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A Search for Jet Handedness in Hadronic Z^0 Decays*

The SLD Collaboration

Stanford Linear Accelerator Center,
Stanford University, Stanford, CA 94309, USA

Represented by

Y. Hasegawa

Department of Physics, Tohoku University,
Sendai 980-77, Japan

We have searched for signatures of polarization of partons in hadronic jets from $Z^0 \to q\bar{q}$ decays using the 'jet handedness' method. We find no evidence for jet handedness in a sample of light quark jets. We set an upper limit of 9.1% on magnitude of the analyzing power of this technique at the 95% C.L. We have studied an alternative definition of jet handedness and found no signal.

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 collisions is observable via the final-state fragmentation products in the resulting jet. The Z^0 resonance is an ideal place to study this issue as the fermions in Z^0 decays are predicted by the Standard Model (SM) [1] to be highly longitudinally polarized. If a method of observing such polarization were developed, it could be applied to jets produced in a variety of hard processes, elucidating the spin dynamics of the underlying interactions. Nachtmann [2] and Efremov *et al.* [3] have speculated that the polarization of the underlying quarks may be observable inclusively via a triple product of track momenta in jets. Arguing that quark fragmentation may resemble an n-body strong decay, they note that the simplest spin-sensitive observable has the form:

$$\Omega \equiv \hat{t} \cdot (\vec{k_1} \times \vec{k_2}) \tag{1}$$

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where $\hat{t}$ is a unit vector along the jet axis, corresponding to the spin direction of a longitudinally polarized quark which produced the jet, and $\vec{k_1}$ and $\vec{k_2}$ are the momenta of two particles in the jet chosen by some method and taken in some suitable frame.

A jet may be defined as left- or right-handed if Ω is negative or positive respectively. For an ensemble of jets the jet handedness H is defined as the asymmetry in the number of left- and right-handed jets:

$$H \equiv \frac{N_{\Omega<0} - N_{\Omega>0}}{N_{\Omega<0} + N_{\Omega>0}}. \tag{2}$$

It can then be asserted that

$$H = \alpha P \tag{3}$$

where P is the expected polarization of the underlying partons in the ensemble of jets, and α is the analyzing power of the method.

Polarization

In the process $e^+e^- \to Z^0 \to f\bar{f}$ the polarization of an outgoing fermion f is given at tree level in the SM by

$$P_f(\theta) = -\frac{A_f(1+\cos^2\theta) + 2A_Z\cos\theta}{1 + 2A_f A_Z \cos\theta + \cos^2\theta} \tag{4}$$

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where $A_Z = (A_e + P_{e^-})/(1 + A_e P_{e^-})$, $A_e \simeq -0.16$, $A_{u,c} \simeq -0.67$ and $A_{d,s,b} \simeq -0.94$. P_{e^-} is the polarization of the electron beam and θ is the polar angle of the outgoing fermion with respect to electron beam. The outgoing antiferimon has opposite polarization. In hadronic events it is therefore necessary to distinguish quark from antiquark jets in order to measure a handedness signal.

There are two ways to do this. One is the "helicity-based" method in which the tracks used in the triple product are ordered by momenta, *i.e.* $\Omega \equiv \vec{t} \cdot (\vec{k_>} \times \vec{k_<})$ where $|\vec{k_>}| > |\vec{k_<}|$. For this method the expected polarization of partons is independent of flavor, but depends on θ, $P_{hel} = -2A_Z \cos\theta/(1+\cos^2\theta)$. And it reaches $\mp 0.72(\pm 0.52)$ at $\cos\theta = \pm 1$ for the 1993 SLC beam polarization of -0.63 ($+0.63$). Another alternative called the "chirality-based" method orders the tracks by charge, *i.e.* $\Omega \equiv \vec{t} \cdot (\vec{k_+} \times \vec{k_-})$. The sign of Ω_{chi} in antiquark jets is the same as that in quark jets of the same flavor and opposite polarization. The expected polarization is given by A_f for a given flavor. The up- and down-type quarks have opposite charges, so that one might expect an effective parton polarization, $P_{chi} = 2R_u A_u - 3R_d A_d \simeq 0.39$, where $R_u \simeq 0.17$and $R_d \simeq 0.22$ are the SM fractions of hadronic Z^0 decays into $u\bar{u}$ or $c\bar{c}$ and $d\bar{d}$ or $s\bar{s}$ or $b\bar{b}$, respectively.

Measurements

Here we present the results of a search for jet handedness using a sample of $\sim 50,000$ hadronic Z^0 decays collected by the SLD experiment [4] in 1993. We have performed two analyses suggested in [3,5] and [6]. In each case we used both helicity- and chirality-based methods of defining Ω and hence H. A handedness signal may be diluted in heavy quark events ($Z^0 \to c\bar{c}, b\bar{b}$), since many tracks are from decays of spinless heavy mesons, and Dalitz *et al.* have concluded [7] that any effect resulting from D^* or B^* decays should be very small. We therefore used a light-quark(u, d, s) sample and sought evidence for polarization.

The trigger and initial selection of hadronic events is described in [8]. The analysis presented here is based on charged tracks measured in the central drift chamber and vertex detector. 2-jet events were selected using the JADE clustering algorithm [9] at $y_{cut} = 0.03$, with the requirement that the jet acollinearity angle be less than 20°. Events of light (u, d or s) quark origin were selected based on impact parameters of charged tracks measured in the vertex detector. The 9,977 events containing no track with impact parameter transverse to the beam axis more than 3σ from the collision point were selected. The purity of the sample was estimated from simulations to be 85%.

Following [5] 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/c^2 The tracks making up the higher mass pair were used to calculate $\Omega_{hel} = \hat{t} \cdot (\vec{k_>} \times \vec{k_<})$ and $\Omega_{chi} = \hat{t} \cdot (\vec{k_+} \times \vec{k_-})$, where $\hat{t}$ is the thrust [10] axis signed so as to point along the jet direction. The handedness was then calculated according to Eqn.(2) separately, in the case of the helicity-based method, 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 samples were then averaged. Preliminary results are summarized in Table 1. In all cases, the measured handedness and the analyzing power are consistent with zero. We therefore set upper limits at 95% confidence level on the magnitude of the analyzing power, also shown in Table 1.

Following [6] 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 chirality-based method. In each jet the

Method	Expected Polarization	$H(\%)$	$\alpha(\%)$	(Averaged)	Upper Limits on $\alpha(\%)$
Helicity:					
$P_{e^-} < 0, \hat{t_z} > 0$	-0.44	$+2.1 \pm 2.5$	-4.7 ± 5.8	-3.4 ± 3.4	9.1
$P_{e^-} < 0, \hat{t_z} < 0$	$+0.44$	-5.1 ± 2.5	-11.7 ± 5.8		
$P_{e^-} > 0, \hat{t_z} > 0$	$+0.32$	$+3.2 \pm 2.8$	$+10.0 \pm 8.9$		
$P_{e^-} > 0, \hat{t_z} < 0$	-0.32	-1.5 ± 2.8	$+4.7 \pm 8.8$		
Chirality:	$+0.39$	-0.8 ± 1.3	-2.0 ± 3.4		7.8

Table 1: Preliminary measured jet handedness, H, analyzing power, α and the associated upper limits at 95% C.L. on the magnitude.

tracks were ordered in rapidity and assigned an integer number $n_i = 1, ..., n_{tracks}$, where $n_i = 1$ for the track with highest rapidity. We then required pairs of tracks i, j to have $|n_i - n_j| < \Delta n$ 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 $|p_{ti}| + |p_{tj}| > p_{min}$. We calculated Ω^{ij}_{hel} and Ω^{ij}_{chi} in the lab frame for each pair passing the cuts and averaged them to obtain Ω_{hel} and Ω_{chi}. The cuts, $\Delta n, n_{max}$ and p_{min} were varied in an attempt to maximize the handedness signal.

For both analyses we found no evidence for non-zero jet handedness. We obtained upper limits in the range 5-9% for all n_{max} and Δn for $p_{min} \leq 2$ GeV/c. Statistics become poor in the potentially interesting high-p_{min} region.

A number of systematic checks was performed for each method. All results were found to be insensitive to the track and event selection cuts, and to the jet-finding algorithm and y_{cut} values used to select 2-jet events. Each analysis was found to be insensitive to the values of the selection criteria for tracks used to define Ω. Each analysis was performed on samples of Monte Carlo events in which no spin transport was simulated; all H were consistent with zero, implying that any analysis bias is below 1%.

Conclusions

We have searched for evidence of quark polarization in hadronic Z^0 decays using two jet handedness techniques. In an attempt to optimize a signal we studied a wide range of parameters for each technique. In each case we employed both helicity- and chirality-based methods, and restricted the sample to light quark jets. We found no evidence for a non-zero jet handedness, implying that the transport of quark polarization through the jet fragmentation process in small. We derive upper limit in the range 5-9% on the magnitude of the analyzing power for the methods presented here.

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