

# Chapter 5

## $CP$ Asymmetry

As stated, if the isospin breaking contribution is significant, there could be an observable direct  $CP$  asymmetry in  $B^\mp \rightarrow \rho^\mp \rho^0$  decays. We define the  $CP$  asymmetry in this decay as

$$\mathcal{A}_{CP}(B^\mp \rightarrow \rho^\mp \rho^0) = \frac{N_{(\rho^- \rho^0)} - N_{(\rho^+ \rho^0)}}{N_{(\rho^- \rho^0)} + N_{(\rho^+ \rho^0)}}. \quad (5.1)$$

In the following sections, we describe a search for  $CP$  asymmetry.

### 5.1 Fitting Results

Figure 5.1 shows the fits to the  $\Delta E$  distributions separately for  $B^-$  and  $B^+$  mode. As described (see section 3.9.2), the  $\Delta E$  fits include four components: **signal**, **mis-reconstructed signal**, **continuum**, and  $B\bar{B}$  component. Here, the  $B\bar{B}$  component is fixed to one half of the  $B\bar{B}$  yield of the  $B^\pm$  fit results (i.e. 84.5 events), since the generic  $B\bar{B}$  should have the same contributions to  $\rho^+ \rho^0$  and  $\rho^- \rho^0$ . In addition, we shift the mean values from signal-MC for  $\rho^- \rho^0$  and  $\rho^+ \rho^0$  differently according to the calibration results described in the following section.

The fits give

$$N_{(\rho^- \rho^0)} = 29.30 \pm 9.47,$$

$$N_{(\rho^+ \rho^0)} = 29.25 \pm 9.09.$$

### 5.2 Statistical Errors

Since the measurements are independent, there are no correlation between the  $B^-$  signal yield and the  $B^+$  signal yield. The error of  $\mathcal{A}_{CP}$  is

$$(\Delta \mathcal{A}_{CP})^2 = \left( \frac{\partial \mathcal{A}_{CP}}{\partial N_{\rho^- \rho^0}} \right)^2 (\Delta N_{\rho^- \rho^0})^2 + \left( \frac{\partial \mathcal{A}_{CP}}{\partial N_{\rho^+ \rho^0}} \right)^2 (\Delta N_{\rho^+ \rho^0})^2,$$

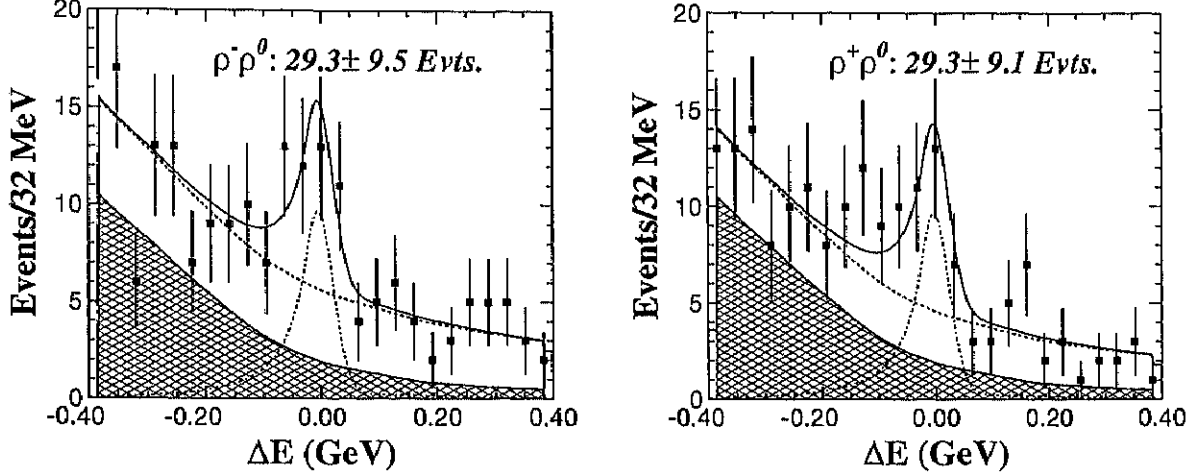


Figure 5.1: The  $\Delta E$  fit to the  $B^- \rightarrow \rho^- \rho^0$  (left) and the  $B^+ \rightarrow \rho^+ \rho^0$  (right) candidate events. The sum of the  $B\bar{B}$  and continuum components is shown as a dashed line. The cross-hatched histogram represents the  $B\bar{B}$  background.

so that

$$\Delta\mathcal{A}_{CP} = \frac{2}{(N_{\rho^-\rho^0} + N_{\rho^+\rho^0})^2} \sqrt{(N_{\rho^+\rho^0} \Delta N_{\rho^-\rho^0})^2 + (N_{\rho^-\rho^0} \Delta N_{\rho^+\rho^0})^2}.$$

Substituting the numbers given in section 5.1, we obtain the statistical error  $\Delta\mathcal{A}_{CP}(B^\mp \rightarrow \rho^\mp \rho^0) = 22.4\%$ .

### 5.3 Systematic Errors

The  $\mathcal{A}_{CP}$  systematic errors may be caused by the asymmetric detector performance, reconstruction and the fitting procedure.

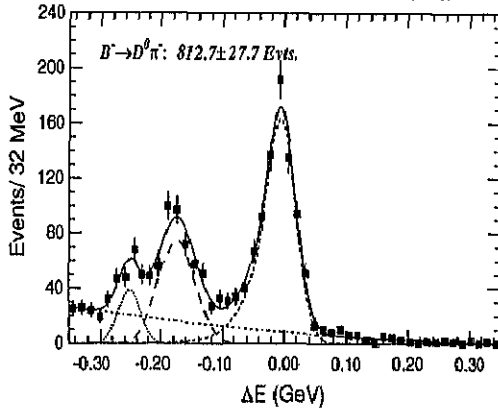
The possible charge asymmetry of the detector performance and the reconstruction procedure is checked by using the decays of  $B^+ \rightarrow \bar{D}^0 \pi^+$ ,  $\bar{D}^0 \rightarrow K^+ \pi^- \pi^0$  and its charge conjugate mode. The analysis procedure is the same as that for  $B^+ \rightarrow \rho^+ \rho^0$  except that we select one kaon and two pions instead of three pions, and require the invariant mass of  $M(K\pi\pi^0)$  to be within  $0.05 \text{ GeV}/c^2$  of the nominal  $D^0$  mass. The results of the fits to  $B^- \rightarrow D^0(K^-\pi^+\pi^0)\pi^-$  and  $B^+ \rightarrow \bar{D}^0(K^+\pi^-\pi^0)\pi^+$  are shown in Fig. 5.2, and listed in Table 5.1, which indicate  $\mathcal{A}_{CP}(B^\mp \rightarrow D^0\pi^-(\bar{D}^0\pi^+)) = (-2.1 \pm 2.5)\%$ , consistent with 0 within errors. We take the 2.5% as the systematic error for the detection and reconstruction based asymmetry.

Removing the  $\mathcal{LR}$  cut, again we examine the asymmetry of  $B \rightarrow D^0(K\pi\pi^0)\pi$  decays,  $\mathcal{A}_{CP}(B^\mp \rightarrow D^0\pi^-(\bar{D}^0\pi^+)) = 0.16 \pm 2.11\%$ , also consistent with 0.

In addition, we see a 2.9 MeV shift in the mean value between  $B^- \rightarrow D^0\pi^-$  and

MINUIT Likelihood Fit to Plot 200&2  
dE(MC)(r085)  
File: data-minus.out  
Plot Area Total/Fit 1830.0 / 1830.0  
Func Area Total/Fit 1829.7 / 1829.7  
Likelihood = 50.0  
 $\chi^2 = 44.7$  for 50 - 12 d.o.f., C.L. = 21.0%

Errors	Parabolic	Minos		
Function 1: CB Line Shape				
AREA	812.73 ± 27.75	- 0.	+ 0.	
MEAN	-6.11377E-03 ± 1.2289E-03	- 0.	+ 0.	
SIGMA	2.40242E-02 ± 1.1442E-03	- 0.	+ 0.	
*ALPHA	0.79405 ± 0.	- 0.	+ 0.	
*N	130.00 ± 0.	- 0.	+ 0.	
Function 2: Chebyshev Polynomial of Order 2				
NORM	778.12 ± 84.25	- 0.	+ 0.	
CHEB01	-1.2201 ± 3.4306E-02	- 0.	+ 0.	
CHEB02	0.23145 ± 3.9365E-02	- 0.	+ 0.	
Function 3: Gaussian (sigma)				
AREA	387.80 ± 35.28	- 0.	+ 0.	
MEAN	-0.17493 ± 2.5891E-03	- 0.	+ 0.	
SIGMA	2.92038E-02 ± 2.9494E-03	- 0.	+ 0.	
Function 4: Gaussian (sigma)				
AREA	127.63 ± 23.44	- 0.	+ 0.	
MEAN	-0.25227 ± 3.8997E-03	- 0.	+ 0.	
SIGMA	1.85848E-02 ± 2.5218E-03	- 0.	+ 0.	



MINUIT Likelihood Fit to Plot 200&1  
dE(MC)(r085)  
File: data-plus.out  
Plot Area Total/Fit 1917.0 / 1917.0  
Func Area Total/Fit 1916.7 / 1916.7  
Likelihood = 65.0  
 $\chi^2 = 58.8$  for 50 - 12 d.o.f., C.L. = 1.7%

Errors	Parabolic	Minos		
Function 1: CB Line Shape				
AREA	847.98 ± 31.94	- 0.	+ 0.	
MEAN	-4.57749E-03 ± 1.1857E-03	- 0.	+ 0.	
SIGMA	2.33645E-02 ± 1.0090E-03	- 0.	+ 0.	
*ALPHA	0.79405 ± 0.	- 0.	+ 0.	
*N	130.00 ± 0.	- 0.	+ 0.	
Function 2: Chebyshev Polynomial of Order 2				
NORM	770.77 ± 84.14	- 0.	+ 0.	
CHEB01	-1.2806 ± 3.8257E-02	- 0.	+ 0.	
CHEB02	0.33745 ± 4.9793E-02	- 0.	+ 0.	
Function 3: Gaussian (sigma)				
AREA	487.91 ± 42.79	- 0.	+ 0.	
MEAN	-0.17451 ± 3.5042E-03	- 0.	+ 0.	
SIGMA	3.37434E-02 ± 3.9985E-03	- 0.	+ 0.	
Function 4: Gaussian (sigma)				
AREA	122.02 ± 43.84	- 0.	+ 0.	
MEAN	-0.25708 ± 4.7484E-03	- 0.	+ 0.	
SIGMA	1.76713E-02 ± 6.4878E-03	- 0.	+ 0.	

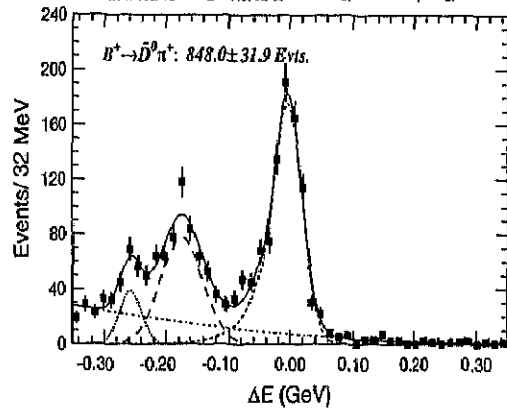


Figure 5.2: The  $\Delta E$  fits to the  $B^- \rightarrow D^0 \pi^-$  candidate events (left) and  $B^+ \rightarrow \bar{D}^0 \pi^+$  candidate events (right). A shift of 2.9 MeV in the mean value is found.

	$B^- \rightarrow D^0 \pi^-$	$B^+ \rightarrow \bar{D}^0 \pi^+$	$\mathcal{A}_{CP}(\%)$
$\mathcal{L}R > 0.85$	$812.7 \pm 27.7$	$848.0 \pm 31.9$	$-2.1 \pm 2.5$
no $\mathcal{L}R$ cut	$2128.0 \pm 64.1$	$2121.3 \pm 63.1$	$0.16 \pm 2.1$

Table 5.1: Bias check by using the decay of  $B^+ \rightarrow \bar{D}^0 \pi^+$ ,  $\bar{D}^0 \rightarrow K^+ \pi^- \pi^0$  and its charge conjugate mode.

$B^+ \rightarrow \bar{D}^0\pi^+$ , which may be explained by the difference in tracking between positive and negative particles. This is taken into account when fitting the  $\Delta E$  distributions for  $B^- \rightarrow \rho^-\rho^0$  and  $B^+ \rightarrow \rho^+\rho^0$ .

We estimate the  $\mathcal{A}_{CP}$  systematic error due to the  $\Delta E$  fit by shifting each parameter of the fitting functions by  $\pm 1\sigma$ , including the constrained  $B\bar{B}$  yield. The quadrature sum of the percentage change in  $\mathcal{A}_{CP}$  for each parameter is taken as the fitting systematic error. A  $+0.8\%/ -1.2\%$  systematic error is assigned for the fitting procedure.

Parameter	$B^-$	$B^+$	$\mathcal{A}_{CP}(\%)$	$\Delta\mathcal{A}_{CP}(\%)$
normal fit	$29.3 \pm 9.5$	$29.3 \pm 9.1$	$0.1 \pm 22.4$	
mean $-1\sigma$	29.28	29.52	-0.41	-0.49
$+1\sigma$	29.25	28.97	0.48	0.41
sigma $-1\sigma$	28.59	28.64	-0.09	-0.17
$+1\sigma$	29.91	29.82	0.15	0.07
alpha $-1\sigma$	30.27	30.69	-0.70	-0.77
$+1\sigma$	28.39	28.04	0.63	0.55
N $-1\sigma$	30.32	30.68	-0.58	-0.66
$+1\sigma$	28.69	28.43	0.45	0.37
Gau/CB $-1\sigma$	28.92	28.85	0.13	0.05
$+1\sigma$	29.63	29.66	-0.06	-0.14
signal $-1\sigma$	29.12	29.17	-0.09	-0.17
$+1\sigma$	29.41	29.33	0.14	0.06
Cheby slope $-1\sigma$	28.53	28.45	0.13	0.06
$+1\sigma$	30.14	30.16	-0.04	-0.11
$N_{BB}$ yield $-1\sigma$	28.66	28.67	-0.01	-0.08
$+1\sigma$	29.64	29.58	0.09	0.02
Total $\Delta\mathcal{A}_{CP}(\%)$	+0.79 / -1.17			

Table 5.2: The percentage change in  $\mathcal{A}_{CP}$  by varying each parameter of the fitting functions by  $\pm 1\sigma$ .

The quadrature sum of these errors is taken as the total  $\mathcal{A}_{CP}$  systematic error, listed in Table 5.3.

	$\Delta\mathcal{A}_{CP}(\%)$
Fitting	0.8 / -1.2
Bias	2.5
Total	2.6 / -2.8

Table 5.3: The  $\mathcal{A}_{CP}$  systematic errors

In summary, we obtain the  $CP$  asymmetry

$$\mathcal{A}_{CP}(\mathbf{B}^{\mp} \rightarrow \rho^{\mp} \rho^0) = (0.1 \pm 22.4(\text{stat.})_{-2.8}^{+2.6}(\text{sys.}))\%.$$

This result of  $\mathcal{A}_{CP}$  is consistent with zero, within quite large errors. To reduce the errors, we need more data, or more powerful separation to reduce the backgrounds.