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MEASUREMENT OF THE ELECTROWEAK ASYMMETRY IN THE REACTION $e^+e^- \to \tau^+\tau^-$ at 29 GeV

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ABSTRACT

This paper reports the electroweak asymmetry in the reaction $e^+e^- \to \tau^+\tau^-$ at 29 GeV. The results came from data taken with the High Resolution Spectrometer at PEP corresponding to an integrated luminosity of 256 pb^{-1}. The 7372 observed events give $A_{\tau\tau} = -(4.4 \pm 1.4 \pm 0.5)\%$. Events selected in the central region of the detector measure a total cross section of $R_{\tau\tau} = 1.06 \pm 0.02 \pm 0.04$.

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The e^+e^- scattering reactions leading to final state lepton pairs $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \tau^+\tau^-$ provide clean tests of the Glashow-Weinberg-Salam theory of the electroweak interaction. Forward-backward asymmetries have been measured by many experiments[1], including the High Resolution Spectrometer (HRS) collaboration, for all three reactions.[2] In this paper we present updated results on the $e^+e^- \to \tau^+\tau^-$ reaction based on an integrated luminosity of 256 pb^{-1}.

The HRS detector has been described in detail elsewhere[3]. Features of the detector relevant for this analysis include charged-particle tracking over 90% of the solid angle in a solenoidal magnetic field of 16.2 kG, and measurement of electromagnetic shower energy with lead-scintillator calorimeters covering the angular intervals $|\cos\theta|<0.60$ (barrel) and $0.70<|\cos\theta|<0.96$ (endcap), where θ is the angle with respect to the beam direction. The momentum resolution for high momentum tracks at large angles is $\sigma_p/p \simeq 2 \times 10^{-3} \cdot p$ (p in GeV/c). The charge is unambiguously identified for $|\cos\theta|<0.90$. The 40 module barrel shower counter system has an energy resolution of $\sigma_E/E = 16\%/\sqrt{E}$ (E in GeV) and a time of flight resolution of $\sigma = 360$ ps. The energy resolution for the 40 module endcap system is $\sigma_E/E = 20\%/\sqrt{E}$.

The τ-pair production of $\sqrt{s} = 29$ GeV yields a final state with a clear back to back topology, allowing the events to be selected with little background. We restrict this analysis to cases in which the τ decays to one or three charged particles. In order to select the events with good efficiency, to limit detector biases, and to discriminate against backgrounds, all of the events were required to satisfy the following selection criteria: Each event had zero net charge and contained 2, 4 or 6 tracks, with 1 or 3 tracks in each hemisphere. The distance of closest approach of a track to the interaction point was less than 1 cm radially and less than 9 cm along the beam direction. The scalar sum of the charged momenta was between 7.25 GeV/c and 23.2 GeV/c. The background from Bhabha scattering was reduced by requiring that the total momentum of any jet be less than 13 GeV/c. Two photon contamination was minimized by requiring that the acollinearity angle between the two jets be less than 45°.

Additional selection criteria were applied separately to the two-prong, and to the four- and six-prong events. For two-prongs, the momentum of each track was required to be greater than 1 GeV/c. Non-instrumented regions of the detector were avoided by requiring that each track be at least 2 cm from the edge of the shower counter modules and lie in the angular region $|\cos\theta| < 0.55$. Cosmic rays were rejected by requiring that the time of flight of each track be within 3 ns of the expected time. To reject $e^+e^- \to e^+e^-e^+e^-$ and $e^+e^- \to e^+e^-$ events, no more than one track was allowed to deposit a shower energy larger than 3 GeV or greater than one half of its momentum, and the total shower energy was required to be less than 14.5 GeV. The backgrounds from $e^+e^- \to e^+e^-\mu^+\mu^-$ and $e^+e^- \to \mu^+\mu^-$ were rejected by requiring that if both tracks were consistent with being minimum ionizing particles, as seen in the shower counters, then the momentum of at least one track had to be greater than 5 GeV/c, and the momentum of each track had to be less than 11 GeV/c.

The additional selection criteria for four- and six-prong events were as follows: The thrust axis of the events was required to be in the angular region $|\cos\theta|<0.85$. A source of background in the four-prong events is radiative Bhabha scattering with the photon converting in the beam pipe: these events were rejected by requiring that no more than one track deposit a shower energy greater than 90% of its momentum. Low multiplicity hadronic events were reduced by requiring that for four prongs the invariant mass of the three-prong jets be less than 1.6 GeV/c^2; for six-prong events, the neutral energy was included in the mass calculation and the cut was set at 2 GeV/c^2. For six-prong events in addition, the scalar sum of the charged momenta was required to be greater than 12 GeV/c. These selections yielded 3167 two-prong, 2403 four-prong and 140 six-prong events.

The detection efficiencies and backgrounds have been estimated using a Monte Carlo simulation of the experiment. The simulation produced τ pair events according to the standard electroweak theory including α^3 QED corrections.(4) Each tau was allowed to decay according to the known branching ratios.(5)

Table I summarizes the event numbers, detection efficiency and a breakdown of the sources of background.

Table 1. Data, Detection Efficiency, and Background Summary

Event Topology	1 - 1	1 - 3	3 - 3
Number of Events	3167	2403	140
Detection Efficiency (%)	10.7 ± 0.11	28.0 ± 0.2	20.9 ± 0.6
Final State		Background Fraction (%)	
e^+e^-	< 0.1	-	-
$\mu^+\mu^-$	1.8 ± 0.1	-	-
$e^+e^-\mu^+\mu^-$	5.7 ± 0.3	-	-
$e^+e^-\ \tau^+\tau^-$	0.3 ± 0.1	0.8 ± 0.1	0.8 ± 0.7
$e^+e^-q\bar{q}$	-	< 0.2	-
$q\bar{q}$		4.9 ± 1.1	6.6 ± 2.3

The charge asymmetry was measured using three different techniques: by comparing the number of events in the forward and backward hemisphere, and by fitting the corrected angular distribution using both a minimum χ^2 and a maximum likelihood technique. The different techniques gave compatible results: we quote the result based on the maximum likelihood technique. The differential cross section is shown in Fig. 1 with the best fit curve. The result is $A_{\tau\tau} = -(4.4 \pm 1.4 \pm 0.5)\%$. The total number of events when corrected for the acceptance give $R_{\tau\tau} = 1.06 \pm 0.02 \pm 0.04$.

The standard model predicts the differential cross section, with the interference terms included, to be:

$$d\sigma/d\cos\theta = (\pi\alpha^2/2s)\left[(1 + \cos^2\theta) + A\cos\theta\right] ,$$

where

$$R_{\tau\tau} = 1 + 2\, g_v^\tau g_v^e \,\mathrm{Re}\,\chi \quad \text{and} \quad A = 4\, g_a^\tau g_a^e \,\mathrm{Re}\,\chi \quad .$$

The energy variation is contained in the χ term which is given by:

$$\chi = \left(4 \sin^2\theta_W \cos^2\theta_W\right)^{-1} \left[s/(s - M_Z^2 + iM_Z\Gamma_Z\right] \quad .$$

The charge asymmetry is then $A_{\tau\tau} = 3A/8R_{\tau\tau}$. The standard model values for the vector and axial-vector coupling constants are $g_v^\tau g_v^e = 0.25\ (1 - 4 \sin^2\theta_W)^2 = 0.036$ and $g_a^\tau g_a^e = 0.25$, for $\sin^2\theta = 0.22$, where θ_W is the Weinberg angle. Assuming a Z mass of 93 ± 2 GeV, the predicted values of $A_{\tau\tau} = -5.9\%$ and $R_{\tau\tau} = 1.00$. Our measurements are therefore consistent with these predictions.

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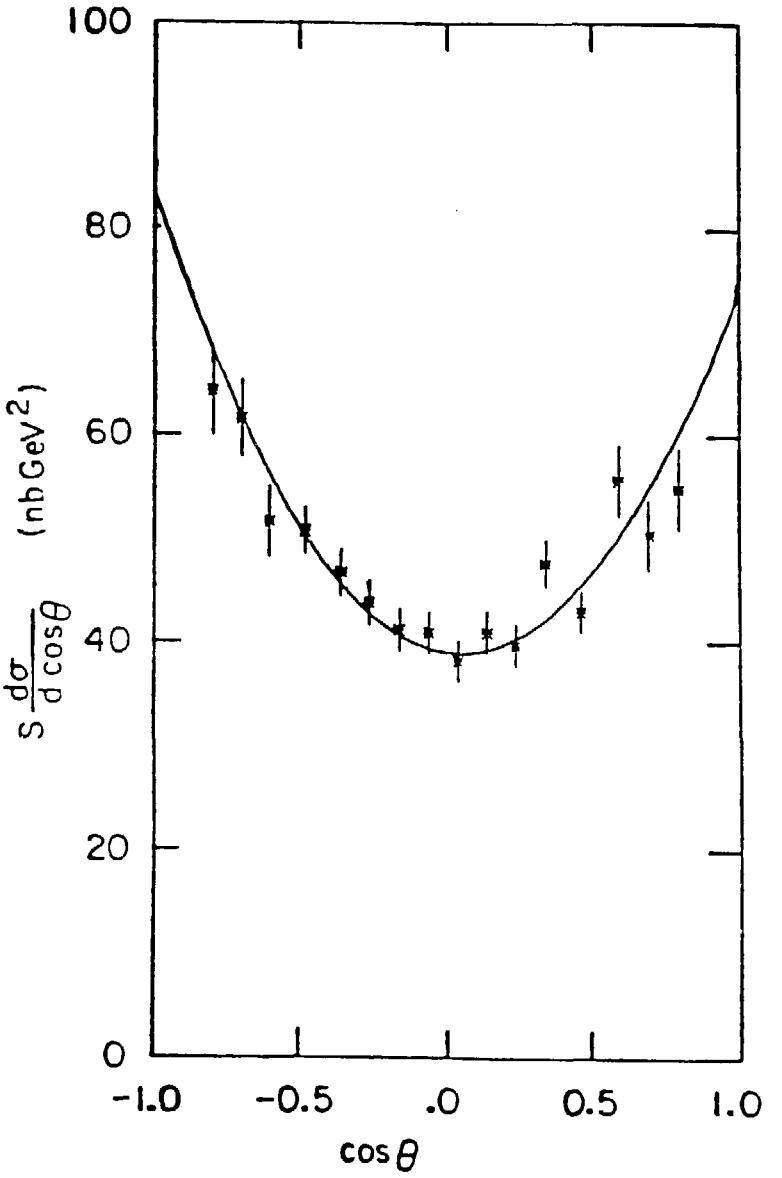

Figure 1. The differential cross section for the events of 1-1, 1-3, and 3-3 topologies. The curve is the best fit to the data including electroweak interference.