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\[\nu_\tau \text{ helicity from } h^\pm \text{ energy correlations}\]


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We report a measurement of the magnitude of the $\nu_\tau$ helicity from $\tau$-pair events taken with the CLEO detector at the CESR electron-positron storage ring. Events in which each $\tau$ undergoes the decay $\tau \rightarrow h \nu$, with $h$ a charged pion or kaon, are analyzed for energy correlations between the daughter hadrons, yielding $|\xi_h| = 1.03 \pm 0.06 \pm 0.04$, with the first error statistical and the second systematic. [S0556-2821(97)05311-3]

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\[ d^2\sigma/dx_+dx_- = F_1(x_+,x_-) + \xi_h^2F_2(x_+,x_-), \]  

with $F_{1,2}$ being known kinematic functions. This correlation is maximal and identical for a left-handed ($\xi_h = -1$) and a right-handed ($\xi_h = +1$) $\nu_\tau$, and it vanishes for no preferred handedness ($\xi_h = 0$). It is not explicitly parity violating but is a consequence of parity violation in $\tau$ decay.

The data analyzed here correspond to a luminosity of 1.64 fb$^{-1}$ (1.5x10$^6$ $\tau^+\tau^-$ events), collected at the Cornell Electron Storage Ring (CESR) with the CLEO II detector [10]. A set of three concentric drift chambers in a 1.5 T axial magnetic field measures charged particle momenta with resolution $\sigma_p/p(\%) = \sqrt{(0.15p) + (0.5)^2} / p$ in GeV/c. Surrounding the drift chambers, but inside the superconducting magnet coil, is a CsI(Tl) crystal electromagnetic calorimeter. Barrel crystals surround the tracking chambers, covering $|\cos \theta| < 0.82$, with $\theta$ the angle with respect to the $e^+\text{ beam}$ direction. Two identical end caps occupy $0.80 < |\cos \theta| < 0.98$. Particle time of flight is provided by 5-cm-thick scintillation counters located just inside the calorimeter in the barrel and end cap. Muons are identified by their penetration through the calorimeter, coil, and one or more of three 36-cm-thick slabs of magnet iron; three layers of faroccii tube chambers instrument the gap behind each slab. A three-stage hardware trigger [11] uses combinations of calorimeter, tracking chamber, and time-of-flight information to initiate detector readout.

To measure $|\xi_h|$ we first extract $\tau^+\tau^- \rightarrow (h^+\bar{\nu})(h^-\nu)$ events that are relatively free of backgrounds from non-$\tau$ processes. Monte Carlo samples of events from $V$ and $V^{\pm A}$ processes are then generated and mixed appropriately to obtain a desired value of $\xi_h$. We determine what value of $\xi_h$ best fits the data using likelihood and $\chi^2$ methods, investigating both two-dimensional ($x_+,x_-$) and one-dimensional ($c_+,c_-$) distributions. The techniques are then analyzed for systematic biases and uncertainties.

Events are selected that have exactly two oppositely charged tracks in the fiducial volume of the tracking system with $|\cos \theta| < 0.7$ and $x_+ > 0.2$ and which project back to the $e^+e^-$ luminous region. To reduce the contamination of non-$\tau\tau$ QED events, we demand that at most one track have $x_+ > 0.8$, that neither track have $x_+ > 0.95$, and that the total
shower energy in the calorimeter be less than 0.85\sqrt{s}. To remove backgrounds from final states that involve electrons, each track must have its calorimeter energy less than 85% of its measured momentum.

Final states that contain photons from neutral pions are suppressed by demanding that there be no photonlike showers in the calorimeter that are not matched to charged tracks. A combination of energy and isolation criteria is used to identify such showers. This requirement also greatly reduces the contamination from events with a single photon, such as from the process $e^+e^- \rightarrow \gamma\gamma$. To suppress these radiative events further the two charged tracks are required to have an opening angle of greater than 90$^\circ$ in the $r$-$\phi$ projection. To minimize possible systematic effects, events must satisfy trigger criteria that are suitable for two-track events and that are uniform throughout the data set.

The most effective variable for removing events from $\gamma\gamma$ interactions is $\Theta_{\text{min}}$, defined by

$$\sin\Theta_{\text{min}} = |\vec{p}_\perp|/E_b(2-x_+-x_-),$$

i.e., the ratio of $|\vec{p}_\perp|$, the missing net momentum transverse to the beams, to the missing energy of the event [12,13]. This requirement also effectively suppresses radiative QED events in which radiated photons go undetected. Events are retained if $\sin\Theta_{\text{min}} > 0.10$. Because particles from $\gamma\gamma$ interactions tend to have low momentum, at least one of the tracks is also required to have $x_+ > 0.3$.

Discrimination against muons involves four mutually exclusive criteria, three of which use information from the muon chambers and one of which demands the particle leave an energy deposition in the calorimeter that is inconsistent in magnitude and shape with that of a muon. This last criterion is invoked only if the charged track projects into uninstrumented regions at the azimuthal boundaries of the iron absorber. Each track must pass one of these four criteria for the event to be accepted. The efficiency of the combination of these criteria to select a track as a pion has been measured using an independent subsample of hadrons in $\tau^+\tau^-$ decays involving a lepton recoiling against one or more neutral pions and a single track that is assumed to be a charged pion or kaon [\cite{1}], $x_\pm \sim 0.2$ to 60% at $x_\pm \sim 0.25$, and reaches a plateau of about 70% by $x_\pm \sim 0.5$. Studies of radiative $\mu$-pair ($\mu\mu\gamma$) events in both data and simulation indicate a rate for misidentification of a muon as a pion of less than 2% per track over the kinematic range of this analysis.

These selection criteria result in 2041 $h^+h^-$ candidates. Simulations indicate that the overall signal efficiency is 9%, consistent with other CLEO $\tau$ analyses and our restrictive particle identification requirements. These candidates are binned in $x_+$ vs $x_-$ with a bin size of 0.1 and range $0.2 < x_+ < 0.95$, as shown in Fig. 1. The missing corner bins at $x_+=x_-$ are the result of the energy criteria that help suppress $\gamma\gamma$ events and QED events. This figure clearly shows the depletion in the other corners that have one “hard” and one “soft” hadron, as expected for $V\pm A$. Using the measured momenta and assuming the energy of each $\tau$ to be the beam energy we determine $c_+$ and $c_-$ for each event. The distribution of the product $c_+c_-$ exhibits a logarithmic divergence at zero, as seen in Fig. 2.

The Monte Carlo simulations start with the KORALB [14] $\tau$-pair generator and use the GEANT package [15] to model the detector response. Monte Carlo studies indicate that over 97% of these events were of the five final states $\pi^+\pi^-\nu\overline{\nu}$ (81%), $\pi^+K^-\nu\overline{\nu}$ (9%), $\pi^+\rho^-\nu\overline{\nu}$ (4%), $\pi^-\mu^-\nu\overline{\nu}(\overline{\nu}/\nu)$ (2%), and $\pi^+K^+\nu\overline{\nu}$ (2%); the next leading mode was $\pi^+e^+\nu\overline{\nu}/(\nu/\nu)$ (0.8%). For these five specific decay channels, large samples were generated with both $(V-A)$ and pure $V$ coupling. In the case of $\pi^+\mu^-\nu\overline{\nu}(\overline{\nu}/\nu)$ events were also thrown with a $(V+A)$ coupling; for the other final states, the $(V+A)$ and $(V-A)$ predictions are identical. These events are then appropriately scaled to be added together for comparison to the data distributions. For each bin in either the $(x_+,x_-)$ or $c_+c_-$ analysis, the number of predicted events for any given value of $\xi_h$ is expressed in terms of the number from the $(V-A)$, $(V+A)$, and $V$ simulations by

$$n_j(\xi_h) = C_{-1}N_j^{V-A} + C_0N_j^{V+A} + C_0N_j^V,$$

with $C_{-1} = (\xi_h^2-\xi_h)/2$ and $C_0 = (1-\xi_h^2)$. A binned maximum likelihood fit in the one parameter $\xi_h$ is then performed, with the resulting likelihood distribution for the $(x_+,x_-)$ analysis shown in Fig. 3. The result is $|\xi_h|$.
studies with very large samples of simulated events
resolution functions instead of full detector simulation
for speed, had their kinematic variables smeared with typical
20% in these branching fractions produced changes in
the distributions in the $x_{\pm}$ plane. We therefore varied
the limit on $\sin\Theta_{\text{min}}$ down to 0.05 and up to 0.20, observing changes in the fitted
value of $<0.02$. Replacing the limit on $\sin\Theta_{\text{min}}$ with requirements
on acoplanarity or visible event energy (also effective
in suppressing $\gamma\gamma$ backgrounds, but less so) produced similar
changes in $|\xi_h|$, but of the opposite sign. An uncertainty
of $\pm 0.01$ was assigned to this effect.

Other event selection variables were also evaluated by
varying the requirements, leading to very small uncertainties.
An exception was the $h/\mu$ discrimination, for which we tried
using various subsets of the four criteria as well as changing
the limits in them individually, leading to an associated un-
certainty of $\pm 0.025$. Similarly we tightened and loosened
(where possible) the trigger requirements with effects ob-
served of $\pm 0.015$.

All of the efficiencies depend on the Monte Carlo simu-
lations. The most critical aspects of this are the photon veto
(for which hadronic splittings need to be properly modeled),
the $h/\mu$ discrimination, and the trigger. To investigate these
more thoroughly, samples of events were obtained in both
data and in Monte Carlo simulation for the $Y(h(n\pi^0)\to
h\mu)$ topology previously described. From these studies we obtained
$x_{\pm}$-dependent corrections to the efficiencies for all three
aspects of the analysis. Applying these indicated very small
shifts, some positive and some negative, in the fitted value of
$|\xi_h|$. Based on this we applied no shift in the central value
and assigned a systematic uncertainty of $\pm 0.01$.

Taking all the effects in quadrature yields an overall sys-
tematic uncertainty of $\Delta |\xi_h| = \pm 0.040$ for the $(x_+, x_-)$ analysis.
For the $c_+ c_-$ analysis, the biases shift the central value
to $|\xi_h| = 1.036$ with a systematic uncertainty of $\Delta |\xi_h| =
\pm 0.049$. Our quoted value for the helicity and its uncertain-
ties is the simple average of these two analyses.

In summary, we have measured the magnitude of the he-
cility of the $\nu_\tau$ from the energy-energy correlation in
$\tau^+ \tau^- \rightarrow (h^+ \nu)(h^- \nu)$ events, obtaining $|\xi_h| = 1.03$
$\pm 0.06 \pm 0.04$. This is consistent with the other measures of
the $\nu_\tau$ helicity [2--6]. Considering only $V$ and $A$
interactions, the physical bounds are $0 < |\xi_h| < 1$, and our result corre-
sponds to $|\xi_h| > 0.87$ at 95% C.L. From Eq. 5 this implies at
most 24% pure $V$ (or pure $A$) at 95% C.L.

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[2] ARGUS Collaboration, H. Albrecht et al., Z. Phys. C 58, 61 (1993). Using asymmetries in \( hh\nu \) decays, the signed result is \( \xi = -1.25 \pm 0.23 \pm 0.15 \).
[3] ARGUS Collaboration, H. Albrecht et al., Phys. Lett. B 337, 383 (1994). Using the final state \( \pi\nu \) yielded \( |\xi| = 1.022 \pm 0.028 \pm 0.030 \).
[4] ALEPH Collaboration, D. Buskulic et al., Phys. Lett. B 346, 379 (1995); 363, 265(E) (1995). For the \( \pi\nu \) mode their result is \( |\xi| = 0.987 \pm 0.057 \pm 0.027 \); combining all modes, the ALEPH result is \( |\xi| = 1.006 \pm 0.032 \pm 0.019 \).
[5] L3 Collaboration, M. Acciarri et al., Phys. Lett. B 377, 313 (1996). Averaging over \( \pi\nu \) and \( \rho\nu \) decays produced a value of \( |\xi| = 0.973 \pm 0.053 \pm 0.011 \).
[6] OPAL Collaboration, R. Akers et al., Z. Phys. C 67, 45 (1995). Using asymmetries in \( hh\nu \) decays yielded the signed result of \( \xi = -1.08^{+0.46+0.14}_{-0.41-0.25} \).
[16] Using the mean of this distribution, i.e., \( \langle c_+ c_- \rangle \), as the estimator gives \( |\xi| = 1.05 \pm 0.06 \). No systematic study of this zero-dimensional analysis was performed.