LIMITS ON THE WEAK ELECTRIC AND ANOMALOUS WEAK MAGNETIC DIPOLE MOMENTS OF THE TAU LEPTON

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We present preliminary measurements of the weak electric and anomalous weak magnetic dipole moments d_τ^w and a_τ^w of the τ lepton, as measured with the L3 Detector in Z decays at LEP. The measurements are based on asymmetries in angular distributions of the decays $\tau \to \pi\nu$ and $\tau \to \rho\nu$. Observed asymmetries are consistent with zero, and 95% C.L. limits are placed on d_τ^w and a_τ^w.

1 Theoretical Motivation and Definitions

Although the fundamental parameters of the electron and muon have been measured to high precision, knowledge of τ lepton properties is much less precise. We have undertaken a measurement of its weak electric and anomalous weak magnetic dipole moments d_τ^w and a_τ^w using $Z \to \tau^+\tau^-$ decays at LEP. Unexpected values for these dipole moments would indicate the effects of new physical processes. In particular, a non-zero d_τ^w would indicate a CP violating process. In some extensions of the Standard Model(SM), such dipole moments are enhanced for heavier leptons, making the τ a natural candidate for investigation[1]. In this measurement, the weak dipole moments are inferred from possible net transverse polarization of the τ pairs produced in Z decays. The transverse polarization is examined here via angular distributions of final-state hadrons from $\tau \to \rho\nu$ and $\tau \to \pi\nu$ decays. Experimental asymmetries are defined from which d_τ^w and a_τ^w are extracted.

We begin by defining an effective interaction Lagrangian to be added to the SM Lagrangian[1]:

$$L = \frac{1}{2}\frac{eF_2^w}{2m_\tau}\bar{\psi}\sigma_{\mu\nu}\psi Z_{\mu\nu} + -\frac{i}{2}\frac{eF_3^w}{2m_\tau}\bar{\psi}\gamma_5\psi Z_{\mu\nu}$$

where $Z_{\mu\nu} \equiv \partial_\mu Z_\nu - \partial_\nu Z_\mu$. The dipole moments are then $a_\tau^w \equiv F_2^w$ and $d_\tau^w \equiv \frac{eF_3^w}{2m_\tau}$. SM expectation for a_τ^w is $a_\tau^w \approx -(2.10 + 0.61\,i) \times 10^{-6}$. In the SM, d_τ^w is expected to be unobservably small. Indirect, model-dependent limits[2] can be set on these moments from the good agreement between measurements of and SM expectations for $\Gamma(Z \to \tau^+\tau^-)$: $|d_\tau^w| < O(10^{-17}\mathrm{e}{-}cm)$ and $|a_\tau^w| <$

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$O(10^{-2})$. In addition, direct limits[3,4] on d_τ^w have been obtained from the study of CP-odd observables: $|\mathrm{Re}(d_\tau^w)| < 7.8 \times 10^{-18}\, e$-cm and $|\mathrm{Im}(d_\tau^w)| < 4.5 \times 10^{-17}\, e$-cm. No previous direct limits on a_τ^w have been published.

Non-zero values for d_τ^w and a_τ^w would lead to non-zero average transverse polarizations of τ's produced in Z decay, with d_τ^w creating polarization normal to the τ production plane and a_τ^w creating transverse polarization within that plane[1]. As in measurements of longitudinal τ polarization, the $V-A$ coupling of τ decays is exploited to determine the net polarization. In one respect, measurement of transverse polarization is simpler than that of longitudinal because one merely counts decays in one hemisphere *vs.* another. In another respect, however, this measurement is more complicated because one must reconstruct the original $\tau^\pm$ directions from their decay products, as described below.

The differential cross section for τ production / decay in the presence of weak dipole moments can be written[1]: $d\sigma = d\sigma_{\mathrm{SM}} + X'_\pm \cos\phi_{h^\pm} + Y'_\pm \sin\phi_{h^\pm}$ where $X'_\pm = X'_\pm(\theta_{\tau^-}, F_2^w)$, $Y'_\pm = Y'_\pm(\theta_{\tau^-}, F_3^w)$, θ_{τ^-} is the polar angle of the τ^- w.r.t. the e^- beam direction, and $\phi_{h^\pm}$ is the azimuthal angle of the hadronic decay product (ρ or π) in a reference frame with the z axis along the τ^- direction and the x axis lying in the τ production plane. From these formulae, it is natural to define asymmetries in $\phi_{h^\pm}$. Following ref. 1, we define the asymmetries A_{SC} and A_{CC} between the ranges $[0 < \phi_{h^\pm} < \pi]$ and $[\pi < \phi_{h^\pm} < 2\,\pi]$ and between the ranges $[\frac{-\pi}{2} < \phi_{h^\pm} < \frac{\pi}{2}]$ and $[\frac{\pi}{2} < \phi_{h^\pm} < \frac{3\pi}{2}]$, respectively, where $A_{\mathrm{SC}} \to d_\tau^w$ and $A_{\mathrm{CC}} \to a_\tau^w$.

For A_{CC} there is a non-zero contribution not only from a_τ^w, but also from helicity-flipping tree-level terms, while A_{SC} should depend upon only d_τ^w. Treating $\rho^\pm$ and $\pi^\pm$ decays separately, one expects ideally:

$$\begin{array}{ll} A_{sc}^{\rho^-} = +A_{sc}^{\rho^+} = -3.8 F_3^w & A_{cc}^{\rho^-} = -A_{cc}^{\rho^+} = +5.0 F_2^w + 0.0003 \\ A_{sc}^{\pi^-} = +A_{sc}^{\pi^+} = -10.6 F_3^w & A_{cc}^{\pi^-} = -A_{cc}^{\pi^+} = +10.6 F_2^w + 0.0007 \end{array}$$

2 Method of Measurement

In order to measure the asymmetries defined above, we must know the direction of the $\tau^\pm$. Neglecting photon radiation, we assume that they are exactly opposite in direction, each carrying the full beam energy ($\approx M_Z/2$). With two missing neutrinos, each with three unknown momentum components, and with four constraints from energy / momentum conservation and two constraints from requiring $m_{h\nu} = m_\tau$, we have six unknowns and six equations relating them. This allows solution, but with a two-fold ambiguity. In the present analysis, we do not attempt to resolve the ambiguity. Instead we always choose the positive magnitude of an algebraic quantity whose sign reflects the ambiguity. As a result, the $\phi_{h^\pm}$ value reconstructed is incorrect approximately half the time, leading to an asymmetric resolution function for $\phi_{h^\pm}$. An important consequence is that the asymmetries $A_{\rm SC}$ and $A_{\rm CC}$ can receive contributions from <u>both</u> the F_2^w and F_3^w form factors.

Another experimental difficulty comes from imperfect detector resolution in determining the directions and especially the energies of the $\rho^\pm$ and $\pi^\pm$ candidates, which are reconstructed as described in ref. 5. In addition, both initial- and final-state photon radiation interfere with $\tau^\pm$ kinematic reconstruction. Together, resolution and radiation lead to more than a 40% loss in efficiency in the ρ-ρ, ρ-π, and π-π channels considered here. The effects of the reconstruction ambiguity, resolution, and efficiency have been simulated in detail and the relations among $A_{\rm SC}$, $A_{\rm CC}$, d_τ^w and a_τ^w corrected to include them. Systematic uncertainties from several sources have been considered. The most severe by far comes from the $\phi_{h^\pm}$ determination because of the asymmetric resolution function. In general, the observed distributions in data and Monte Carlo agree well, both in reconstruction of τ decays and of $\tau^\pm$ kinematics. Fractions of events in each channel and fractions of events successfully reconstructed also agree well between data and Monte Carlo.

We obtain the eight asymmetries given below, where the first error is statistical, and the second is systematic:

$A_{cc}^{\rho^-}$:	$-0.001 \pm 0.021 \pm 0.035$	$A_{cc}^{\pi^-}$:	$-0.015 \pm 0.029 \pm 0.063$
$A_{cc}^{\rho^+}$:	$+0.033 \pm 0.020 \pm 0.035$	$A_{cc}^{\pi^+}$:	$+0.037 \pm 0.029 \pm 0.063$
$A_{sc}^{\rho^-}$:	$+0.035 \pm 0.021 \pm 0.035$	$A_{sc}^{\pi^-}$:	$+0.017 \pm 0.029 \pm 0.063$
$A_{sc}^{\rho^+}$:	$-0.023 \pm 0.020 \pm 0.035$	$A_{sc}^{\pi^+}$:	$+0.029 \pm 0.029 \pm 0.063$

From these asymmetries we derive: $d_\tau^w = (-2.2 \pm 3.9) \times 10^{-17}\, e{\cdot}{\rm cm}$ and $a_\tau^w = -0.0025 \pm 0.0070$, and we obtain the following 95% C.L. limits:

$$\begin{array}{rcccl} -9.8 \times 10^{-17} e \cdot cm & < & d_\tau^w & < & 5.4 \times 10^{-17} e \cdot cm \\ -0.016 & < & a_\tau^w & < & 0.011 \end{array}$$

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