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A STUDY OF JET HANDEDNESS IN HADRONIC Z^0 DECAYS[1]

David Muller
Representing
The SLD Collaboration
Stanford Linear Accelerator Center
Stanford University, Stanford, CA 94309

Abstract

We have searched for inclusive signatures of polarization in hadronic jets from $Z^0 \to q\bar{q}$ decays using the 'jet handedness' method. We exploited the large polar angle asymmetry induced by the high SLC electron beam polarization to select samples of quark jets and antiquark jets, expected to be left- and right-polarized respectively. We find no evidence for jet handedness in our global sample and set a preliminary upper limit of 7% at 95% C.L. on the magnitude of the analyzing power of this technique. We have used the SLD vertex detector to exclude events containing heavy (b, c) quarks, in which the handedness is expected to be small due to the dominance of decays of spinless mesons. We find no evidence for jet handedness in this high-purity sample of light (u, d and s) quark jets, and set a preliminary upper limit of 11% on the magnitude of the analyzing power in this case. We have investigated several alternative definitions of jet handedness in an attempt to optimize the analyzing power. We find no evidence of jet handedness by any method.

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1 Introduction

The transport of parton polarization through the hadronization process is of fundamental interest in Quantum Chromodynamics (QCD). It is at present an open question whether the polarization of a parton produced in a hard collision is observable via the final-state fragmentation products in its resulting jet. The Z^0 resonance is an ideal place to study this issue as the quarks in $Z^0 \rightarrow q\bar{q}$ decays are predicted to be highly longitudinally polarized in the Standard Model (SM). Z^0 bosons are produced at the SLAC Linear Collider (SLC) in collisions of polarized electrons with unpolarized positrons and the SM predicts a large difference in polar angle distributions between quarks and antiquarks. This provides an unbiased separation of quark and antiquark jets, which are predicted to have opposite polarization. A method of observing this polarization might be developed at e^+e^- colliders, and could then be applied to samples of jets resulting from lepton-hadron or hadron-hadron collisions, elucidating the spin dynamics of such collisions.

Nachtmann [1] and more recently Efremov *et al.* [2] have speculated that the underlying parton polarization may be observable semi-inclusively via a triple product of track momenta in a jet. Arguing that parton fragmentation may resemble an n-body strong decay, they note that the simplest parity-conserving and spin-dependent amplitude has the form: $M \propto \vec{\sigma} \cdot (\vec{k_1} \times \vec{k_2})$, where $\vec{k_i}$ are 3-momenta of two suitably chosen decay products, $\vec{\sigma}$ is the spin of the decaying particle, and the triple product is calculated in the rest frame of the decaying particle. For a jet, an analogous triple product Ω may be defined:

$$\Omega \equiv \vec{t} \cdot (\vec{k_1} \times \vec{k_2})$$

where $\vec{t}$ is a unit vector along the jet axis, corresponding to the spin direction of a longitudinally polarized parton which produced the jet, $\vec{k_1}$ and $\vec{k_2}$ are the momenta of two particles in the jet chosen by some prescription, *e.g.* the two fastest particles, and the calculation is done in some rest frame. In analogy with the strong decay of the a_1 meson, it is argued [3] that a signal might be maximized for triplets of pions nearby in rapidity in which an oppositely charged pair has invariant mass near the ρ mass. The unpaired track along with the oppositely charged track in the pair would then be used to calculate Ω in the 3-pion rest frame. It is also argued that a polarization signal is more likely to be visible in leading tracks.

Recently Ryskin proposed [4] a model of the transport of parton polarization in the context of a string fragmentation scheme. In this model a spinning quark or antiquark at the end of an expanding color-string emits a color magnetic dipole field, which can interact with the $q\bar{q}$ pairs created in string breaks. Since the q and $\bar{q}$ have opposite momentum transverse to the string direction and opposite color charge, this interaction imparts equal momentum kicks perpendicular to the plane containing the string and their original p_t. This results in a nonzero Ω in the laboratory frame if $\vec{k_1}$ and $\vec{k_2}$ are the momenta of two hadrons containing quarks from the same string breakup.

A jet may be defined as left-(right-)handed if Ω calculated by some method is negative (positive). For an ensemble of jets the handedness is defined as the asymmetry in the number of left- and right-handed jets:

$$H \equiv \frac{N_{\Omega<0} - N_{\Omega>0}}{N_{\Omega<0} + N_{\Omega>0}}. \tag{1}$$

It can then be asserted that $H = \alpha P$, where P is the average polarization of the underlying partons in the ensemble of jets, and α is the analyzing power of the method. The polarization of an outgoing fermion f in $e^+e^- \to Z^0 \to f\bar{f}$ is given at tree level in the Standard Model [5] by

$$P_f(\theta) = -\frac{A_f(1+\cos^2\theta) + 2A_Z\cos\theta}{1 + 2A_fA_Z\cos\theta + \cos^2\theta}, \tag{2}$$

where $A_Z = (A_e + P_{e^-})/(1 + A_eP_{e^-})$, A_f are the SM asymmetries, ($A_e = -0.16$, $A_u = -0.67$ and $A_e = -0.94$), P_{e^-} is the polarization of the electron beam and θ is the polar angle of the outgoing fermion with respect to the electron beam. The outgoing antifermion has opposite polarization, $P_{\bar{f}}(\theta) = -P_f(\theta + \pi)$. In hadronic events it is therefore necessary to distinguish quark from antiquark jets in order to measure a handedness signal.

One way around this is to order the tracks used in the triple product by charge, *i.e.* $\Omega \equiv \vec{t} \cdot (\vec{k_+} \times \vec{k_-})$. This has the effect of flipping the sign of Ω in antiquark jets to be the same as in quark jets of the same flavor. The up- and down-type quarks have opposite charges, however the net effective parton polarization, $P_{chg} = 2R_uA_u - 3R_dA_d = 0.39$, where R_j is the fraction of hadronic Z^0 decays into $j\bar{j}$, is large since there are more down-type quarks in Z^0 decays and their SM asymmetry is larger. For large electron beam polarizations, the net polarization of partons is independent of flavor, but depends on θ, $P_{pol} = -2A_Z\cos\theta/(1+\cos^2\theta)$, and is large, reaching 0.71 (0.51) at large $\cos\theta$ for the 1993 SLC beam polarization of $-(+)0.62$. This alternative provides the important cross-checks that measured polarization of jets in the forward and backward hemispheres with respect to the electron beam direction should have opposite sign for a given beam polarization, and that measured polarizations should change in both sign and magnitude for negatively vs. positively polarized electron beam.

here we present the preliminary results of a search for handedness using the methods suggested in [2, 3], which we also generalize to use a larger number of the tracks in each jet. We then present an alternative analysis following [4]. In each case we have used both the charge-signed and polarized methods of defining jet handedness, and have varied cuts over wide ranges. In addition, we have divided our data cleanly into samples of light (u, d, s) and heavy (b, c) quark events according to the method described in [6]. A handedness signal may be diluted in heavy quark events, since most leading tracks are from the decays of spinless mesons, and Dalitz *et al.* have concluded [7] that any effect resulting from D^* or B^* decays should be very small.

2 Experimental Method

The SLD is a multi-purpose detector and is described in [8]. The analysis presented here is based on charged tracks measured in the central drift chamber and vertex detector. Tracks were required to have (i) a closest approach to the beam axis within 5 cm, and within 10 cm along the beam axis of the measured interaction point; (ii) a polar angle θ with respect to the beam axis with $|\cos\theta| < 0.80$, and (iii) a minimum momentum transverse to this axis of $p_\perp > 150$ MeV/c. Events were required to contain a minimum of five such tracks, a thrust [9] axis direction with respect to the beam axis, θ_T, within $|\cos\theta_T| < 0.71$, and a minimum charged visible energy $E_{vis} > 20$ GeV, where all tracks were assigned the charged pion mass.

Two-jet events were selected using the JADE clustering algorithm [10] at $y_{cut} = 0.03$, and the jet acollinearity angle was required to be less than 20°. From our 1993 data sample 30,314 events passed these cuts, of which 17,438 were assigned to the light quark sample.

2.1 Method A

Following [3] we first considered the three highest momentum tracks in each jet in their rest frame as long as they had net charge ± 1. The invariant mass of both opposite charge pairs was required to be in the range $0.6 < m < 1.6$ GeV. The tracks making up the higher mass pair were used to calculate $\Omega_{chg} = \hat{t} \cdot (\vec{k_+} \times \vec{k_-})$ and $\Omega_{pol} = \hat{t} \cdot (\vec{k_1} \times \vec{k_2})$, where $|k_1| > |k_2|$ and $\hat{t}$ is the thrust axis signed so as to point along the jet direction. The handedness was then calculated according to eqn. (1) separately, in the case of the polarized analysis, for positive and negative electron beam polarization and for forward ($\hat{t}_z > 0$) and backward jets. The analyzing power was calculated from $\alpha = H/P$ where the appropriate expected parton polarization P was averaged over our acceptance in $\cos\theta$ for that sample. The analyzing powers of the four polarized samples were then combined. Preliminary results are summarized in table 1. In all cases, the measured handeness and analyzing power are consistent with zero. We therefore set upper limits at the 95% confidence level on the magnitude of the analyzing power, also shown in table 1. All results were found insensitive to variations in the event and track selection criteria.

We then generalized this method to use the N_{lead} fastest particles in each jet. We considered all opposite charge pairs i,j among these N_{lead} particles, without imposing mass cuts, and calculated Ω^{ij}_{chg} and Ω^{ij}_{pol} for each pair in the N_{lead}-particle rest frame. The Ω^{ij} were then averaged to give Ω^{jet}_{chg} and Ω^{jet}_{pol}. Figure 1 shows the measured handedness as a function of N_{lead} for the light quark sample using the polarized method. In all cases the measured handedness is consistent with zero and we set 95% upper limits on the magnitude of the analyzing power, shown in fig. 2a(b) for the charge-signed (polarized) method. The limits are similar to the original analysis for $N_{lead} \leq 10$, where statistics begin to decrease.

Sample	Expected Polarization	Analyzing Power α (%) All jets	Light Jets	Heavy Jets
Charge Signed:	0.39	-2.7±2.0	-0.4±2.7	-5.3± 3.1
Polarized:				
$P_{e^-} < 0, \hat{t}_z > 0$	−0.43	2.2±4.4	3.0±5.9	1.3± 6.8
$P_{e^-} > 0, \hat{t}_z > 0$	+0.31	-2.1±6.6	-2.2±8.9	-2.0± 10.2
$P_{e^-} < 0, \hat{t}_z < 0$	+0.43	3.8±4.4	4.6±5.9	2.9± 6.8
$P_{e^-} > 0, \hat{t}_z < 0$	−0.31	8.7±6.6	11.9±8.9	5.0± 10.2
Combined		2.3±2.6	4.1±3.5	0.5± 4.0
		Upper Limit on $\|\alpha\|$ (%)		
Charge Signed:		6.6	5.7	11.4
Pol. Combined:		7.3	11.0	8.3

Table 1: Preliminary measured analyzing powers in % of jet handedness using method A, and the associated upper limits at 95% C.L. on the magnitude.

2.2 Method B

Following [4] we attempted to select pairs of tracks likely to contain quarks from the same string breakup. In studies using the JETSET [11] Monte Carlo we found one variable to be useful for this, namely the relative rapidity of tracks in a pair with respect to the jet axis. Requiring opposite charge does not improve the selection, but was used in the charge-signed analysis. In each jet the tracks were ordered in rapidity and assigned a number $n_i = 1...n_{tracks}$, where $n = 1$ for the track with highest rapidity. We then required pairs of tracks i,j to have $|n_i - n_j| < \Delta$ and $\max(n_i,n_j) \leq n_{max}$. Since the signal is expected to increase with momentum transverse to the thrust axis, we also required $|p_{ti}| + |p_{tj}| > p_0$. We calculated Ω^{ij}_{chg} and Ω^{ij}_{pol} in the lab frame for each pair passing the cuts and averaged them to obtain Ω^{jet}. The cuts, Δ, n_{max}, and p_0 were varied in an attempt to maximize the handedness signal.

In no case do we find evidence for non-zero jet handedness. Figure 3 shows the 95% C.L. upper limit on the magnitude of the analyzing power a) vs. Δ and b) vs. p_0. For loose cuts we again have limits in the vicinity of 6% for the full sample and about 10% for the light and heavy samples, however statistics are poor in the more interesting, high-p_0 region.

3 Conclusions

We have searched for evidence of parton polarization in hadronic Z^0 decays using two jet handedness techniques and wide variation of parameters. In each case we employed both charge-signed and polarized analyses, and sought signals in samples of

light and heavy quark jets as well as in the global sample. We found no evidence for a non-zero jet handedness by any method. We are continuing our investigation of jet handedness, and look forward to more data with higher electron beam polarization in upcoming runs.

Figure Captions

1. Measured jet handedness vs. N_{lead} for the light quark sample and the polarized method. In (a) $P_{e^-} = -0.62$ and (b) $P_{e^-} = +0.62$ the open squares are the forward jets and the triangles are the backward jets.

2. 95% C.L. upper limits on the magnitude of the analyzing power of the jet handedness method described in the text vs. N_{lead} for (a) the charge-signed method and (b) the polarized method. In each case, the squares are for the entire data sample and the circles and triangles are for the light and heavy quark sample respectively.

3. 95% C.L. upper limits on the magnitude of the analyzing power of the jet handedness method described in the text vs. (a,c) Δ and (b,d) p_0, for (a,b) the charge-signed and (c,d) the polarized method. In each case, the squares are for the entire data sample and the circles and triangles are for the light and heavy quark sample respectively.

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Figure 1a

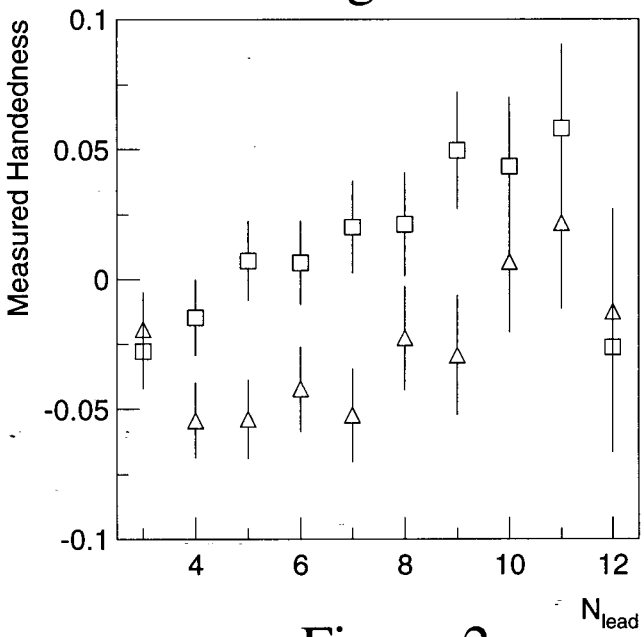

Figure 1b

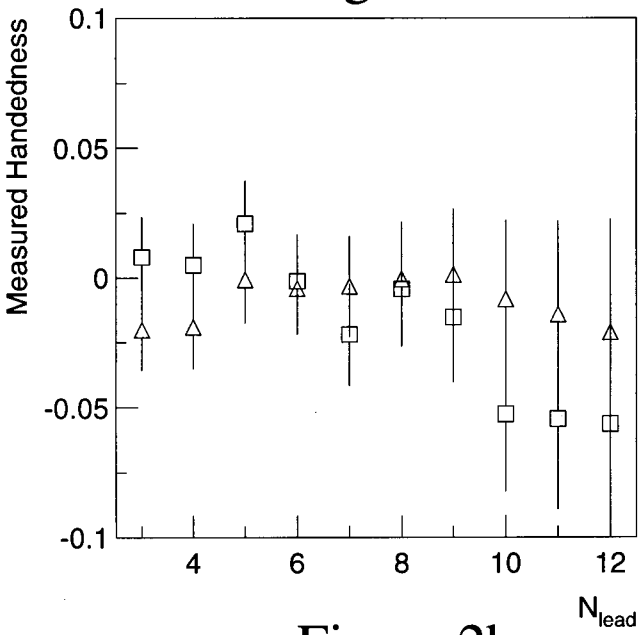

Figure 2a

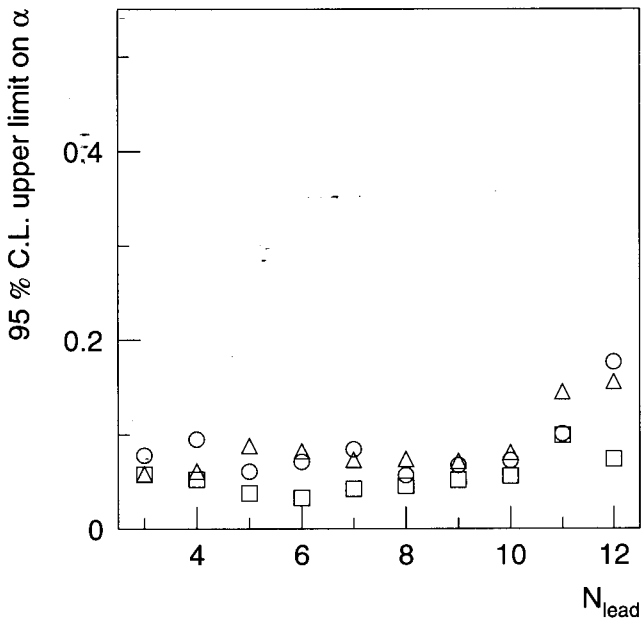

Figure 2b

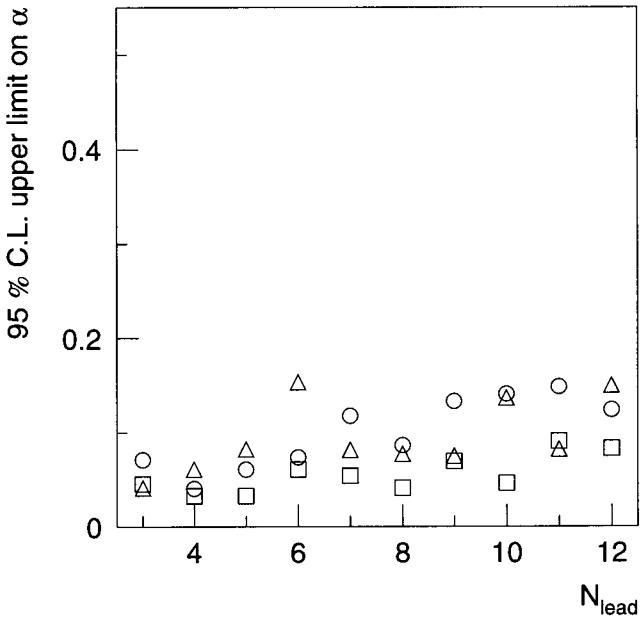

Figure 3a

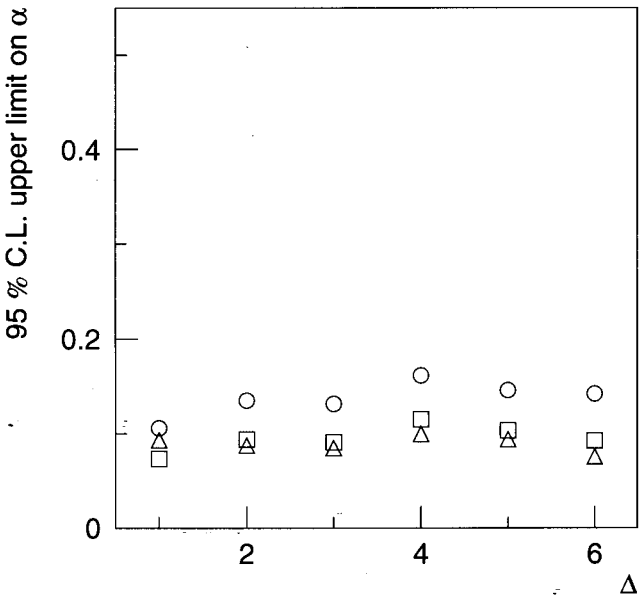

Figure 3b

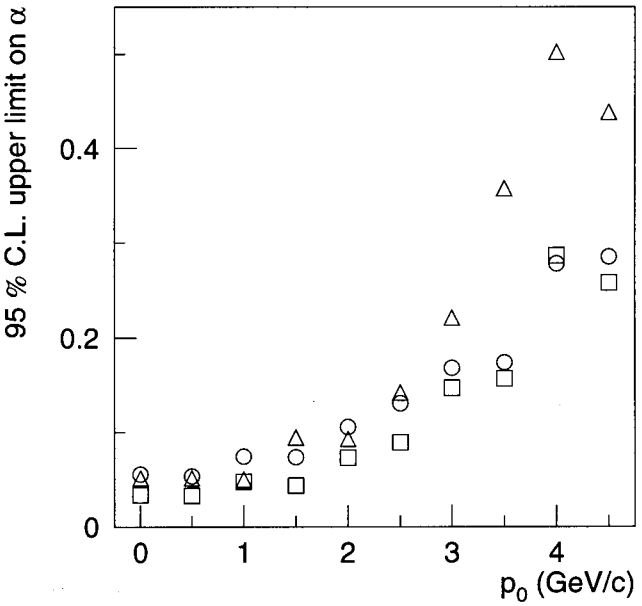

Figure 3c

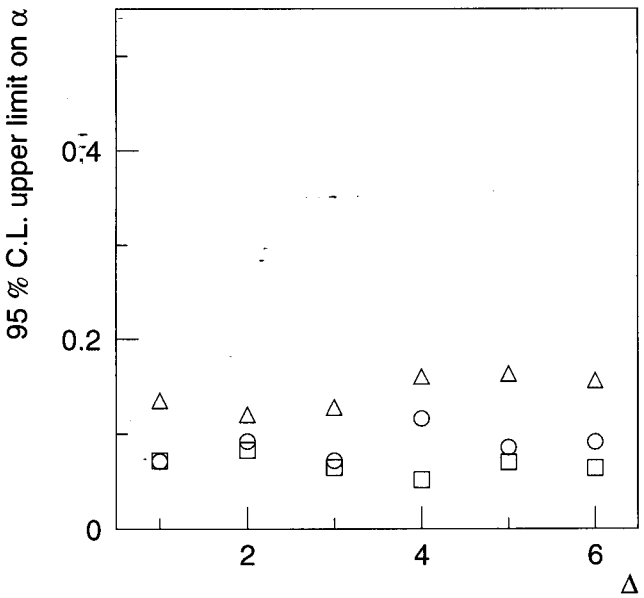

Figure 3d