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Measurement of A_c with charmed mesons at SLD*

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Abstract

We present a direct measurement of the parity-violation parameter A_c. The measurement is based on 550k Z^0 decays collected by the SLD detector. The mean electron-beam polarization is $|P_e| = 73\%$. The tagging of c-quark events was performed using two methods: The exclusive reconstruction of D^{*+}, D^+, and D^0 mesons, and the inclusive P_T spectrum of soft-pions (π_s) in the decay of $D^{*+} \to D^0\pi_s^+$. The results of these two methods are combined to give

$$A_c = 0.688 \pm 0.035(stat.) \pm 0.025(sys.) \text{ (preliminary).}$$

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1 Introduction

In the Standard Model, the electroweak interaction of Z^0 to fermions has both vector (v) and axial-vector (a) couplings. Measurement of fermion asymmetries at the Z^0 resonance probe a combination of these couplings given by $A_f = 2v_f a_f/(v_f^2 + a_f^2)$. The parameters A_f express the extent of parity violation at the Zff vertex and provide sensitive tests of the Standard Model.

At the Born-level, the differential cross section for the reaction $e^+e^- \to Z^0 \to f\bar{f}$ is

$$\sigma_f(z) \equiv d\sigma_f/dz \propto (1 - A_e P_e)(1 + z^2) + 2A_f(A_e - P_e)z,$$

where P_e is the longitudinal polarization of the electron beam and $z = \cos\theta$ is the direction of the outgoing fermion relative to the incident electron. At the SLAC Linear Collider (SLC), the ability to manipulate the longitudinal polarization of the electron beam allows the isolation of the parameter A_f independently through formation of the left-right forward-backward double asymmetry: $\tilde{A}^f_{FB}(z) = |P_e|A_f 2z/(1 + z^2)$.

In this note, we present the direct measurement of the parity-violation parameter for c-quarks, A_c. The tagging of c-quarks was performed using exclusively reconstructed D^{*+}, D^+, and D^0 mesons, as well as an inclusive sample of $D^{*+} \to D^0\pi_s$ decays identified by the soft-pion (π_s).

2 Apparatus and event selection

The measurement described here is based on 550k Z^0 decays recorded in 1993-98 with the SLC Large Detector (SLD) at the SLC e^+e^- collider. A general description of the SLD can be found elsewhere [1]. For charged-particle tracking devices, we use the central drift chamber (CDC)[2] and a pixel-based silicon vertex detector (VXD)[3, 4]. The Liquid Argon Calorimeter (LAC)[5] measures the energy of charged and neutral particles and is also used for electron identification. Muon tracking is provided by the Warm Iron Calorimeter (WIC)[6]. The Čerenkov Ring Imaging Detector (CRID)[7] provides particle identification. The SLC was operated with a polarized electron beam and an unpolarized positron beam [8]. The average polarization magnitude measured for the 1993-98 data sample is $|P_e| = 73\%$.

Hadronic events are selected by requiring at least 5 charged tracks, a total visible energy of at least 20 GeV/c, and a thrust axis calculated from charged tracks satisfying $|\cos\theta_{thrust}| < 0.87$. As $Z^0 \to b\bar{b}$ events are also a copious source of D mesons, they represent a potential background. We reject these events using the invariant mass of charged tracks associated with reconstructed secondary decay vertices[9, 10]. Specifically, we require that the reconstructed secondary vertices have mass less than 2.0 GeV/c^2. Our simulations show that this cut rejects 57% of $b\bar{b}$ events with 99% of the remainder being $c\bar{c}$ events.

3 A_c measurement with exclusive charmed-meson reconstruction

D^{*+} mesons are identified via their decay $D^{*+} \to \pi_s^+ D^0$ followed by:

$$
\begin{array}{lll}
D^0 \to K^-\pi^+ & & \text{“}K\pi\text{''}, \\
D^0 \to K^-\pi^+\pi^0 & & \text{“}Satellite\text{''}, \\
D^0 \to K^-\pi^+\pi^-\pi^+ & & \text{“}K\pi\pi\pi\text{''}, \text{ or} \\
D^0 \to K^-l^+\nu_l & (l\text{=e or } \mu) & \text{“}Semileptonic\text{''}.
\end{array}
$$

To form the D^{*+} candidate, we use all tracks which have VXD hits in one event hemisphere. For the D^0 candidate, a number of tracks corresponding to the charged multiplicity in each D^0 decay mode are combined with assuming one of them to be a kaon and the others are pions. Only candidates with the correct charge combinations are selected. A vertex fit is performed on the tracks in a candidate, and we require that the combination has a χ^2 probability of all tracks coming from the same vertex be greater than 1%. Then if the calculated invariant mass lies within the mass ranges of 1.765 GeV/c^2 $<$ m$_{D^0}$ $<$ 1.965 GeV/c^2 ($K\pi$), 1.500 GeV/c^2 $<$ m$_{D^0}$ $<$ 1.600 GeV/c^2 (*Satellite*), 1.795 GeV/c^2 $<$ m$_{D^0}$ $<$ 1.935 GeV/c^2 ($K\pi\pi\pi$), and 1.100 GeV/c^2 $<$ m$_{D^0}$ $<$ 1.800 GeV/c^2 (*Semileptonic*), combine with a soft-pion candidate track which has a charge opposite to the kaon candidate, to form the D^{*+} candidate.

To reconstruct the D^*, we use two sets of selection criteria. One is based on event kinematics and the other on event topology. We select the combinations which satisfy either of the two. In the former one, we require the candidate to have $x_{D^*} > 0.4$ ($K\pi$, *Satellite*, and *Semileptonic*) or 0.6 ($K\pi\pi\pi$), where $x_{D^*} \equiv 2E_{D^*}/E_{CM}$, and $|\cos\theta^*| < 0.9$ ($K\pi$, *Satellite*, and *Semileptonic*) or 0.8 ($K\pi\pi\pi$), where θ^* is the opening angle between the direction of the D^0 in the lab. frame and the kaon in the D^0 rest frame. We also require the soft-pion candidate to have momentum greater than 1 GeV/c. In the selection based on the event topologies, we require the reconstructed D^0 vertices to have decay length $L/\sigma_L > 2.5$, and the xy impact parameter of the D^0 momentum vector to the IP to be less than 20 μm ($K\pi$ and $K\pi\pi\pi$) or 30 μm (*Satellite* and *Semileptonic*). Finally, a cut of $x_{D^*} > 0.3$ ($K\pi$, *Satellite*, and *Semileptonic*) or 0.4 ($K\pi\pi\pi$) is applied. Then the mass difference $\Delta M = M_{D^*} - M_{D^0}$ is formed. We regard the combination as a signal when $\Delta M < 0.148$ GeV/c^2 ($K\pi$ and $K\pi\pi\pi$), < 0.155 GeV/c^2 (*Satellite*), or < 0.16 GeV/c^2 (*Semileptonic*). The side-band region is defined as $0.16 < \Delta M < 0.20$ GeV/c^2 or $0.17 < \Delta M < 0.20$ GeV/c^2 (*Semileptonic*), to estimate random combinatoric background (RCBG) contamination in the signal region. The mass difference spectra for the four reconstructed D^{*+} decay modes are shown in Fig. 1.

The D^+ and D^0 mesons are identified via the decay of:

$$
\begin{array}{l}
D^+ \to K^-\pi^+\pi^+ \text{ and} \\
D^0 \to K^-\pi^+.
\end{array}
$$

For the D^+ reconstruction, we combine two same-sign pion candidates with an opposite-sign kaon candidate. We apply the cuts $x_{D^+} > 0.4$, and $\cos\theta^* > -0.8$. We require that the χ^2

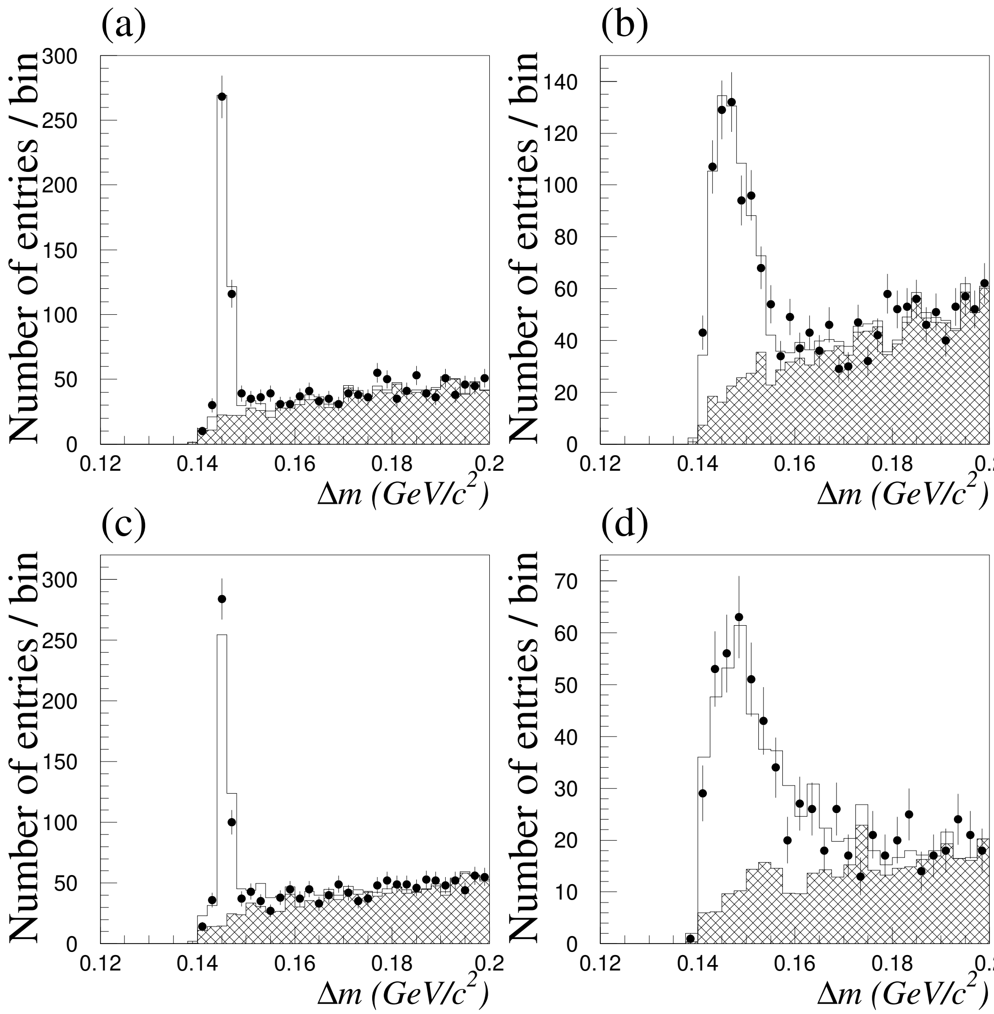

Figure 1: The mass-difference distributions for the decay of (a)$D^{*+} \to D^0 \pi_s$, $D^0 \to K\pi$, (b)$D^0 \to K\pi\pi^0$, (c)$D^0 \to K\pi\pi\pi$, and (d)$D^0 \to K^- l^+ \nu_l$ (l =e or μ). The solid circles indicate the exp. data, and histograms are MC of signal (open) and RCBG (hatched).

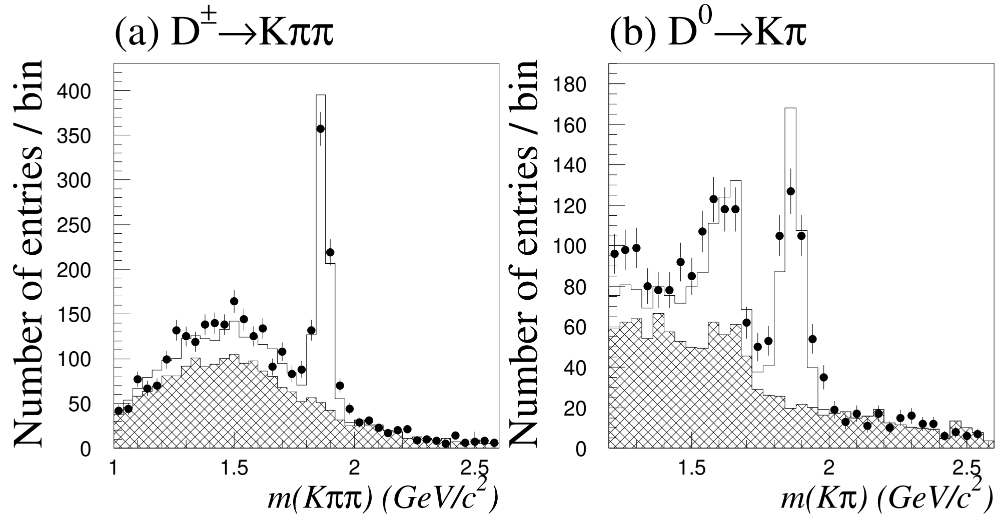

Figure 2: The mass distributions for (a)D^+ and (b)D^0 mesons. The solid circles indicate the exp. data, and histograms are the MC of signal (open) and RCBG (hatched).

probability of the good vertex fit be $> 1\%$, and apply the D^+ decay length cut of $L/\sigma_L > 3.0$. The collinearity angle between the D^+ momentum vector and the vertex flight direction is required to be less than 5 mrad in xy and less than 20 mrad in rz.

To form the D^0 vertices, kaon-candidate tracks identified with the CRID are combined with another opposite-sign pion candidate. We require $x_{D^0} > 0.4$, χ^2 probability $> 1\%$, and $L/\sigma_L > 3.0$. Finally, we require the xy impact parameter of the D^0 momentum vector to the IP to be less than 20 μm. The D^+ and D^0 candidates in the ranges of $1.800 < m(K^-\pi^+\pi^+) < 1.940$ GeV/c^2 and $1.765 < m(K^-\pi^+) < 1.965$ GeV/c^2 are regarded as signals, respectively. The sideband regions are defined as $1.640 < m(K^-\pi^+\pi^+) < 1.740$ GeV/c^2 and $2.000 < m(K^-\pi^+\pi^+) < 2.100$ GeV/c^2 for D^+, and $2.100 < m(K^-\pi^+\pi^+) < 2.500$ GeV/c^2 for D^0. In the Fig. 2, the invariant mass spectra for the D^+ and D^0 are plotted.

From 1993-98 SLD data, we select 3967 candidates which consist of 2829 $c \to D$ signal, 281 $b \to D$, and 857 RCBG.

The charge of the primary c-quark is determined by the sign of the $D^{(*)+}$, or K^- (in the D^0 case). The direction of the primary quark is estimated from the direction of the reconstructed D meson. Fig. 3 shows $y \equiv q\cos\theta_D$ distributions for the selected D meson sample separately for left- and right-handed electron beams.

To extract A_c, we use an unbinned maximum likelihood fit based on the Born-level cross section for fermion production in Z^0-boson decay. The likelihood function used in this analysis is

$$\begin{aligned}\ln\mathcal{L} = \sum_{i=1}^{n} \quad \ln \quad & \{P_c^j(x_D^i)\cdot[(1-P_eA_e)(1+y_i^2)+2(A_e-P_e)y_i\cdot A_c^D\cdot(1-\Delta_{QCD}^c(y_i))] \\ + \quad & P_b^j(x_D^i)\cdot[(1-P_eA_e)(1+y_i^2)+2(A_e-P_e)y_i\cdot A_b^D\cdot(1-\Delta_{QCD}^b(y_i))]\end{aligned}$$

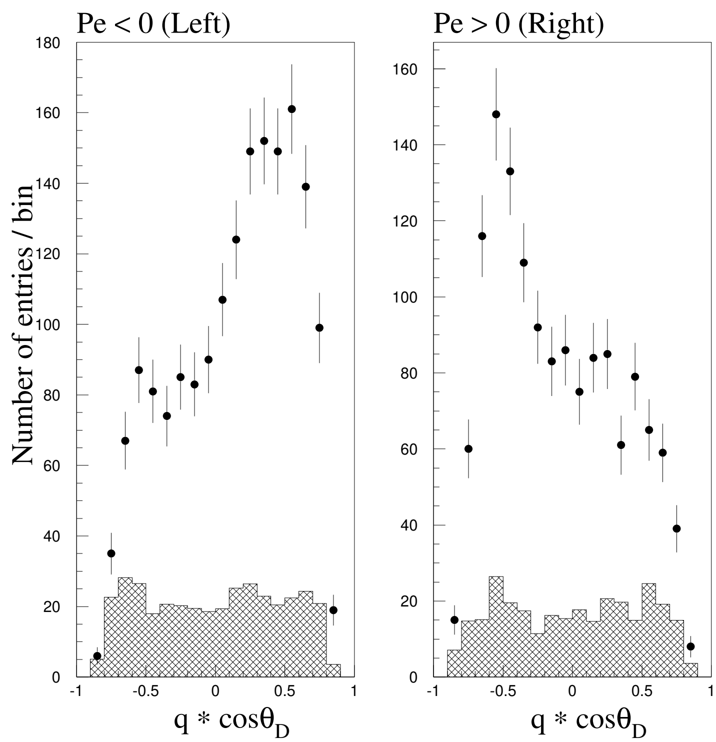

Figure 3: The distributions of the $q \cdot \cos\theta_D$ for the selected D meson sample for (a) left- and (b) right- handed electron beams. The solid circles are exp. data, and hatched histograms are RCBG estimated from side-band regions.

$$+ \quad P^j_{RCBG}(x^i_D) \cdot [(1 + y_i^2) + 2A_{RCBG}y_i]\}$$

where n is the total number of candidates, and A_c^D and A_b^D are the asymmetries from D^*, D^+, and D^0 mesons in $c\bar{c}$ and $b\bar{b}$ events, respectively. The index j indicates each of the six charm decay modes. For the asymmetry for the RCBG, we take $A_{RCBG} = 0$ for the central value. For A_e, we have taken $A_e = 0.1512 \pm 0.0043$ from the SLD measurement[11]. P_c^j, P_b^j, and P^j_{RCBG} are the probabilities that a candidate from the jth decay mode is a signal from $c\bar{c}$, $b\bar{b}$, or RCBG. $\Delta^f_{QCD}(y)$ is the $O(\alpha_s)$ QCD correction to the asymmetry. Only A_c^D is treated as a free parameter, and A_b^D is taken to be fixed.

Performing the maximum likelihood fit to the data sample, we obtain

$$A_c = 0.690 \pm 0.042,$$

where the error is statistical only.

4 Inclusive soft-pion analysis

In this analysis, c-quarks are identified using an inclusive soft-pion. Since the decay $D^{*+} \to D^0\pi_s$ has a small Q value of $m_{D^*} - m_{D^0} - m_\pi = 6$ MeV/c^2, the maximum transverse momentum of π_s with respect to the D^* flight direction is only 40 MeV.

To determine the D^* direction, charged tracks and neutral clusters are clustered into jets, using an invariant-mass algorithm where particles are merged together in an iterative way if their invariant mass is less than 4.6 GeV/c^2. The jets which satisfy 1) at least 3 charged tracks, 2) at least one track has a momentum of P $>$ 5 GeV/c, 3) a net charge of the jet $\leq$ 2e, 4) sum of the normalized impact parameters of the largest and second largest tracks $>$ 2.5 σ, and 5) there is at least one opposite-charged-tracks pair which has the χ^2 probability of two tracks coming from the same vertex of greater than 1%, are selected as D^* jets. The transverse momentum P_T to the D^* jet axis for the soft-pion tracks, which have a momentum of $1 < P < 3$ GeV/c and an impact parameter of $< 2\sigma$, are calculated. Fig. 4 shows the P_T^2 distribution for the soft-pion tracks. The background shape is determined by the function of $F_{BG}(P_T^2) = a/(1 + bP_T^2 + c(P_T^2)^2)$. The region of $P_T^2 < 0.01$ (GeV/c)^2 is regarded as a signal region, where a signal-to-background ratio of 1:2 is observed. From 1993-98 data, 12992 soft-pion tracks are selected which consist of 3791 $c \to D^{*+}$, 500 $b \to D^{*+}$, and 8701 background tracks.

To extract A_c, we also use an unbinned maximum likelihood fit discussed in the exclusive analysis. We obtain

$$A_c = 0.683 \pm 0.052(stat.)$$

for the inclusive-soft-pion analysis.

5 Results

Possible systematic errors have been estimated and are summarized in Table 1. We get the

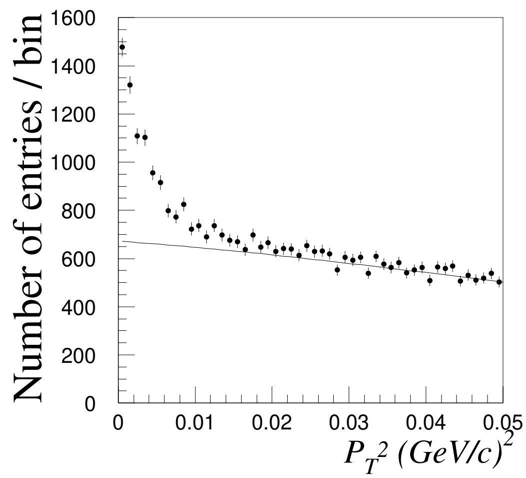

Figure 4: The P_T^2 distribution for soft-pion tracks. The solid circles indicate the exp. data. Background shape is obtained by the function described in the text.

Systematic error source	Exclusive	Inclusive
f_{RCBG}	0.0111	0.0244
Choice of BG shape	–	0.0385
A_{RCBG}	0.0028	0.0093
RCBG x distribution	0.0112	0.0018
RCBG acceptance	0.0087	0.0122
$f_{b\to D}/(f_{b\to D}+f_{c\to D})$	0.0011	0.0018
$A_{b\to D}$ (A_b)	0.0033	0.0040
$A_{b\to D}$ (Mixing)	0.0099	0.0122
$< x_c >$	0.0003	0.0020
$< x_b >$	0.0003	0.0010
d(x_D) shape	0.0040	0.0003
A_e	0.0004	0.0011
Polarization	0.0051	0.0047
CRID Kaon ID	0.0022	–
α_s	0.0004	0.0005
Correction to QCD corr.	0.0018	0.0024
2nd Order QCD corr.	0.0006	0.0008
Gluon splitting	0.0001	0.0004
Total	0.0222	0.0502

Table 1: Contributions to the estimated systematic error.

preliminary results of the parity-violation parameter A_c using two kinds of c-quark tagging methods:

$$A_c = 0.690 \pm 0.042(stat.) \pm 0.022(sys.) \text{ and}$$

$$A_c = 0.683 \pm 0.052(stat.) \pm 0.050(sys.),$$

from exclusive charmed-meson reconstruction and inclusive soft-pion analysis, respectively. To combine them, we avoided double counting signal events from both samples. 1182 events are counted as overlap events in the analyses. This increased the statistical error for soft-pion analysis to 0.061.

The combined result from the two analyses is

$$A_c = 0.688 \pm 0.035(stat.) \pm 0.025(sys.) \text{ (preliminary)}.$$

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