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A MEASUREMENT OF THE LEFT-RIGHT, FORWARD-BACKWARD ASYMMETRY FOR CHARM QUARKS USING D^{*+} AND D^{+} MESONS

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ABSTRACT

Longitudinal polarization of the SLC e^- beam allows a direct measurement of the left-right, forward-backward asymmetry of c-quarks to be made with the SLD. Events from $Z^0 \to c\bar{c}$ are tagged using fully and partially reconstructed decays of D^{*+} mesons, and fully reconstructed decays of D^+ mesons. We measure $A_c = 0.77 \pm 0.22$ (stat.) $\pm$ 0.10 (syst.).

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1. Introduction

In the Standard Model, the vector and axial-vector couplings of the electroweak interaction result in forward-backward asymmetries, A_{FB}, in the differential cross section $d\sigma/d\cos\theta$ for $e^+e^- \rightarrow f\bar{f}$, where θ is the angle between the incoming e^- and the outgoing fermion f. Fermion asymmetries are directly related to electroweak coupling parameters, and provide a sensitive test of the Standard Model. For example, for the c quark asymmetry, $A_c = 2v_c a_c/(v_c^2 + a_c^2)$, where v_c (a_c) is the vector (axial-vector) coupling in the electroweak interaction.[1] At the Stanford Linear Collider (SLC), the selection of the incident e^- helicity (left (L) or right (R)) facilitates the cancellation of the e^- coupling such that a *direct* measurement of the final state c quark asymmetry, A_c, can be made from the polarization, P_e , and A_{FB}:

$$\tilde{A}_{FB}(P_e) = 3/4 \cdot P_e \cdot A_c = \frac{\sigma_F^L + \sigma_B^R - \sigma_B^L - \sigma_F^R}{\sigma_F^L + \sigma_B^R + \sigma_B^L + \sigma_F^R}.$$

In this double asymmetry, geometric asymmetries in the acceptance, and asymmetries in charge, cancel.

2. Event Selection

The SLAC Large Detector (SLD)[2] 1993 data sample contains ~50,000 Z^0's produced at 91.26 ± 0.02 GeV. The e^- beam is longitudinally polarized to 63.0 ± 1.1 %.[3] For this analysis, only the vertex detector,[4] the central drift chamber,[5] and the calorimeter[6] are used. These devices cover 76%, 85%, and 95% of 4π sr, respectively. Multi-hadron events must have at least five charged tracks, a charged energy to center-of-mass energy ratio greater than 0.20, and $|\cos\theta_T| < 0.8$, where θ_T is the angle between the e^- beam and the thrust axis.

3. Charm Tagging

To isolate $c\bar{c}$ events from $b\bar{b}$ and *uds* backgrounds, kinematic and vertex analyses are used to find events containing two $D^{*+} \rightarrow D^0\pi_s^+$ decay chains; *i.e.*, where $D^0 \rightarrow K\pi$ or $D^0 \rightarrow K\pi\pi^0$. In the latter, the π^0 is not reconstructed. Vertexing techniques also cleanly isolate the mode $D^+ \rightarrow K^-\pi^+\pi^+$. In the D^{*+} kinematic analysis, D^0 candidates are formed by cutting on the D^0 invariant mass spectrum as follows: for the $K\pi$ mode, 1.765 GeV < $m(D^0 \rightarrow K^-\pi^+)$< 1.965 GeV and, for the "satellite" peak, 1.500 GeV < $m(D^0 \rightarrow K^-\pi^+\pi^0)$ < 1.700 GeV. A helicity angle cut, $\left|\cos\theta^*\right| > 0.9$, is applied, where θ^* is the opening angle between the direction of the D^0 candidate in the lab frame, and the K in the rest frame of the D^0 candidate. After this cut, remaining candidates are combined with a "slow" pion having the correct charge and $p_\pi > 1.0$ GeV/c. To reduce combinatoric background and eliminate D^{*+}'s from $Z \rightarrow b\bar{b}$ events, we require x_{D^*}, defined as $2 \cdot E_{D^*}/E_{cm}$, to be ≥ 0.4. The mass difference between the D^{*+} and its associated D^0, Δm, divides the data into a signal region ($\Delta m < 0.150$ GeV), and a sideband region (0.16 GeV < Δm <0.20 GeV).

In the D^{*+} vertex analysis, the helicity angle and p_π cuts are eliminated, and the x_{D^*} cut is reduced to $x_{D^*} \geq 0.2$. We require D^0 tracks to have a good 3D-vertex fit, with a 3D-decay length (L) distinct from the IP by $2.5 \cdot \sigma_L$, where σ_L is the error on L. The 2D-impact parameter of the D^0 to the IP is required to be $< 20\mu m$. The vertex and impact parameter cuts strongly reject combinatoric background, and D^{*+} from beauty cascades.

To isolate $D^+ \rightarrow K^-\pi^+\pi^+$ in $c\bar{c}$ events, a vertex-style analysis is used. We require $x_{D^+} \geq 0.4$, and $\cos\theta^* > 0.8$, where the θ^* helicity angle of the K^- with respect to the D^+. The difference between the $K^-\pi^+\pi^+$ invariant

mass, and the invariant mass of the K^- and each one of the π's, is required to be >0.160 GeV. This cut insures that neither of the $K^-\pi^+\pi^+$ combinations comes from a D^{*+} decay. The magnitude of the 3D-decay length measured from the IP, L, is required to be at least $3 \cdot \sigma_L$. The angle between a line drawn from the D^+ vertex to the IP, and the direction of the D^+, must be <5 mr in the XY plane, and <20 mr in the RZ plane. This requirement is analogous to the impact parameter cut of the D^{*+} analysis. The signal region is defined as 1.800 GeV < $m(D^+)$ < 1.940 GeV.

The signal from each mode is shown in Fig. 1. To reduce dependence on branching fractions, the shape of each signal and background is taken from Monte Carlo (MC). The data is fit separately to the sum of these two components to determine the number of background events, and the relative number of $c\bar{c}$ and $b\bar{b}$ events, lying in the signal mass region. The solid lines in Fig. 1 indicate the fitted backgrounds. There are 317 entries in the signal region, of which 173 are from the desired $c\bar{c}$ signal, 59 are from $b\bar{b}$ events, and 85 are from random combinatoric background.

The raw asymmetry, shown in Fig. 2, is plotted as a product of the e^- helicity, the charge of the charm meson, and $\cos\theta_D$, where θ_D is the angle the D meson makes with respect to the thrust axis. To extract A_c, we perform an unbinned maximum likelihood fit to the form of the polarized differential cross section for each contributing flavor.[7] Three pieces of information from each event are used in the fit: the incident polarization, $\cos\theta_D$, and x_D. Probabilities are assigned for each event to be from $c\bar{c}$ or $b\bar{b}$ Z^0 decays, or from random combinatoric background, based on the event's x_D value. Sideband data and MC are used to simulate the x_D distributions after cuts, while the relative normalization and errors are fixed by the fitted decomposition of the 317 events, as previously described. A mixing-diluted value for A_b of 0.635 ± 0.135, and a sideband asymmetry, are input to the fit. The fitted value of A_c is adjusted by +0.9% (+6.1%) for

QED (QCD) radiative corrections (refer to Section 4), yielding $A_c = 0.77 \pm 0.22$ (stat.).

4. Systematic Errors

The largest systematic errors arise from limited knowledge of the random combinatoric background's asymmetry (4.9%), magnitude (4.4%), x_D distribution (3.0%), and acceptance (4.7%). The b-asymmetry, feed-down from b events, and b-fragmentation contribute 2.7%, 0.6%, and 0.6%, respectively. Charm fragmentation contributes 3.1%, while the polarization uncertainty adds 1.3%. The charm asymmetry calculated at tree-level is modified by small QED and QCD radiative corrections. The QED corrections originate from initial and final state radiation; *i.e.*, from corrections to the $Z^0 e^+ e^-$ and the $Z^0 c\bar{c}$ vertices. Higher order weak processes, such as box diagrams, are negligible. The "oblique" corrections to the Z^0 propagator (seen as changes in the effective $\sin^2 \theta_W$) are not made. The total QED correction is estimated using ZFITTER to be < 0.85%.

Final state QCD corrections have been calculated to $O(\alpha_s^2)$.[8] Mass corrections for the c-quark are negligible. The lowest order correction is weakly $\cos\theta$ dependent, and it has been accounted for by adjusting A_c by 3.6%. The $O(\alpha_s^2)$ correction depends on acceptance cuts for four-jet events, wherein a radiated gluon emerges as a pair of light quarks. We have taken 2.5% for the correction, and include ±1.8% as the total QCD uncertainty. Combining all systematic errors, we find $A_c = 0.77 \pm 0.22$ (stat.) $\pm$ 0.10 (syst.).

5. References

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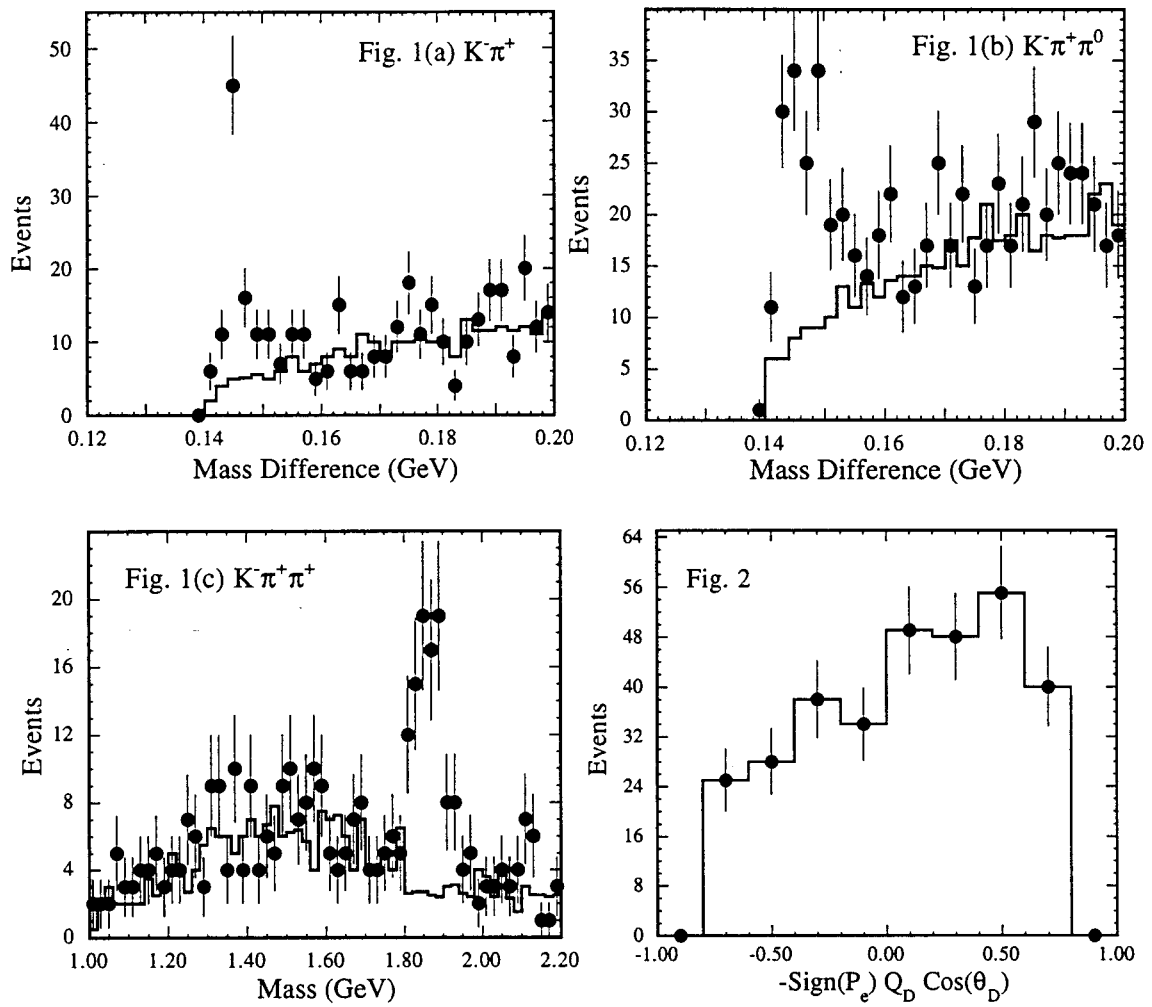

Fig. 1. The Δm distributions for kinematic and vertex analyses for (a) $D^{*+} \to D^0 \pi_s^+$, $D^0 \to K\pi$ and (b) $D^{*+} \to D^0 \pi_s^+$, $D^0 \to K\pi\pi^0$, and (c) the mass distribution for $D^+ \to K^- \pi^+ \pi^+$.

Fig. 2. The uncorrected asymmetry, shown for the distribution of 317 events in the signal mass region in $-Q_D \cdot SIGN(P_e) \cdot \cos\theta_D$.