

# Time-Integrated Charge Asymmetries at DØ

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## Abstract

We have measured the time-integrated charge asymmetries in dimuon events and semileptonic  $B_s$  decays. These results are the most precise semileptonic charge asymmetries in  $B$  decays to date. We combine these results with measurements from the decay  $B_s \rightarrow J/\psi\phi$  to determine the CP-violating phase  $\phi_s$ . We find  $\phi_s = -0.56 + 0.44 - 0.41$ .

## 1 Introduction

In the neutral  $B_s$ , mixing occurs through  $|\Delta B| = 2$  transitions. These oscillations can be described by three physical quantities:  $|M_{12}|$ ,  $|\Gamma_{12}|$  and  $\phi_s$ , where  $|M_{12}|$  and  $|\Gamma_{12}|$  are the elements of the complex mass matrix, and  $\phi_s$  is a CP violating phase.

$$\phi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right). \quad (1)$$

Determining the value of  $\phi_s$  is interesting because new physics can lead to an enhancement of  $\phi_s$ . Also, because  $\phi_s$  is predicted to be small in the Standard Model[1], any sizeable measurement of  $\phi_s$  would be a clear signal for new physics. In this paper we will discuss two measurements which are used to determine the value of  $\phi_s$ . These results are preliminary as of September 2006.

## 2 Dimuon Asymmetry

The dimuon charge asymmetry measures the charge asymmetry in direct decays of  $B\bar{B}^0$  pairs. One can determine the charge asymmetry using

$$A_{SL} = \frac{N(b\bar{b} \rightarrow \mu^+\mu^+X) - N(b\bar{b} \rightarrow \mu^-\mu^-X)}{N(b\bar{b} \rightarrow \mu^+\mu^+X) + N(b\bar{b} \rightarrow \mu^-\mu^-X)} \quad (2)$$

Using dimuon pairs has an advantage over single muon events because the dimuon events are relatively clean. To first order there is no charge asymmetry in dimuon background processes.

This analysis uses approximately  $1 \text{ fb}^{-1}$  of data collected during Fermilab RunII collider operations. This resulted in approximately 3 million dimuon events. Sources of background dimuon events include cosmic rays, charged pion and kaon decays, punch throughs and  $W^\pm$  and  $Z^0$  decays. The majority of these backgrounds are removed by applying timing cuts and cuts on the  $p_T$  of the muon. Imposing the requirement that muons traverse the DØ toroid significantly reduces the number of punch throughs.

The DØ detector has two separate spectrometers used for muon reconstruction. The central tracking device includes a silicon microstrip tracker and a scintillating-fiber tracker located within a 2T superconducting solenoid. The muon system consists of toroidal magnets with proportional/mini drift tubes and scintillation counters for muon detection and triggering. The magnets in the two spectrometers can be reversed independently which allows cancellation of many detector asymmetries, as shown in Figure 1.

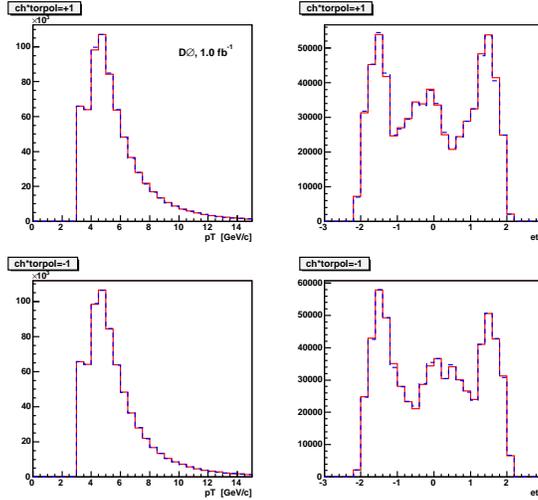


Figure 1: Muon  $p_T$  (left) and  $\eta$  (right) distributions. Each plot contains two separate histograms with each histogram having the same product of muon charge $\times$ toroid polarity. The two histograms lie nearly on top of each other indicating that the detector response for opposite charges are nearly the same. The top plots are for the positive charge $\times$ polarity while the bottom plots contain the negative charge $\times$ polarity.

To determine the semileptonic charge asymmetry, we divide the sample into eight subsamples on the basis of the toroid polarity ( $\beta$ ), muon charge ( $q$ ) and the sign of the pseudorapidity ( $\gamma$ ). We then use the eight subsamples ( $n_q^{\beta\gamma}$ ) to calculate  $A_{SL}$  using the following expression:

$$A_{SL}/f_B + A_{fb}A_{ns} = \left[ (n_+^{++} + n_+^{+-} - n_-^{++} - n_-^{+-}) + e(n_+^{-+} + n_+^{--} - n_-^{-+} - n_-^{--}) \right] / \left[ (n_+^{++} + n_+^{+-} + n_-^{++} + n_-^{+-}) + e(n_+^{-+} + n_+^{--} + n_-^{-+} + n_-^{--}) \right]. \quad (3a)$$

In this expression  $A_{fb}$  is the tendency of a  $\mu^\pm$  to travel in the  $p^\pm$  direction,  $A_{ns}$  is the north/south detector asymmetry, and  $e$  is the ratio of events with opposite toroid polarities.  $f_B$  is the fraction of the time that a  $B$  meson decays to a muon. We find that the product  $A_{fb} \times A_{ns}$  is consistent with zero, and we use this product to estimate our systematic uncertainty.

The number of dimuon events is listed in Table 1. Using these events, we determine the dimuon semileptonic charge asymmetry to be  $A_{SL} = (-0.0044 \pm 0.0040 \pm 0.0028)[2]$ . This value is competitive with the measurements from the B-factories[3, 4, 5].

Table 1: Number of dimuon events		
Sample	Relative Polarities	
	Opposite	Same
$N^{++}$	177,950	156,183
$N^{--}$	176,939	156,148
$N^{+-}$	1,175,547	1,209,605

The systematic errors associated with this measurement are listed in Table 2. The largest source of systematic error results from charged kaon decays. Because of the presence of  $S = -1$  baryons, the inelastic interaction length for  $K^+$  is different from that of  $K^-$ . This results in a charge asymmetry of  $-0.0028 \pm 0.0007$ . We correct for this and apply the error on the correction as a systematic uncertainty. Other sources of systematic error are significantly smaller than the  $K^\pm$  contribution.

The dimuon semileptonic charge asymmetry can be used to determine the  $B_s$  semileptonic charge asymmetry. This is because our sample contains decays from both  $B_d$  and  $B_s$  mesons. Our measured

Table 2: Dimuon charge asymmetry systematic errors.

Source of Error	$\Delta A$
$K^\pm$ Decay + prompt $\mu$	0.00068
Sample Normalization	0.00018
Misreconstructed charge	0.00015
Detector	0.00015
Cosmic Rays	0.00010
Punch through	0.00001
Total	0.00074

asymmetry value can be related to both  $A_{SL}^d$  and  $A_{SL}^s$  by

$$A_{SL}(D\bar{O}) = A_{SL}^d + \frac{f_s Z_s}{f_d Z_d} A_{SL}^s. \quad (4)$$

where  $Z_q = \frac{1}{1-y_q^2} - \frac{1}{1+x_q^2}$  and  $f_q$  is the fraction of the time a  $b$  quark produces a  $B_q$  meson;  $q$  is either  $d$  or  $s$ . Using a value of  $A_{SL}^d = 0.0011 \pm 0.0055$  derived from the results from BaBar, Belle and CLEO[6], we find  $A_{SL}^s = -0.0076 \pm 0.0102$ .

### 3 $B_s$ Semileptonic Asymmetry

The  $B_s$  semileptonic charge asymmetry can be measured using the decay  $B_s \rightarrow D_s \mu \nu$ . We do not determine the sign of the other  $B_s$ , and the untagged semileptonic charge asymmetry can be written

$$A_{SL}^{untagged} = \frac{N(B_s \rightarrow D_s \mu^+) - N(B_s \rightarrow D_s \mu^-)}{N(B_s \rightarrow D_s \mu^+) + N(B_s \rightarrow D_s \mu^-)}. \quad (5)$$

Because the  $B_s$  oscillations occur rapidly, the untagged charge asymmetry can be related to  $A_{SL}^s$ , the  $B_s$  charge asymmetry, via the following relationship.

$$\begin{aligned} A_{SL}^{untagged} &= \frac{1}{2} \frac{x_s^2}{1+x_s^2} A_{SL}^s \\ A_{SL}^{untagged} &\simeq \frac{1}{2} A_{SL}^s \end{aligned} \quad (6)$$

For this measurement we reconstruct the  $D_s$  using the decay  $D_s^\pm \rightarrow \phi \pi^\pm$ . As in the dimuon analysis, we divide the sample into eight subsamples based upon the muon charge, sign of the pseudorapidity and the toroid polarity. The charge asymmetry is then determined in a similar manner to the dimuon charge asymmetry analysis. Again, the ability to reverse the  $D\bar{O}$  magnet polarities significantly reduces any detector induced charge asymmetries. Figure 2 shows the reconstructed  $D_s$  mass for the eight subsamples. The two peaks in the plot correspond to  $D^+$  and  $D_s$  decays.

Table 3: Systematic errors in the  $B_s$  charge asymmetry.

Source	$\Delta A$
Mass fitting	0.0027
Sample composition	0.0022
$\pi^\pm$ interactions	0.0004
Contribution from $A_{SL}^d$	0.0002
Total	0.0035

The systematic uncertainties associated with this measurement are shown in Table 3. The two largest sources of uncertainty are the determination of the sample composition and the determination of the number of events. To obtain a systematic error for the sample composition, we varied each contribution by one sigma and examined the change in the charge asymmetry. The systematic error associated with the mass fitting was arrived at by varying the slope of the background by one sigma and also by changing the width of the mass peak by one sigma.

Including the effects of the systematic uncertainty, we find  $A_{SL}^s = 0.0245 \pm 0.0193 \pm 0.0035$ [7]. This is the first direct measurement of  $A_{SL}^s$ , and we find no significant charge asymmetry.

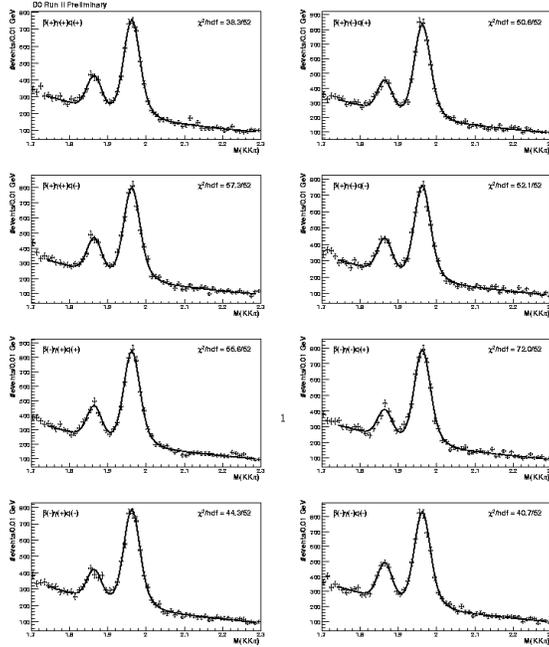


Figure 2: The invariant  $\phi\pi^\pm$  mass distributions. The peak on the left corresponds to  $D^+$  decays, while the peak on the right corresponds to  $D_s$  decays. The eight plots show the mass distributions for each of the eight subsamples defined in the text.

## 4 Combined Results

The results from the  $D\bar{O}$  semileptonic charge asymmetries can be combined together to place a constraint on  $\phi_s$ . The combined  $A_{SL}^s$  measurement from the two results presented in this paper is  $A_{SL}^s = -0.0007 \pm 0.0090$ . Using the relationship

$$A_{SL}^s = \frac{\Delta\Gamma_s}{\Delta m_s} \tan \phi_s, \quad (7)$$

one can extract a value for  $\phi_s$ . In addition, the  $D\bar{O}$  experiment has determined  $\phi_s$  and  $\Delta\Gamma_s$  from the decay  $B_s \rightarrow J/\psi\phi$ . We find  $\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.03 \text{ ps}^{-1}$  and  $\phi_s = -0.79 \pm 0.56^{+0.13}_{-0.01}$ [8]. Combining these results from the semileptonic results with those from the purely hadronic mode, we find  $\Delta\Gamma_s = 0.15^{+0.09}_{-0.08} \text{ ps}^{-1}$  and  $\phi_s = -0.56^{+0.44}_{-0.41}$ [9]. The constraints on  $\phi_s$  and  $\Delta\Gamma_s$  can be seen in Figure 3.

## 5 Conclusions

The  $D\bar{O}$  experiment has made precise charge asymmetry measurements. We find the following two results:

- $A_{SL} = -0.0044 \pm 0.0040 \pm 0.0028$  (Dimuon)

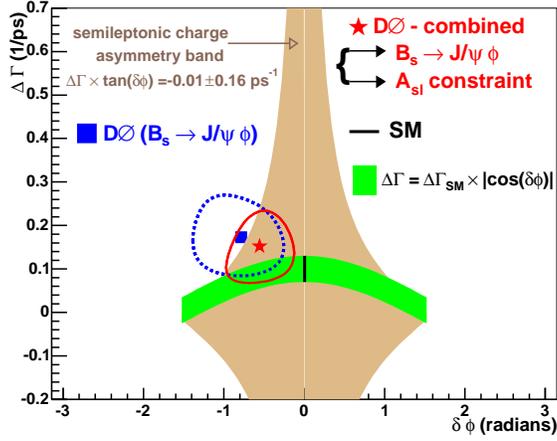


Figure 3: The  $D\bar{O}$  combined result on  $\Delta\Gamma_s$  and  $\phi_s$ . The blue curve shows the result solely from our measurement of  $B_s \rightarrow J/\psi\phi$  while the red curve shows the combined constraint including the semileptonic charge asymmetry results.

- $A_{SL}^s = 0.0245 \pm 0.0193 \pm 0.0035$  (Semileptonic  $B_s$ )

These new measurements can be used in conjunction with our recent measurement of  $B_s \rightarrow J/\psi\phi$  to place constraints on the CP violating phase  $\phi_s$ . We find  $\phi_s = -0.56^{+0.44}_{-0.41}$ . This result on the CP phase is consistent with the Standard Model prediction that  $\phi_s$  be small.

## References

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