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# 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 $B_s \to J/\psi\phi$ 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 quantitites: $|M_{12}|$, $|\Gamma_{12}|$ 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:

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

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 measurement of a sizeable value 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 $B\bar{B}$ pairs. One can determine the charge asymmetry, $A_{SL}$, using

$$A_{SL} = \frac{N(b\bar{b} \to \mu^+\mu^+X) - N(b\bar{b} \to \mu^-\mu^-X)}{N(b\bar{b} \to \mu^+\mu^+X) + N(b\bar{b} \to \mu^-\mu^-X)}. \tag{2}$$

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.

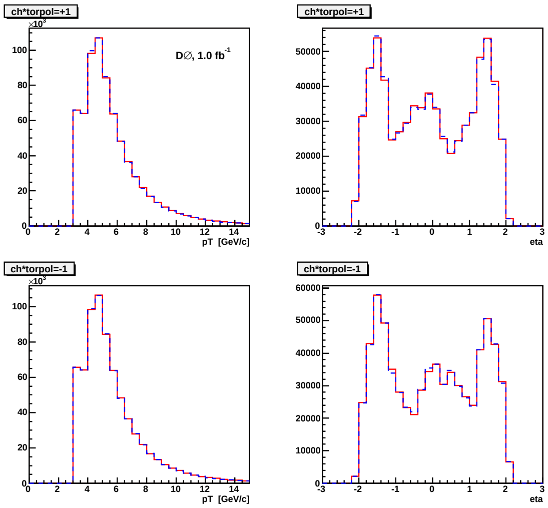

Figure 1: Muon $p_T$ (left) and $\eta$ (right) distributions. Each plot contains two separate histograms with each histogram having the same product of muon charge×toroid polarity. The two histograms lie nearly on top of each other indicating that the detector response for opposite charges are nearly the same. The top plots are for the positive charge×polarity while the bottom plots contain the negative charge×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 ($n_q^{\beta\gamma}$), keeping terms up to second order, to calculate $A_{SL}$ using the following expression:

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

In this expression $A_{fb}$ is the tendency of a $\mu^{\pm}$ 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 DØ 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 $-0.0028 \pm 0.0007$. 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 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 $A^d_{SL}$ and $A^s_{SL}$ by

$$A_{SL}(\text{D0}) = A^d_{SL} + \frac{f_s Z_s}{f_d Z_d} A^s_{SL}, \tag{4}$$

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 $A^d_{SL} = 0.0011 \pm 0.0055$ derived from the results from BaBar, Belle and CLEO[6], we find $A^s_{SL} = -0.0076 \pm 0.0102$.

# 3 $B_s$ Semileptonic Asymmetry

The $B_s$ semileptonic charge asymmetry can be measured using the decay $B_s \to D_s\mu\nu$. We do not perform any initial state flavor tagging, and the untagged semileptonic charge asymmetry can be written

$$A^{untagged}_{SL} = \frac{N(B_s \to D_s^- \mu^+) - N(\bar{B}_s \to D_s^+ \mu^-)}{N(B_s \to D_s^- \mu^+) + N(\bar{B}_s \to D_s^+ \mu^-)}. \tag{5}$$

Because the $B_s$ oscillations occur rapidly, the untagged charge asymmetry can be related to $A^s_{SL}$, the $B_s$ charge asymmetry, via the following relationship:

$$\begin{aligned} A^{untagged}_{SL} &= \frac{1}{2}\frac{x_s^2}{1+x_s^2} A^s_{SL}, \\ A^{untagged}_{SL} &\simeq \frac{1}{2} A^s_{SL}. \end{aligned} \tag{6}$$

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 |

For this measurement we reconstruct the $D_s$ using the decay $D_s^\pm \to \phi\pi^\pm$. 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 D0 magnet polarities significantly reduces

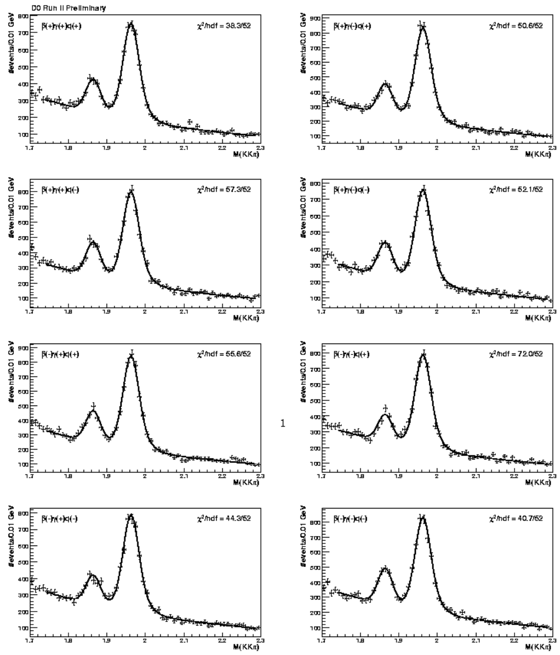

Figure 2: The invariant $\phi\pi^{\pm}$ mass distributions. The peak on the left corresponds to $D^+$ decays, while the peak on the right corresponds to $D_s$ decays. The eight plots show the mass distributions for each of the eight subsamples defined in the text.

any detector induced charge asymmetries. Fig. 2 shows the reconstructed $D_s$ mass for all $B_s \to D_s^- \mu^+$ 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 $A^s_{SL} = 0.0245 \pm 0.0193 \pm 0.0035$[7]. This is the first direct measurement of $A^s_{SL}$, and we find no significant charge asymmetry.

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 $A^d_{SL}$ | 0.0002 |
| Total | 0.0035 |

## 4 Combined Results

The results from the DØ semileptonic charge asymmetries can be combined together to place a constraint on $\phi_s$. The combined $A^s_{SL}$ measurement from the two results presented in this paper is $A^s_{SL} = -0.0007 \pm$

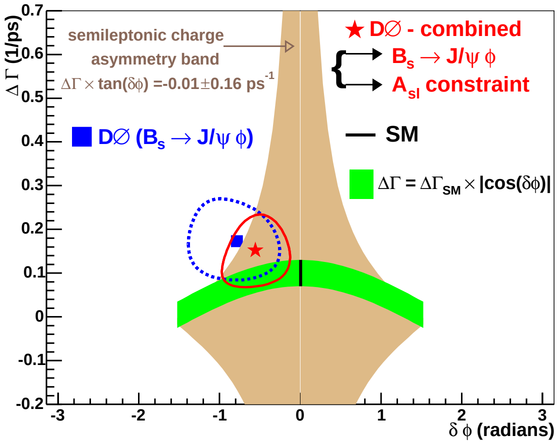

Figure 3: The DØ combined result on $\Delta\Gamma_s$ and $\phi_s$. The blue curve shows the result solely from our measurement of $B_s \rightarrow J/\psi\phi$ while the red curve shows the combined constraint including the semileptonic charge asymmetry results.

0.0090. Using the relationship

$$A^s_{SL} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s, \tag{7}$$

one can extract a value for $\phi_s$. In addition, the DØ experiment has determined $\phi_s$ and $\Delta\Gamma_s$ from the decay $B_s \rightarrow J/\psi\phi$. We find $\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.03$ ps$^{-1}$ and $\phi_s = -0.79 \pm 0.56^{+0.13}_{-0.01}$[8]. Combining the results from the semileptonic and purely hadronic analyses, we find $\Delta\Gamma_s = 0.15^{+0.09}_{-0.08}$ 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 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),
- $A^s_{SL} = 0.0245 \pm 0.0193 \pm 0.0035$ (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, although the precision of the measurements are at present limited.

## References

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