Forward-backward charge asymmetry of quark pairs produced at the KEK TRISTAN e^+e^- collider

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We report on a measurement of the forward-backward charge asymmetry in $e^+e^- \to q\bar{q}$ at KEK TRISTAN, where the asymmetry is near maximum. We sum over all flavors and measure the asymmetry by determining the charge of the quark jets. In addition we exploit flavor dependencies in the jet charge determination to enhance the contributions of certain flavors. This provides a check on the asymmetries of individual flavors. The measurement agrees with the standard model expectations.

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INTRODUCTION

The forward-backward charge asymmetry in e^+e^- annihilation is sensitive to the interference of photon and Z^0 as the mediating bosons and is therefore a good test of the standard electroweak theory. Previously [1] we reported a measurement of the forward-backward asymmetry in all quark flavors combined using a $27.4pb^{-1}$ sample of $e^+e^- \to q\bar{q}$. Here we repeat the measurement using $179pb^{-1}$. The added statistics allow us to make a detailed study of various methods for determining the charge of a jet and take advantage of their different characteristics to enhance the asymmetry contribution of different flavors. This allows a check of individual quark asymmetries.

FORMALISM OF ASYMMETRY

The electroweak theory allows electron-positron annihilation into quarks through two channels: γ exchange and Z^0 exchange. The different cross section for $e^+e^- \to \{\gamma, Z^0\} \to q\bar{q}$ is

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$$\frac{d\sigma}{d\Omega}=\frac{3\alpha^2}{4s}[R_q(1+\cos^2\theta_q)+B_q\cos\theta_q] , \quad (1)$$

where θ_q is the production angle of the quark measured from the electron direction. The coefficients R_q and B_q contain the couplings of the γ and Z^0 to the fermions (q, $\bar{q}$, e^+, and e^-). They are given by

$$R_q=Q_q^2-8Q_q g_V^e g_V^q \mathrm{Re}(\chi)+16(g_V^{e2}+g_A^{e2})(g_V^{q2}+g_A^{q2})|\chi|^2 , \quad (2)$$

$$B_q=16Q_q g_A^e g_A^q \mathrm{Re}(\chi)+128 g_V^e g_V^q g_A^e g_A^q |\chi|^2 , \quad (3)$$

where Q_q is the electric charge of the quark, g_V^e and g_V^q are the weak vector couplings of the electron and the quark, and g_A^e and g_A^q are the weak axial vector couplings of the electron and the quark. χ contains the Breit-Wigner function of the Z^0:

$$\chi=\frac{1}{16\sin^2\theta_W\cos^2\theta_W}\frac{s}{(s-M_Z^2+iM_Z\Gamma_Z)} . \quad (4)$$

There are some general features that are worth noting. The differential cross section contains two terms. The $R_q(1+\cos^2\theta_q)$ term is symmetric in $\cos\theta_q$ and has the angular form expected from QED for spin-$\frac{1}{2}$ particles. The $B_q\cos\theta_q$ term is asymmetric in $\cos\theta_q$ and does not appear if only the QED (γ exchange) diagram is used. The Q_q^2 term, within R_q, comes purely from γ exchange (QED). The $|\chi|^2$ terms come purely from Z^0 exchange (weak). The $\mathrm{Re}(\chi)$ terms come from interference between γ and Z^0 exchange (electroweak). Notice that the purely weak terms have a maximum when $\sqrt{s}=M_Z$ as expected. Likewise, the interference terms drop out in both the pure QED limit ($\sqrt{s}=0$) and in the pure weak limit ($\sqrt{s}=M_Z$).

The asymmetry of B_q in $\cos\theta_q$ causes the backward direction ($\cos\theta_q<0$) to be favored over the forward direction. This gives rise to a forward-backward asymmetry which can be defined as the percentage of excess events in the forward direction, i.e., $A\equiv(N_F-N_B)/(N_F+N_B)$. Within the electroweak formalism, this asymmetry can be written in terms of the coupling coefficients as $A_q=\frac{3}{8}(B_q/R_q)$. It is then possible to rewrite the differential cross section in terms of the forward-backward asymmetry as

$$\frac{d\sigma}{d\Omega}=\frac{3\alpha^2}{4s}R_q[(1+\cos^2\theta_q)+\tfrac{8}{3}A_q\cos\theta_q] . \quad (5)$$

At KEK TRISTAN energies, B_q (and therefore the asymmetry) is dominated by the electroweak interference term so its measurement in this energy region is a sensitive test of electroweak interference. The standard model [2] predictions for the asymmetries are shown in Fig. 1. Notice that their magnitudes are near maximum and nearly equal in the KEK TRISTAN energy region.

It is only feasible to measure the forward-backward asymmetry *directly* for heavy quarks, and then only with a reduced efficiency [3]. Alternatively, we combine all five quark flavors and study the asymmetry in hadron production. As a result, the production angle needs to be

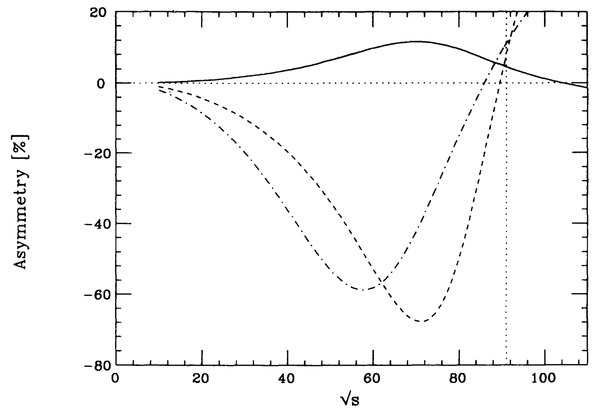

FIG. 1. Forward-backward asymmetry of quark production as a function of the center of mass energy $\sqrt{s}$. The dashed line is for u quarks, the dot-dash line is for d quarks, and the solid line is for all quark flavors combined using the quark charge to determine the direction.

redefined since the direction of the outgoing quark cannot be unambiguously determined. So the electric charges of the quark jets are determined and the production angle is defined to be between the incoming negative charge (i.e., the electron) and the outgoing negative charge (i.e., the d,s,b quark or the u or c *anti*quark). Since it includes all hadron production events and is defined with respect to electric charge the asymmetry which is measured is called the *hadronic charge asymmetry*.

Defining the production angle with respect to charge causes a 180° change for up-type (u and c) quarks which flips the sign of their asymmetry. This makes the up-type quarks and down-type quarks have nearly equal and opposite asymmetries. When they are combined in the hadron asymmetry there is near cancellation. The cancellation is not complete since up-type quarks are produced more often than down-type quarks in the KEK TRISTAN energy region. The resulting asymmetry is around $+10\%$ at 60 GeV as shown in Fig. 1.

EVENT SELECTION

The measurements described here are made with the AMY detector using a $179pb^{-1}$ sample of 17 085 multihadronic events. Charged particles with sufficient momentum transverse to the beam axis, $P_T>0.4$ GeV, are tracked in a 3 T solenoidal field with good efficiency over the angular range $|\cos\theta|<0.85$. The thrust axis, calculated using only charged particles, is used as the production angle of the quark pair. Monte Carlo studies show that the thrust axis corresponds to the quark pair direction to within about 5° at 1σ. The particles are divided into two hemispheres by the plane perpendicular to the thrust axis. These hemispheres are henceforth called jets.

To assure containment of the jets in the central detector, we require that the thrust axis be well within the detector's acceptance, i.e., $|\cos\theta_T|<0.65$. To remove events with high-energy gluon radiation, a thrust requirement of $T>0.85$ is used. In addition, the JADE clustering algorithm [4] is used [$Y_{\mathrm{cut}}=(13/E)^2$] and events with more than three clusters are discarded. To suppress initial-state radiation effects, events with isolated photons having $E_\gamma>4$ GeV are cut. 11 445 events meet these requirements.

JET CHARGE METHODS

We will examine and use various methods to determine which jet corresponds to the negative quark-antiquark direction. But, in none of them is it possible to correctly identify the negatively charged jet for every event. Any misidentification will affect the asymmetry by mistakenly inverting each misidentified event from the forward region to the backward region, or vice versa. If P_q is defined as the percentage of events of flavor q for which the sign of the jet charge is correctly identified, then the number of q events *measured* to be in the forward and backward directions are $N_F^M=P_qN_F+(1-P_q)N_B$ and $N_B^M=P_qN_B+(1-P_q)N_F$, where the superscript M is used to indicate that the effect of misidentification has been incorporated. The measured asymmetry is then $A_q^M=(N_F^M-N_B^M)/(N_F^M+N_B^M)=(2P_q-1)A_q$. There is also the possibility that the selection cuts favor some flavors more than others. To account for this, f_q is defined to be the fraction of q events passing the cuts. The values for the P_q's and f_q's depend upon the method used to determine the jet charge and are determined from Monte Carlo studies [5]. Including the P's and f's in the original definition of asymmetry a prediction for the hadronic charge asymmetry can be written as

$$A_h^M=\frac{\sum_{q=d,u,s,c,b} f_qR_q(2P_q-1)A_q}{\sum_{q'=d,u,s,c,b} f_{q'}R_{q'}} . \tag{6}$$

This expresses the hadronic charge asymmetry as a sum of the asymmetries of the individual flavors. The contribution which each flavor's asymmetry makes to the sum is weighted by the P and f values for that flavor as well as its production rate (specified by the R terms). To make A_h large (and therefore easy to measure) it is important to make the P_q's and f_q's as large as possible. However, it is also interesting to measure A_h using several different jet charge methods which have different P_q or f_q values for different flavors. This will enhance the contribution to the asymmetry sum of different flavors and provide a check on the asymmetries of individual flavors.

An initial approach to determine the jet charge is to simply sum the charges of all the particles in each jet. However, many of the events have neutral jets and therefore give no information. As a result, the sign of the charge is determined correctly in only 55% of u events (for example). The rest of the events are either incorrectly identified or indeterminate. The primary problem with this method is that it is very sensitive to the low-momentum charged particles resulting from the soft parts of the fragmentation and which cannot really be confidently assigned to one jet or the other.

An alternative method which circumvents this problem is to use the charge of the highest-momentum charged particle in the jet. This is called the *leading particle method*, and it relies on the assumption that the soft particles in the jet come from the soft fragmentation, while the leading (i.e., highest momentum) particle comes from the original quark. The performance of this method is slightly better. It correctly identifies the sign of the jet charge in 62% of u jets. However, there are many events for which the q and $\bar{q}$ jets have the same charge so that although one jet is correctly identified, it is impossible to tell which one is correct and which is incorrect. Such events would have to be cut, drastically reducing the data sample.

It is arbitrary to use only the leading particle since there are often several particles with high momentum. A better approach would be to include all the particles but to weight each particle's contribution by a fragmentation-sensitive property such as its momentum or its pseudorapidity with respect to the jet axis. This weighting is meant to lessen the effect of the particles produced in the soft part of fragmentation [6].

Using pseudorapidity as a weighting, the jet charge could be defined as

$$Q_{\mathrm{jet}}\equiv\frac{\sum_{i=1}^{N} q_i\eta_i^\kappa}{\sum_{i=1}^{N}\eta_i^\kappa} , \tag{7}$$

where the sum runs over all the particles in the jet, q_i is the charge of the ith particle in the jet, and η_i is its pseudorapidity with respect to the jet axis. κ is a parameter which can be varied to change the strength of the weighting. This definition amounts to a pseudorapidity-weighted average of the particle charge. To use momentum as a weighting, η_i would be replaced by $|\mathbf{p}_i|$. It is interesting to note that, aside from a division by the number of particles, the weighting method reduces to the initial charge sum method in the limit $\kappa=0$, and to the leading particle method in the limit $\kappa\rightarrow\infty$. Figure 2(a) shows the jet charge distribution for up-type quarks with pseudorapidity weighting and $\kappa=1$. The performance of this method is rather good; the sign of the charge is determined correctly in 71% of the u jets. Weighting with momentum is similar.

Since the goal is to differentiate between the q and the $\bar{q}$, all that is necessary is to determine which of the jets is the *more* negatively charged jet. Because of that, it is better to look at the charge *difference* between the two jets, and to define the negative jet as the one with the smallest charge, even if both jet charges happen to be positive. This improves the percentage of correctly identified u events to 77%. A distribution of the charge difference, ΔQ, is shown for u quarks in Fig. 2(b).

The κ exponent in the jet charge sum is intended to allow the strength of the weighting to be varied. Figure 3 plots P as a function of κ for each flavor. The plot is shown for both pseudorapidity weighting and momentum weighting. For momentum weighting, a value of $\kappa\approx\frac{1}{2}$ gives a peak for most flavors. For pseudorapidity weighting, the peak occurs at $\kappa\approx1$. The resulting P_q values are

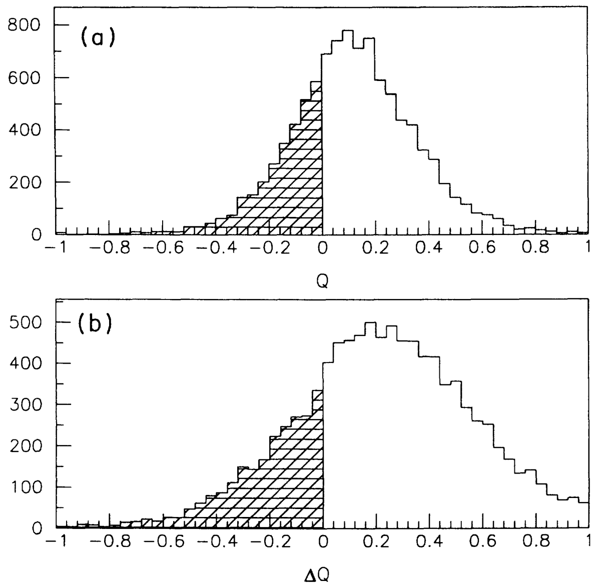

FIG. 2. Jet charge distribution for u quarks using a pseudorapidity-weighted average charge ($\kappa=1$). (a) The distribution for a single jet. (b) The distribution of the charge difference between jets.

shown in Table I.

Notice from Fig. 2(b) that requiring that there be some minimum charge difference, $\Delta Q_{\min}$, between the two jets' charges would improve P. As an extreme example, if only events for which $\Delta Q > 1.0$ are used, then P_u would increase to 94%. Of course, however, this would cut many events. A more conservative value of $\Delta Q_{\min}=0.15$ increases the P values ($P_u=82\%$) without seriously reducing the statistics of the data sample. The resulting P_q values are shown in Table I.

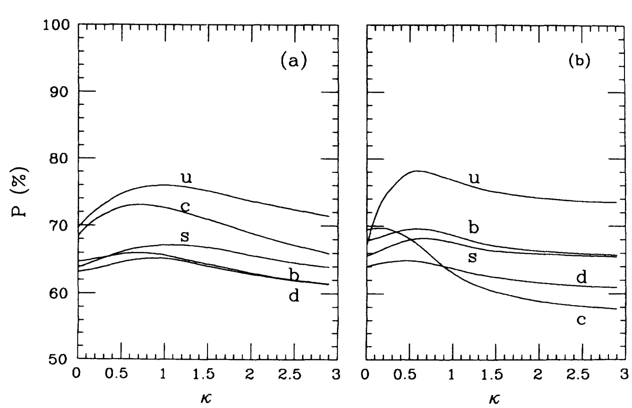

FIG. 3. The percentage of events for which the sign of the jet charge is correctly identified is plotted as a function of the weighting parameter κ. (a) Uses pseudorapidity weighting. (b) uses momentum weighting.

TABLE I. This table lists the percentage of correctly identified events for (a) pseudorapidity weighting with $\kappa=1$, (b) momentum weighting with $\kappa=\frac{1}{2}$, (c) pseudorapidity weighting with $\kappa=1$ and requiring $\Delta Q > 0.15$, and (d) momentum weighting with $\kappa=\frac{1}{2}$ and requiring $\Delta Q > 0.15$. The uncertainties on these values are 0.3% for P_u and P_c, and 0.6% for P_d, P_s, and P_b.

	(a)	(b)	(c)	(d)
P_u	76.0%	78.5%	82.3%	84.2%
P_d	65.3%	65.2%	70.2%	70.3%
P_s	67.1%	68.4%	72.7%	73.9%
P_c	72.6%	68.6%	79.4%	74.2%
P_b	65.6%	70.0%	71.3%	75.4%

HADRONIZATION EFFECTS

Figure 3 has some interesting features. For $\kappa \to 0$, P_u and P_c become equal as do P_d, P_s, and P_b. This is sensible since $\kappa=0$ removes all the flavor-dependent hadronization effects from the jet charge. However, as κ increases the hadronization-related parameter (η or $|\mathbf{p}|$) causes differences among the flavors. This is most noticeable in P_c which drops drastically above $\kappa=1.0$ in momentum weighting. There is a similar effect in pseudorapidity weighting but it is much less pronounced. This effect can be understood in terms of the differences between light-quark and heavy-quark hadronization.

For our purposes, hadronization is thought of as occurring in two distinct phases; fragmentation [7] and decay. Both phases exhibit differences between the light and heavy quarks. The fragmentation is soft in light quarks and hard in heavy quarks. As a result, a heavy quark tends to form a single high-momentum, heavy meson and several very-low-momentum, light mesons while a light quark tends to form mesons without very high momentum. The decay phase is important in heavy quarks since the heavy mesons formed in the fragmentation phase can give large transverse momentum to their decay products while the decay of mesons produced by light quarks does not.

These features explain the different jet charge behavior of the heavy quarks. As an example, a c quark is likely to produce a D^{*+} as the primary meson. Typically this meson will carry about 70% of the total jet energy. The D^{*+} usually decays into $D^0\pi^+$ where the π^+ ends up with very low momentum. In effect, this decay throws away the charge information by sending it into a soft particle. With momentum weighting, as κ is increased soft particles are given very little weighting so that such events cause P_c to decrease sharply as κ becomes large. Furthermore, the D^0 decays into a K^- and one or more pions. Because of its larger mass the kaon is slightly more likely to get a higher momentum than any of the pions. This results in a leading negative charge from the positively charged c quark. This can be thought of as resulting from the quark cascade decay of $c \to s$ with the charge carried away by a low-momentum W.

The b quark behavior can be understood similarly as a quark cascade decay of $b \to c \to s$. In b jets, the leading particles tend to be negative for the same reasons as in c jets. This causes P_b to be larger than P_d or P_s in momentum weighting. However, $B_0\bar{B}_0$ mixing has the opposite effect and reduces P_b somewhat.

The pseudorapidity-weighted jet charge effectively weights each particle's charge by how close the particle is to the jet axis. A jet's width can be attributed to either fragmentation or decay. In light quarks, the soft fragmentation produces most of the width while decays contribute very little. In heavy quarks, it is the other way around since the hard fragmentation is dominated by a single high-momentum heavy meson very close to the original quark direction. It is the decay of that meson which produces most of the final jet's width. Although they arise for different reasons, the widths of light and heavy quark jets are nearly equal at KEK TRISTAN. Heavy quark jets are only slightly wider. This extra width is only sufficient to make P_c and P_b slightly lower than their light quark counterparts. So, the peculiarities of the heavy quarks seen with momentum weighting are not as apparent in pseudorapidity weighting.

MEASURED ASYMMETRY

The measured asymmetry A_h^M depends upon the P and f values and therefore upon the jet charge method used. For the primary measurement, pseudorapidity weighting with $\kappa = 1.0$ is used. For this choice, P_c is larger than in momentum weighting so A_h^M is larger, and therefore easier to measure. In addition, pseudorapidity weighting is more desirable since the direction of the jet, and each particle, can be determined quite precisely while the momentum resolution worsens as the momentum increases. That could affect the jet charge since it is the high-momentum particles which contribute the most to the momentum-weighted sum. A disadvantage of pseudorapidity weighting is that events with hard gluon radiation must be removed (with the $T > 0.85$ cut) since they affect the pseudorapidity of the jet's particles.

Including a charge cut requirement of $\Delta Q > 0.15$, a data sample of 8262 events remains for the measurement. The angular distribution of the negative jets is shown in Fig. 4. It is clearly asymmetric favoring the forward direction. Fitting a curve with the form of Eq. (5) results in an asymmetry value of $A_h^M = 9.6 \pm 1.3\%$. The fitted curve is shown by the solid line and a symmetric curve is shown by the dotted line. The fit is rather good with $\chi^2 = 10.3$ for 10 degrees of freedom. By comparison, $\chi^2 = 56$ for the symmetric curve. This measurement can be compared to the standard model with Eq. (6) using the P_q and f_q values determined from Monte Carlo simulation and the standard model values for the individual quark asymmetries at the average energy of $\langle \sqrt{s} \rangle = 58$ GeV. The expected value is 10.2% if $B^0\bar{B}^0$ mixing is not included, and 10.0% if it is. So, the measured value is consistent with the standard model prediction regardless of $B^0\bar{B}^0$ mixing.

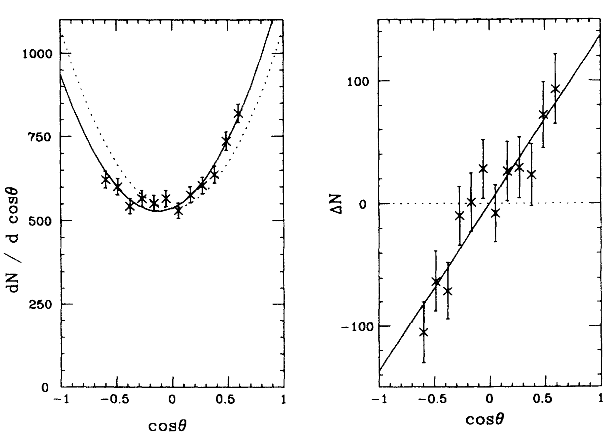

FIG. 4. The angular distribution of the more negatively charged jet from AMY Collaboration data. The solid line is a fit to the data, the dotted line is a fit with the asymmetry forced equal to zero, i.e., the symmetric case. (a) Shows the raw distribution. (b) Shows the difference between the measured data and the symmetric fit, making the asymmetry easy to discern.

SYSTEMATIC UNCERTAINTIES

The systematic uncertainties which have been considered are radiative corrections, s quark suppression, fragmentation modeling, $B_0\bar{B}_0$ mixing, event selection cuts, and the charge determination method. Their contributions are summarized in Table II and each will be discussed in turn. Note that the uncertainties are quoted as %. They are meant as a change in the asymmetry (which is measured in %), *not* as a percentage change in the asymmetry.

Radiative corrections modify the differential cross section. These effects have been calculated by the KEK TRISTAN theory group [8]. Radiation of a photon in the initial or final state reduces the asymmetries of the individual quark flavors by ≈5%. The isolated photon cut was primarily intended to remove events which radiate *high-energy* photons (and consequently distort the thrust axis). It is impossible to remove events which radiate *low-energy* photons, so the cut only removes ≈30% of all the radiative events. Fortunately, however, the near canceling sum of asymmetries reduces the measurement's sensitivity to radiative corrections so the uncertainty contribution is 0.7%.

TABLE II. Summary of the systematic uncertainties.

Source	Uncertainty in A_h^M
Radiative corrections	0.7%
s quark suppression	0.6%
Other fragmentation effects	0.15%
$B^0\bar{B}^0$ mixing	0.15%
Thrust direction and cosθ cut	0.5%
Thrust cut	0.5%
P and f values	0.7%
Total	1.4%

The determination of the charge weighting parameters (P and f) is dependent upon the Monte Carlo event generator. Uncertainty in the suppression of s quark production from the sea used by the Monte Carlo event generator is the dominant systematic since it affects the type of leading particles that are formed. The s quark suppression has been measured by several experiments [9], and their combined results are that the ratio $\gamma_s = 0.33 \pm 0.03$. When the corresponding parameter in the event generator is changed by $\pm 1\sigma$, the asymmetry changes by 0.6% so that is taken as the uncertainty. To estimate the uncertainties arising from the tuned fragmentation parameters in the Monte Carlo model, the LUND parton shower parameters $\Lambda_{\rm QCD}$ and σ_q were varied by 10% from their tuned values. The resulting change in asymmetry is 0.07%. Furthermore, the parameter of the symmetric LUND fragmentation function was varied by 50% of its tuned value. The resulting uncertainty in the asymmetry is 0.13%. Adding these two in quadrature gives 0.15%.

$B_0\bar{B}_0$ mixing affects the charge identification for b events (i.e., P_b) by causing some b events to have their charge misidentified due to mixing. That effect was included in the standard model prediction, and was seen to have a small effect. The uncertainty in the extent of $B_0\bar{B}_0$ mixing leads to an uncertainty in the asymmetry prediction. The latest CLEO measurement [10] is $\chi_d = 0.157 \pm 0.033$. Assuming $\chi_s = 0.5$ (maximal mixing), the uncertainty in χ_d results in an asymmetry uncertainty of 0.15%.

The event selection cuts contribute significant uncertainties. The thrust cut, $T > 0.85$, was implemented to remove events with significant gluon radiation (which distorts the determination of the thrust direction). Since the thrust value changes by 0.03 [full width at half maximum (FWHM)] when the thrust is recalculated using charged and neutral particles, 0.02 was used as an estimate of the 1σ uncertainty in the thrust value. Changing the thrust cut by that amount results in an asymmetry change of 0.5% which is taken to be the corresponding uncertainty.

The uncertainty resulting from the thrust direction is estimated in a similar manner. Monte Carlo studies show that the thrust direction matches the original quark direction to within about 5° at 1σ. This is smaller than the bin size used for fitting the angular distribution so it contributes only at the edges, i.e., in the $|\cos\theta_T| < 0.65$ cut. When that cut is changed by 5° the asymmetry changes by 0.5%.

The primary uncertainty comes from the determination of the P and f values used in the charge weighting. This is in someway built into the fragmentation uncertainties discussed above, but there is also statistical uncertainty from the number of events which have been fully simulated. This results in an uncertainty of 0.7% on the asymmetry.

Adding these systematics in quadrature results in a total systematic uncertainty of 1.4%.

METHOD DEPENDENCE

A_h^M is in agreement with the prediction derived from the standard model. However, that prediction involves a near canceling sum of the individual quark asymmetries, and requires the assumption of quark universality. It is interesting now to look at the flavor dependence of the asymmetry. As pointed out, the jet charge determination is flavor dependent. This can be exploited to enhance certain flavors relative to the rest. This provides a check on the universality assumption and some information about individual quark asymmetries.

The flavor which is most dependent upon the weighting strength κ is c. This sensitivity should be apparent in the asymmetry. As discussed earlier, P_c decreases significantly if strong momentum weighting is used. The lower P_c will suppress the contribution of c quarks to the asymmetry sum. Since the c asymmetry is positive, its suppression should decrease the asymmetry. The P and f values can be determined from Monte Carlo simulation as a function of the weighting strength κ. A prediction for the hadronic charge asymmetry as a function of κ can then be made from those P and f values using Eq. (6). Figure 5 shows the predicted asymmetry as a function of κ for both pseudorapidity and momentum weighting. The prediction for A_h^M exhibits the expected drop in momentum weighting as κ is increased. Pseudorapidity weighting does not decrease as sharply since it does not suppress the c contribution as much as momentum weighting.

To compare this prediction to the data, the asymmetry can be measured using various values of κ with either momentum or pseudorapidity weighting. The results are plotted in the figure and are in agreement with the prediction for both methods. This suggests that the charm contribution to the asymmetry sum is as expected. It is important to note that the data points in Fig. 5 were all measured using the same data sample so the errors are correlated.

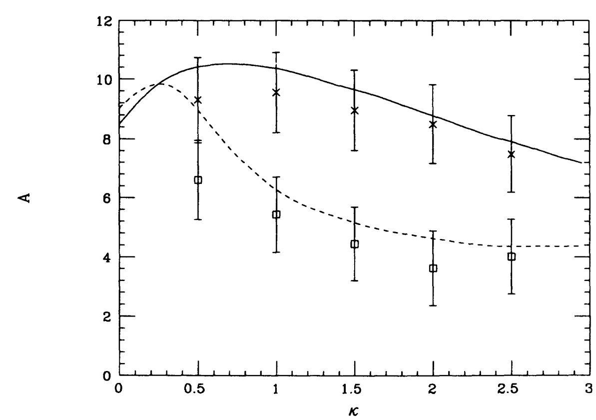

FIG. 5. The asymmetry A_h^M is plotted as a function of the jet charge weighting parameter κ. The solid line shows the prediction for pseudorapidity weighting. The dashed line shows the prediction for momentum weighting. The drop as κ is increased is due to hadronization effects in the heavy flavors. The data points were obtained from the same data sample by repeating the asymmetry measurement using differing values of κ. The crosses are for pseudorapidity weighting, and the squares are for momentum weighting.

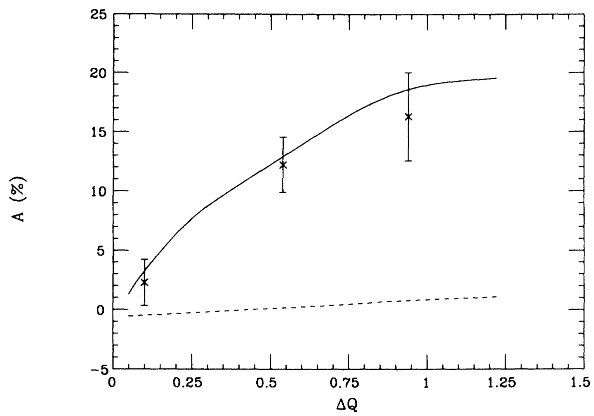

FIG. 6. The asymmetry A_h^M is plotted as a function of the charge difference between jets, ΔQ, using pseudorapidity weighted jet charge with $\kappa=1$. The solid line is the standard model prediction. The dashed line is the prediction with $A_u=0$ indicating the enhanced discernment of u-type quarks at large values of ΔQ.

Another possibility to see the flavor dependence of asymmetry is to suppress the relative contribution of the down-type quarks to enhance the effect of the up-type quarks. The down-type quarks can be suppressed by taking advantage of their lower charge. The quark charge makes the distribution of the charge difference ΔQ between the jets of up-type events wider and shifted farther from zero than a similar distribution for down-type events. As a result, events with a larger charge difference are more likely to be up type. Note that this enhancement is greatly assisted by the fact that the production rate is already much higher for up-type quarks. As before, the P and f values can be determined from Monte Carlo simulation as a function of the charge difference to provide a prediction for A_h^M vs ΔQ. Figure 6 plots this prediction for pseudorapidity weighting. The asymmetry was measured for several ranges of ΔQ and the results are shown in the figure. The data fit the prediction and are obviously different from the prediction determined with $A_u=0$, indicating that the u asymmetry contribution is as expected.

CONCLUSIONS

The forward-backward charge asymmetry in quark production has been measured with $179 pb^{-1}$ at $\langle \sqrt{s} \rangle = 58$ GeV. The measured value is $9.6\pm1.3\pm1.4\%$ which is in agreement with the standard model expectation of 10.0%. The flavor dependence of the asymmetry has been investigated by using different methods for determining the jet charge. By varying the weighting parameter κ, the relative contributions of light and heavy quarks were varied. By varying the charge difference allowed between the quark jet and the antiquark jet, the relative contributions of up-type and down-type quarks were varied. In each case, the asymmetry measurements were consistent with the standard model predictions, indicating that the asymmetries are correct for all flavors.

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