BACKGROUND ESTIMATION IN e^+ e^- ANNIHILATIONS WITH LEPTON FLAVOR VIOLATION (LFV)

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*Abstract.*We search for lepton violating events (eμ, eτ, μτ) in e^+ e^- annihilations using the sample obtained with the L3 detector at LEP2 for energies between 189 and 209 GeV. Criteria have been established to select two lepton channels using Monte Carlo Standard Model events. The LFV signal has been evaluated in different supersymmetric models. Possible scenarios are for neutralino as the lightest superparticle (LSP) or gravitinos as LSP. In the channel e^+ $e^- \rightarrow \tau^+\tau^-$ the background is computed according to Standard Model predictions with subsequent τ disintegration. The contribution of the leptonic decay of taus in the LFV kinematic region is negligible. Specific cuts are applied to select eμ, eτ, μτ events. These cuts are pointing at minimizing the probability to misidentify electrons and muons with the decay products.

1. INTRODUCTION: LFV AT LEP

LEP1 (88 – 94 GeV) established limits for LFV in the reactions e^+ $e^- \rightarrow e^+$ e^-, $\mu^+\mu^-$, $\tau^+\tau^-$, at Z^0 pole (91.1882 GeV).

The limits of violation found by the four experiments at LEP are, for Z:

$$Z \rightarrow e^{\pm}\mu^{\mp} \qquad \Gamma_i / \Gamma < 1.7\ 10^{-6}$$
$$\rightarrow e^{\pm}\tau^{\mp} \qquad \Gamma_i / \Gamma < 9.8\ 10^{-6}$$
$$\rightarrow \mu^{\pm}\tau^{\mp} \qquad \Gamma_i / \Gamma < 1.7\ 10^{-5}$$

The smallest values have been obtained by the OPAL Collaboration [1]. The results are for integrated luminosities of about 5000 nb^{-1} for each channel (ee, μμ, $\tau\tau$) and correspond to a violation cross section of about 4 fb.

At LEP2 (189-209 GeV) the cross section for two lepton Z decay channels drops like 1/s. OPAL collaboration checked the LFV cross sections at an integrated luminosity of about 600 pb^{-1} and found the following limits [2]:

$$\sigma_{e\mu} < 50\, fb\,;\ \sigma_{e\tau} < 100\, fb\,;\ \sigma_{\mu\tau} < 100\, fb$$

The level of violation through Z^0 decay which has been detected is high.

With increasing energy there are other processes which can lead to LFV, namely the production of sleptons pairs.

Lately, supersymmetric models try to include the LFV phenomenon into a more general electroweak symmetry scenario.

2. LFV IN SUPERSYMMETRIC MODELS

Extensions of the Standard Model (SM) with weak scale supersymmetry have been widely studied. These models try to include neutrino mass and its oscillations,

weak decay processes with LFV (like $\mu \to e\gamma$), slepton production and the existence of the lightest supersymmetric particle (LSP), candidate for the dark matter in Universe.

The reaction candidates for LFV through slepton production are [3]:

$$e^+e^- \to \tilde{l}_i^-\tilde{l}_j^+ \to l_\beta^+ l_\alpha^- \tilde{\chi}_b^0 \tilde{\chi}_a^0 \quad (\beta \neq \alpha)$$
$$\to l_\beta^+ l_\alpha^- \tilde{\chi}_b^+ \tilde{\chi}_a^- \quad (\beta \neq \alpha)$$
$$\tilde{\chi}^\pm \to e^\pm \chi^0 \text{ (LSP)}$$

The signature of such reactions is two hard isolated leptons and missing energy or transverse momentum, assuming χ^0 is stable or long living.

The LFV signal appears in the slepton production with flavor mixing.

The background for this signal is given by W^+W^- and $\bar{t}t$ production and can be evaluated in the Standard Model.

There is also a background from two slepton flavor conserving reactions as well as from $\tilde{\tau}\tilde{\tau}^*$ production followed by leptonic decays of τ's.

With the mixing angle being maximal, the flavor violating dilepton signal is high, the same as for flavor conserving signal. For smaller mixing angle the flavor violation signal is significantly smaller and the background is unknown and may not be small.

The cross sections in fb for the signals ($e^\pm\mu^\mp E_T$, $e^\pm\tau^\mp E_T$, $\mu^\pm\tau^\mp E_T$) are given in figure 1 for different beam polarizations [4].
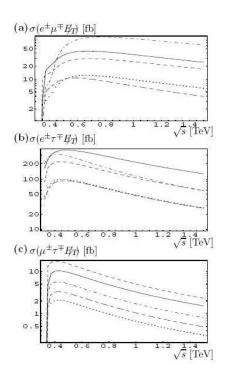
The cross section goes up to 250 fb for the $e^{\pm}\tau^{\mp}E_T$ channel at 500 GeV. This proves the interest in looking for the background in this channel.

3.   BACKGROUND PROCESS FOR LFV

Slepton disintegration ($\tilde{\tau} \to \mu\tilde{\chi}_0$) leads to an energetic muon distribution peaked at:

$$E_0 = \frac{m_{\tilde{\tau},\tilde{e}}^2 + m_{\mu,e}^2 - m_{\tilde{\chi}_0}^2}{2m_{\tilde{\tau},\tilde{e}}}$$

With SUSY parameter values [5], $E_0 \approx 89$ GeV.

In the laboratory system (LS) the energetic distribution is uniform between the limits:

$$E_{\mu,e}^{\max(\min)} = E_0(1 \pm \beta_{\tilde{\tau},\tilde{e}})\gamma_{\tilde{\tau},\tilde{e}}$$

with

$$\beta_{\tilde{\tau},\tilde{e}}^2 = 1 - \frac{4m_{\tilde{\tau},\tilde{e}}^2}{s} \text{ and } \gamma_{\tilde{\tau},\tilde{e}}^2 = \frac{1}{1 - \beta_{\tilde{\tau},\tilde{e}}^2}$$

Looking for LFV signals (τ e E_T, τ μ E_T) we should eliminate the background τ τ E_T with subsequent decay of τ : $\tau \to \mu(e) + \tilde{\upsilon}_e + \upsilon_\tau$.

Since the μ(e) energetic distribution is significantly softer than that of the τ leptons due to the energy shared with the two neutrinos, a cut in μ(e) leptons energy is very helpful.

Such a cut does not affect much the signal but increases dramatically the signal to background ratio.

Figure 2 shows the energetic distribution of electrons and muons from the τ decay in a reaction τ τ E_T simulated in the SM Monte Carlo program at 200GeV.
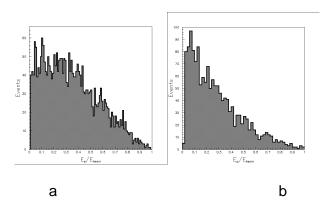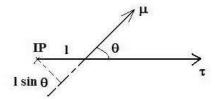

a   b

Fig. 2 - Energetic distribution of electrons (a) and muons (b) from τ decay in τ τ E_T reaction.

Another cut which improves the signal / background ratio is that in the impact parameter of the lepton. The meaning of this parameter is shown in figure 3.

Fig. 3 - Definition of the impact parameter for the decay $\tau \rightarrow \mu \tilde{\upsilon}_\mu \upsilon_\tau$

If the τ decays at the distance l and the muon direction makes an angle θ with the τ direction, the impact parameter is:

$$\langle l \sin\theta \rangle = c\tau_\tau \frac{\beta_\tau \left| p_T^0 \right|}{(p_\parallel^0 + \beta_\tau E^0)}$$

where $c\tau_\tau = 86.93 \mu m$, τ_τ is the lifetime in the rest system of τ; E^0, $p_\parallel^0$, $p_\perp^0$, are the energy and momentum components in the τ rest system and β_τ, γ_τ are the velocity and the Lorentz factor of τ in LS.
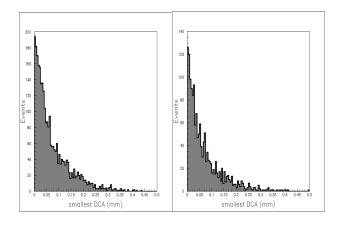
$$l = \gamma_\tau \beta_\tau c\tau_\tau \quad \text{and} \quad \tan\theta = \frac{p_\perp^0}{(p_\parallel^0 + \beta_\tau E^0)\gamma_\tau}$$

The distribution of the impact parameter is a convolution of the τ decaying length into μ(e) with the parent τ energy distribution.

We used instead the minimum distance of closest approach (DCA) distribution which has the same significance. It is shown in Figure 4 for electrons and muons from the τ decay.

The cut limit is given by the vertex resolution. The r.m.s error on SDCA at 45GeV was (110 ± 1) µm [6]. At higher energy we found $\approx 90 \mu m$.

In figure 5 we applied different cuts on min DCA at 50 µm and 100µm on electorn and muon energetic distribution.

Fig. 4 – Smallest DCA distributions for electrons (a) and muons (b) from the τ decay.

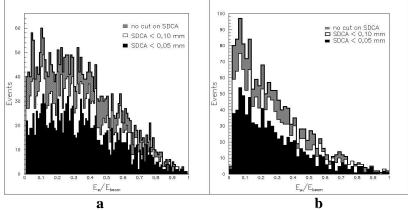a   b

Fig. 5 - Energetic distribution of electrons (a) and muons (b) from the τ decay with two cuts on SDCA.

We applied a cut at SDCA of 100μm in order to select LFV events in τ e and τ μ channels.

4. BACKGROUND EVALUATION FOR LFV AT L3 – LEP2

The background evaluation is based on SM Monte Carlo simulated at LEP2 at 200 GeV with the programs KORALZ, BHWIDE, TEEGG and KK2f [7].

Events have been reconstructed through the L3 detector with the program GEANT. Leptons are identified by their signatures: electrons by matching between trajectories measured in the inner SMD and the energy deposit in the electromagnetic calorimeter, muons using tracks measured in the muon chamber and the energy deposit in the calorimeters. Taus are identified by their hadronic decays into one or three hadrons selected in the central barrel. Events that fail to produce two tau jets are rejected. Taus are selected into classes according to τ decays. Table 1 shows the tau jet types.

Table 1

Tau jet type	Tau decay	Branching ratio (%)
one-prong	$\tau^- \to h^- \nu_\tau (\geq 1\pi^0)$	36.91 ± 0.17
Electron	$\tau^- \to e^- \nu_\tau \bar{\nu}_e$	17.81 ± 0.07
Muon	$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$	17.37 ± 0.09
three-prong	$\tau^- \to h^- h^- h^+ \nu_\tau (\geq 0\pi^0)$	15.18 ± 0.13
Pion (MIP)	$\tau^- \to h^- \nu_\tau$	11.79 ± 0.12

As the neutrinos carry away a fraction of the energy, the reconstructed momenta of the taus is smaller than that of the electrons and muons in the processes $e^+ + e^- \rightarrow e^+ + e^-$, $\mu^+ + \mu^-$.

Finally we used the reconstructed events:
$$e^+ + e^- \rightarrow e^+ + e^-$$
$$e^+ + e^- \rightarrow \mu^+ + \mu^-$$
$$e^+ + e^- \rightarrow \tau^+ + \tau^-$$

by applying cuts on:

- charge conservation
- $|\cos\theta_i|, |\cos\theta_j| < 0.82$
- thrust[1] > 0.95
- $E_{j1} + E_{j2} > E_{beam}$
- max $E_j > 0.8 \, E_{beam}$

Fig. 6 shows the leptons energetic distribution after all cuts (E_{e1}, E_{e2}, $E_{\mu1}$, $E_{\mu2}$, $E_{\tau1}$, $E_{\tau2}$). The events that survive these selection cuts are subject to specific eμ, eτ, $\mu\tau$ selection cuts.

These have been:
$$E_e/E_{beam} > 0.87$$
$$E_\mu/E_{beam} > 0.83$$
$$SDCA < 0.1 \text{ mm}$$

We also cut all events with $E/E_{beam} > 1.1$.

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[1] The thrust is defined as: $2\max\left(\vec{p} \cdot \vec{n} / \sum_{all} |p_i| \right)$ for all tracks with $\vec{p} \cdot \vec{n} > 0$ (the maximum value is taken in respect with $\vec{n}$) [9].
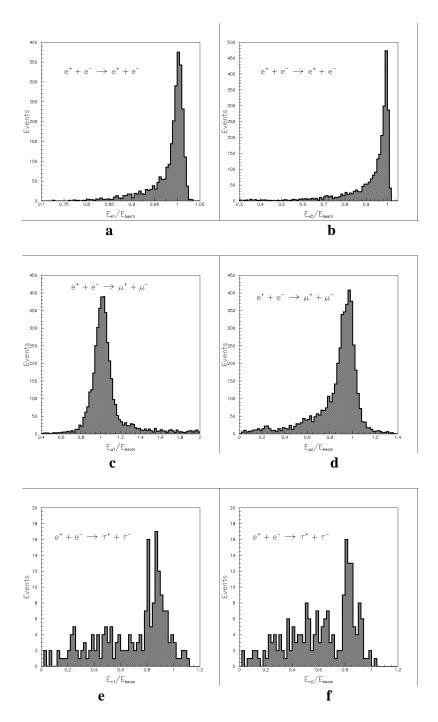
Fig. 6. - The leptons energetic distributions after all cuts (E_{e1} – (a), E_{e2} – (b), $E_{\mu1}$ – (c), $E_{\mu2}$ – (d), $E_{\tau1}$ – (e), $E_{\tau2}$ – (f)).

The efficiency of these cuts has been very high for the eμ channel, but rahter low for eτ and μτ candidates. This is the effect of the low energy spectrum of taus in all the channels. A cut on E_τ/E_{beam} at 0,5 leads to a cleaner sample and has a higher efficiency but we can lose events of interest.

5. CONCLUSIONS

Background effects have been investigated in order to select LFV channels eμ, eτ, μτ in e^+ e^- annihilations at LEP2. Selection cuts have been applied on a Monte Carlo Standard Model sample. A high efficiency selection has been obtained for the eμ channel. The efficiency in the eτ and the μτ channels depends on cuts on τ energy distribution, cuts which are rather arbitrary.

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