

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 ϕ_s . We find $\phi_s = -0.56_{-0.41}^{+0.44}$.

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 ϕ_s , where $|M_{12}|$ and $|\Gamma_{12}|$ are the elements of the complex mass matrix, and ϕ_s is a CP violating phase:

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

Determining the value of ϕ_s is interesting because new physics can lead to an enhancement of ϕ_s . Also, because ϕ_s is predicted to be small in the Standard Model[1], any measurement of a sizeable value of ϕ_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 ϕ_s . These results are preliminary as of September 2006.

2 Dimuon Asymmetry

The dimuon charge asymmetry measures the charge asymmetry in direct decays of $B\bar{B}$ pairs. One can determine the charge asymmetry, A_{SL} , 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 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 Fig. 1.

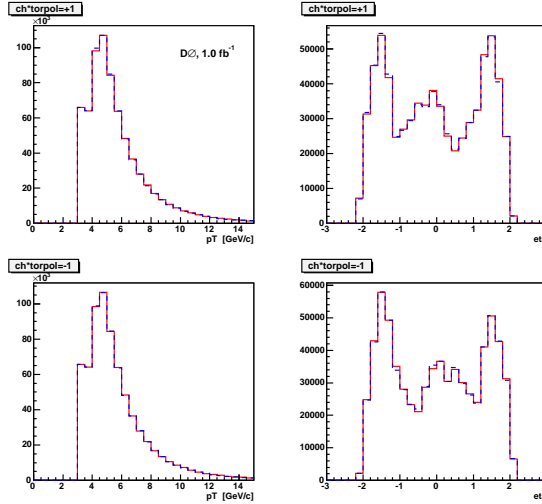


Figure 1: Muon p_T (left) and η (right) distributions. Each plot contains two separate histograms with each histogram having the same product of muon charge \times toroid polarity. The two histograms lie nearly on top of each other indicating that the detector response for opposite charges are nearly 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 (β), muon charge (q) and the sign of the pseudorapidity (γ). We then use the eight subsamples ($n_q^{\beta\gamma}$), keeping terms up to second order, to calculate A_{SL} using the following expression:

$$\begin{aligned}
 A_{SL}/f_B + A_{fb}A_{ns} = & \left[(n_+^{++} + n_+^{+-} - n_-^{++} - n_-^{+-}) \right. \\
 & \left. + e(n_+^{-+} + n_+^{--} - n_-^{-+} - n_-^{--}) \right] / \\
 & \left[(n_+^{++} + n_+^{+-} + n_-^{++} + n_-^{+-}) \right. \\
 & \left. + e(n_+^{-+} + n_+^{--} + n_-^{-+} + n_-^{--}) \right].
 \end{aligned} \tag{3}$$

In this expression A_{fb} is the tendency of a μ^\pm to travel in the proton/antiproton direction, A_{ns} is the north/south detector asymmetry where north is defined as $\eta < 0$. The protons travel from north to south in the $D\bar{O}$ detector. The variable e is the ratio of events with opposite toroid polarities, and f_B is the fraction of the muons that result from B meson decays.

The term $A_{fb} \times A_{ns}$ means that an apparent asymmetry can be induced if the positive (negative) muons tend to go along the direction of the protons (antiprotons) *and* the detector has a north/south asymmetry. The terms A_{fb} and A_{ns} can be estimated by forming the appropriate combinations of $n_q^{\beta\gamma}$ [2]. 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 Tab. 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 with $B\bar{B}$ pairs from the B-factories[3, 4, 5].

The systematic errors associated with this measurement are listed in Tab. 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 ± 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 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

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

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

where $Z_q = \frac{1}{1-y_q^2} - \frac{1}{1+x_q^2}$, with $x_q = \frac{\Delta M_q}{\Gamma_q}$ and $y_q = \frac{\Delta \Gamma_q}{2\Gamma_q}$; q is either d or s . The variable f_q is the fraction of the time a b quark produces a B_q meson. 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 perform any initial state flavor tagging, and the untagged semileptonic charge asymmetry can be written

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

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:

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

Table 2: Dimuon charge asymmetry systematic errors.

Source of Error	ΔA
K^\pm Decay + prompt μ	0.00068
Sample Normalization	0.00018
Misreconstructed Charge	0.00015
Detector	0.00015
Cosmic Rays	0.00010
Punch Through	0.00001
Total	0.00074

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 $D\emptyset$ magnet polarities significantly reduces

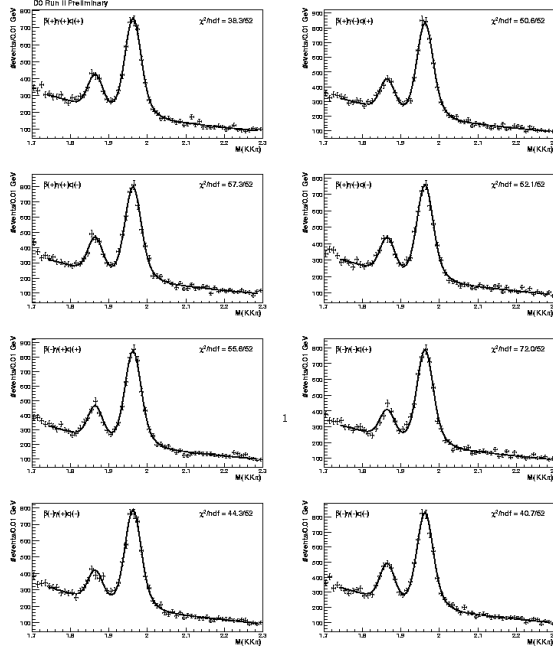


Figure 2: The invariant $\phi\pi^\pm$ mass distributions. The peak on the left corresponds to D^+ decays, while the peak on the right corresponds to D_s decays. The eight plots show the mass distributions for each of the eight subsamples defined in the text.

any detector induced charge asymmetries. Fig. 2 shows the reconstructed D_s mass for all $B_s \rightarrow D_s^- \mu^+$ candidates. The two peaks in the plot correspond to D^+ and D_s decays.

The systematic uncertainties associated with this measurement are shown in Tab. 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.

Table 3: Systematic errors in the B_s charge asymmetry.

Source	ΔA
Mass fitting	0.0027
Sample composition	0.0022
π^\pm interactions	0.0004
Contribution from A_{SL}^d	0.0002
Total	0.0035

4 Combined Results

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

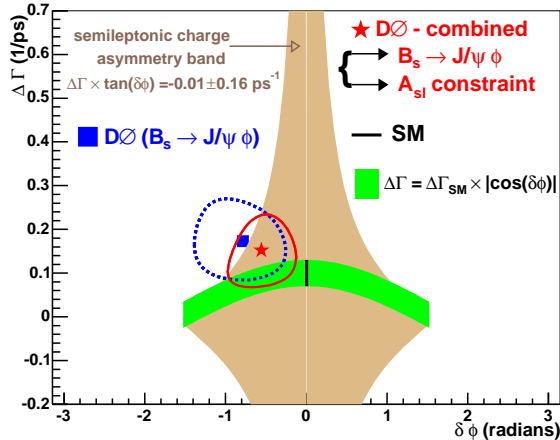


Figure 3: The DØ combined result on $\Delta\Gamma_s$ and ϕ_s . The blue curve shows the result solely from our measurement of $B_s \rightarrow J/\psi\phi$ while the red curve shows the combined constraint including the semileptonic charge asymmetry results.

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 ϕ_s . In addition, the DØ experiment has determined ϕ_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 $\phi_s = -0.79 \pm 0.56_{-0.01}^{+0.13}$ [8]. Combining the results from the semileptonic and purely hadronic analyses, we find $\Delta\Gamma_s = 0.15_{-0.08}^{+0.09} \text{ ps}^{-1}$ and $\phi_s = -0.56_{-0.41}^{+0.44}$ [9]. The constraints on ϕ_s and $\Delta\Gamma_s$ can be seen in Fig. 3.

5 Conclusions

The DØ experiment has made important contributions to charge asymmetry measurements in the B meson sector. We find the following two results:

- $A_{SL} = -0.0044 \pm 0.0040 \pm 0.0028$ (Dimuon),
- $A_{SL}^s = 0.0245 \pm 0.0193 \pm 0.0035$ (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 ϕ_s . We find $\phi_s = -0.56_{-0.41}^{+0.44}$. This result on the CP phase is consistent with the Standard Model prediction that ϕ_s be small, although the precision of the measurements are at present limited.

References

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