. Meth. A384:491-505 (1997)
6. G.T. Bodwin, E. Braaten and G.P. Lepage. Phys. Rev. D 51, 1125 (1995) [Erratum-ibid. D 55, 5853 (1997)].
7. S.P. Baranov and N.P. Zotov, Pis'ma v ZhETF 86, 499 (2007).
8. D. Acosta, *et al.* (CDF collaboration), Phys. Rev. Lett. 88, 161802 (2002)

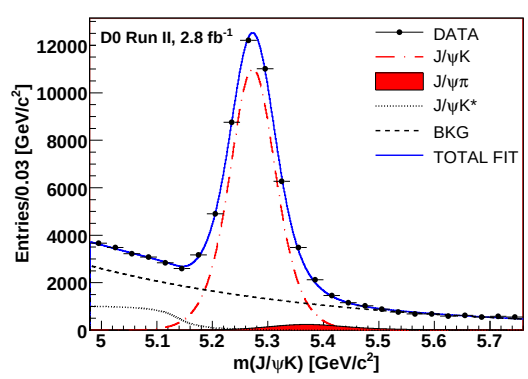

Figure 10. The $J/\psi K^+$ invariant mass distribution along with the projection of the unbinned likelihood fit.

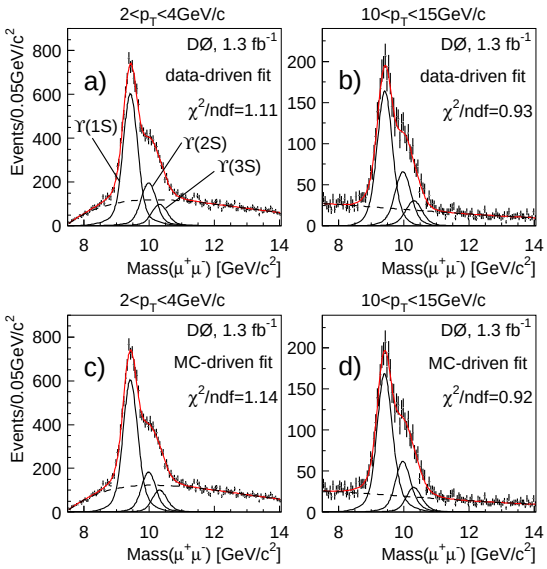

Figure 11. Dimuon invariant mass distribution for events in $0.4 < |cos(\theta^*)| < 0.5$.

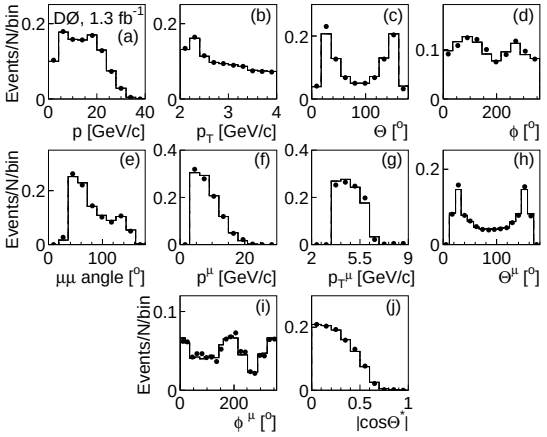

Figure 12. Comparison between Monte Carlo (solid histogram) and data(points) for $\Upsilon(1S)$ with $2 < p_T^{\Upsilon} < 4$ GeV.

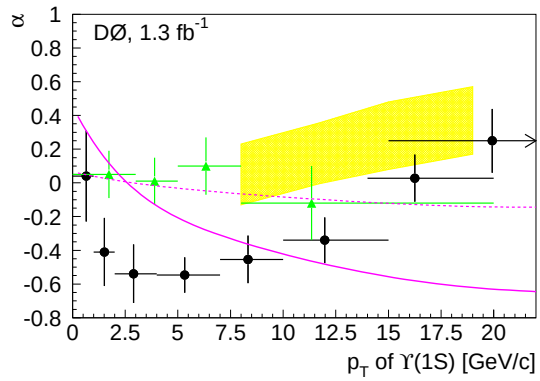

Figure 13. α dependence as a function of p_T^{Υ} for $\Upsilon(1S)$. The different points and curves are explained in the text.

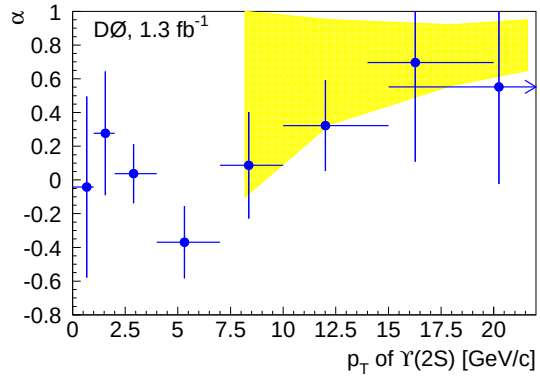

Figure 14. α dependence as a function of p_T^{Υ} for $\Upsilon(2S)$. Circles are D0 data and the grey band is the prediction from NRQCD.