Searching for New Phenomena in the decays of the Tau Lepton.

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The study of the decays of the tau lepton may provide a window to physics beyond the standard model. The large datasets available at electron positron storage rings operating at $\sqrt{s}$=10.56 GeV make it possible to search for increasingly rarer phenomena. We review the basic search techniques and present several new results from the CLEO collaboration, each of which may be significantly improved with the even larger datasets and enhanced detection techniques available at the forthcoming B-factories.

1 Introduction.

The decays of the tau lepton can be used to search for new phenomena beyond the standard model of particle physics. As the third and most massive lepton the decays of the tau are particular sensitive to new interactions that couple to the third generation or to mass dependent couplings. The large dataset of 10^7 events now available, and soon to be significantly increased, allows these searches to be performed with unprecedented sensitivity. We begin with a brief description of the experimental facilities that provide these datasets and the techniques used in these searches. We then describe some recent results.

2 Experimental facilities.

The Cornell electron storage ring (CESR) collides equal energy beams of electrons and positrons at a center of mass energy of 10.56 GeV to produce tau pairs and the CLEO [2] experiment at CESR has to date accumulated a data set of 12 million events of which 4.5 million have been analyzed. The even higher luminosity upgrade of CESR due to commence in late 1999 will yield 14 million tau pairs per year. In addition the new electron storage rings at SLAC and KEK will also collide at a center of mass of 10.56 GeV and the BABAR(SLAC) [3] and BELLE (KEK) [4] experiments will each collect 28 million tau pairs per year at design luminosity.

At $\sqrt{s} = 10.56$ GeV the tau pairs are produced above threshold and recoil against each other in a two jet topology with a momentum of a few GeV. The tau decays to an odd number of charged particles, a neutrino and there may in addition be neutral particles. The signal definition is thus back to back hemispheres each with an odd number of charged tracks (1 vs 1, 1 vs

3 etc.) accompanied by missing energy. In most analysis these requirements are sufficient to remove all backgrounds except for other tau decays where one or more of the particles in the decay has not been detected or has been mis-identified.

3 Search for new lepton number violating interactions.

The tau lepton decays via the weak interaction which is empirically observed to be dominated by a vector-axial vector current structure (V-A). This means that it proceeds via left handed fermions coupling to a vector current. However the fundamental constraints of lorentz invariance and renormalizability allow for the possibility of the weak decays proceeding via left or right handed fermions coupling to a scalar,vector or tensor current. While the decay is predominantly V-A there may be additional small components indicative of a new lepton number conserving interaction. These new interactionchange the energy spectra and angular distributions of the decay products and can be inferred from the experimentally definable Michel parameters $(\rho, \eta, \xi, \delta)$ [5] and the neutrino helicity (h_ν). Using a pure sample of taus decaying to rho mesons or leptons and fitting the decay distributions to the most general decay hypothesis as predicted from a detailed and well tested monte-carlo CLEO has measured these parameters [6](table 1). The constraints on the current structure may then be inferred as shown in figure 1. There is no evidence for new interactions and while these measurements are the most sensitive to date we note that there is still substantial room for small admixture of new currents particularly in the scalar sector.

Table 1: Michel Parameters measured by CLEO

	Measured	Standard Model
ρ	0.747 ± 0.01 ± 0.006	0.75
η	-0.015 ± 0.061 ± 0.062	0.0
ξ	1.007 ± 0.04 ± 0.015	1.0
$\xi\delta$	0.745 ± 0.026 ± 0.009	0.75
h_ν	-0.995 ± 0.010 ± 0.003	-1.0

4 Search for the effects of a massive neutrino in tau decay.

The decay distributions of the tau lepton decay products are measurably altered if the neutrino in the decay has a mass in the MeV range. The classic technique is to measure the end-point energy spectrum (Kurie-plot). If the neutrino has mass the end-point is altered as shown in figure 2. Here the

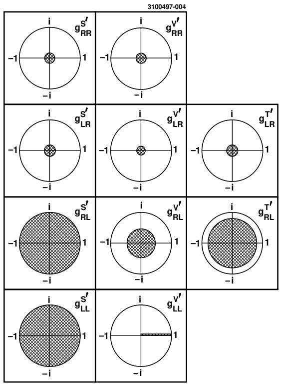

Figure 1: 90% Confidence limits on the coupling constants relative to the standard model strength, i.e g=1 vector is W coupling.

endpoint is measured in two dimensions to enhance sensitivity. The distortion of the endpoint is largest in decays with the large visible energy -i.e high multiplicity decays. CLEO has measured the endpoint spectrum for decays involving four and five charged and neutral pions. The data points are shown in the figure and the distribution is fit to the expected distribution as inferred from a monte-carlo assuming different neutrino mass hypothesis. No evidence of an MeV neutrino is found and the inferred constraints on the neutrino mass[7] are given in table 2.

Table 2: Neutrino mass limits from CLEO

Mode	m_{ν_τ} (95% C.L.)
$\pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau$	< 31 MeV
$\pi^-\pi^-\pi^+\pi^0\pi^0\nu_\tau$	< 33 MeV
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	< 26 MeV

5 Search for CP violation in tau decays.

CP violation is presumed to play a fundamental role in the evolution of a matter-antimatter asymmetric universe. However the standard model of CP violation is insufficient to account for the observed asymmetry. This motivates a search for CP violation beyond the standard model and explicitly in the lepton sector. We present the first such search for these phenomena. CP violation in lepton decay occurs by the introduction of a new CP violating

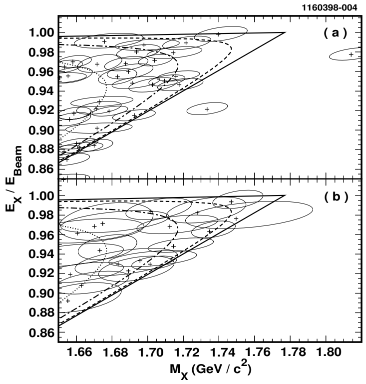

Figure 2: Endpoint Spectrum of Tau decay Products for a) $\tau \to \pi^-\pi^-\pi^-\pi^+\pi^+\nu_\tau$ and b) $\tau \to \pi^-\pi^-\pi^+\pi^0\pi^0\nu_\tau$.

charged current interaction (for example a charged Higgs of the Weinberg [8] model of CP violation) with coupling strength g with respect to the standard model and CP violating phase θ. The interference of the new interaction with the standard model results in a CP asymmetry in the decay angle distributions between τ^+ and τ^- decay products [9].The most favorable channel is $\tau \to K^*\nu$. A complication in the analysis is that detector effects can fake the signature by virtue of different efficiencies between positive and negative tracks. These effects are subtracted using a control sample where no CP violating effects are expected. Table 3 gives the measured asymmetries after subtraction and the monte-carlo expectation. No CP violation is observed and constraints [10] can be set on such interactions $-0.6 < g \sin\theta < 1.7$.

Table 3: Measured and expected CP asymmetries from CLEO

	A^- %	A^+ %
Measured	0.8 $\pm$3.7	-1.0 $\pm$ 3.9
Predicted	-1.6$\pm$0.1 $g\sin\theta$	+1.6$\pm$0.1 $g\sin\theta$

6 Search for Lepton number violating decays.

Lepton number conservation is not enforced by any fundamental symmetries but is rather an empirical observation. It can occur in many extensions to the standard model and in the most optimistic scenarios enters typically at branching ratios of $10^{-6} - 10^{-7}$. There are many possible modes. To illustrate we consider the decay $\tau \to \mu\gamma$. Super-string[11] models imply that $B(\tau \to \mu\gamma) = 2.10^5.B(\mu \to e\gamma)$ while experiment limits $B(\mu \to e\gamma) < 4.9.10^{-11}$. The absence of a neutrino in the decay means that the tau can be fully reconstructed and we plot the data in figure 3[12] in the $m_\tau, \delta E$ plane where $\delta E = E_{beam} - (E_\mu + E_\gamma)$. Three events are observed in the signal region where one would expect 5 events from standard model radiative tau decays ($\tau \to \mu\gamma\nu\nu$) to give a limit of $B(\tau \to \mu\gamma) < 3.0.10^{-6}$. Forty three other modes have also been searched with no positive results[1].

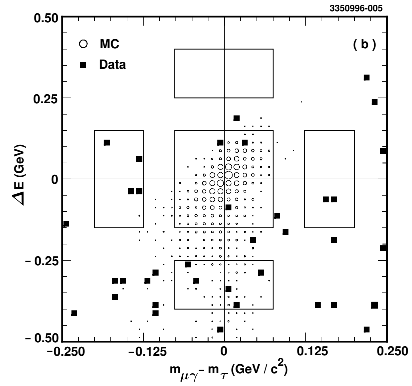

Figure 3: Energy-mass plane for $\tau \to \mu\gamma$. Black is data, white is monte-carlo. Sideband and signal regions are shown.

7 Conclusion.

We have presented the most sensitive searches for a variety of new phenomena in tau decays. In the near future we can expect substantial improvements in sensitivity due both to statistics and detector improvements.

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