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SEARCH FOR A LEPTON FLAVOR VIOLATION SIGNAL IN e^+e^- COLLISIONS AT $\sqrt{s} = 192 - 208$ GeV AT LEP

T. ANGELESCU[1], M. L. ION[1], A. MIHUL[1], A. A. RADU[2]

[1] *Physics Faculty, Bucharest University, P.O. Box MG-11, Bucharest-Magurele, Romania*
[2] *Institute of Space Sciences, P.O. Box MG-23, Bucharest-Magurele, Romania,*
e-mail: aurelian.radu@spacescience.ro

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Abstract: The search for LFV signal in $e^+e^- \to l^+l^-$ is suggested by theoretical predictions in the frame of supersymmetry models. We looked for charged lepton flavor violation (LFV) at energies between 192 and 208 GeV in e^+e^- interactions at LEP2. A Standard Model simulation has been analyzed in order to find preselection and selection criteria. Upper limits for cross sections in $e\mu$, $e\tau$, $\mu\tau$ channels have been found and compared with other experimental results and theoretical predictions.

Key words: lepton flavor violation, supersymmetric models.

1. INTRODUCTION

Neutrino experiments have established the existence of lepton flavor violation (LFV) in the neutral lepton sector.

The Standard Model stipulates only the lepton flavor conservation in the charged lepton sector and has to be extended to account for neutrino masses and mixings. The Minimal Supersymmetric Standard Model (MSSM) induces LFV at the weak scale. Moreover, in the MSSM large $\nu_\mu - \nu_\tau$ mixing can lead to a large $\tilde{\upsilon}_\mu - \tilde{\upsilon}_\tau$ mixing. This leads to clear LFV signals in slepton and sneutrino production and in the decays of neutralinos and charginos into sleptons and sneutrinos in e^+e^- collisions.

W. Porod and W. Majerotto [1] studied the consequences of LFV in the sfermion sector at e^+e^- colliders taking into account the present bounds on rare lepton decays. The processes: $e^+e^- \to$ $\tilde{l}_i^-\tilde{l}_j^+$, $\tilde{\upsilon}_i\tilde{\upsilon}_j$, $\tilde{\chi}_k^0\tilde{\chi}_m^0$, $\tilde{\chi}_n^+\tilde{\chi}_o^-$ have been considered. The main source for LFV signal would be the reaction:

$$e^+e^- \to \tilde{l}_i^-\tilde{l}_j^+ \to l_k^- l_m^+ 2\tilde{\chi}_1^0$$

The background is formed by all possible SUSY cascade decays faking the signal and the SM background from W boson pair production, tquark pair production and τ pair production. The SM background can be calculated with Monte Carlo (MC) programs.

A SUSY background reaction is the chain

$$\tilde{\chi}_2^o \to l_j^- \upsilon_i \tilde{\chi}_S^+ \to l_j^- \upsilon_i l_k^+ \upsilon_m \tilde{\chi}_m^0$$

At 500 GeV the maximal values of cross sections (in fb) are given for LFV in the following reactions:

$$e^+e^- \to e^\pm \mu^\mp \not{E}_T \quad 67\,fb$$
$$e^+e^- \to e^\pm \tau^\mp \not{E}_T \quad 93\,fb$$
$$e^+e^- \to \mu^\pm \tau^\mp \not{E}_T \quad 61\,fb$$

where $\not{E}_T$ is the missing transverse energy.

Background suppression is obtained by angular cuts on the final state leptons, cuts which can increase the signal of LFV at the level of 5σ above the background.

For the case of the maximal selectron and smuon mixing we expect equal number of the e^+e^-, $\mu^+\mu^-$, $e^+\mu^-$, $e^-\mu^+$ accoplanar events with missing transverse momentum $p_\perp > 10$ GeV and accoplanarity angle of the two leptons $\theta_{acc} < 2.55$ rad [2]. In the Standard Model case when mixing is absent e^+e^- and $\mu^+\mu^-$ events are dominantly over $e^+\mu^-$ and $e^-\mu^+$ events due to slepton decays with flavor lepton number conservation.

In this paper we tried to establish preselection and selection criteria on two lepton events obtained at LEP2 by L3 collaboration in order to select a signal of LFV.

2. THE L3 DETECTOR AND PRESELECTION CRITERIA

Fig. 1 presents a general view of the L3 detector [3]. The vertex chamber is surrounded by a BGO electromagnetic calorimeter and a hadron calorimeter, a muon filter and muon tracking chambers, all in cylindrical symmetry. The muon detector is cut at $|\cos\theta| < 0.9$, the tau detector at $|\cos\theta| < 0.94$ and the electron detector at $|\cos\theta| < 0.98$.

In order to eliminate a part of Bhabha scattering, a cut at $|\cos\theta| < 0.7$ has been imposed. The magnetic field was 0.5 T.

The whole detection system is able to register and analyze different hadron and lepton products of e^+e^- interactions.

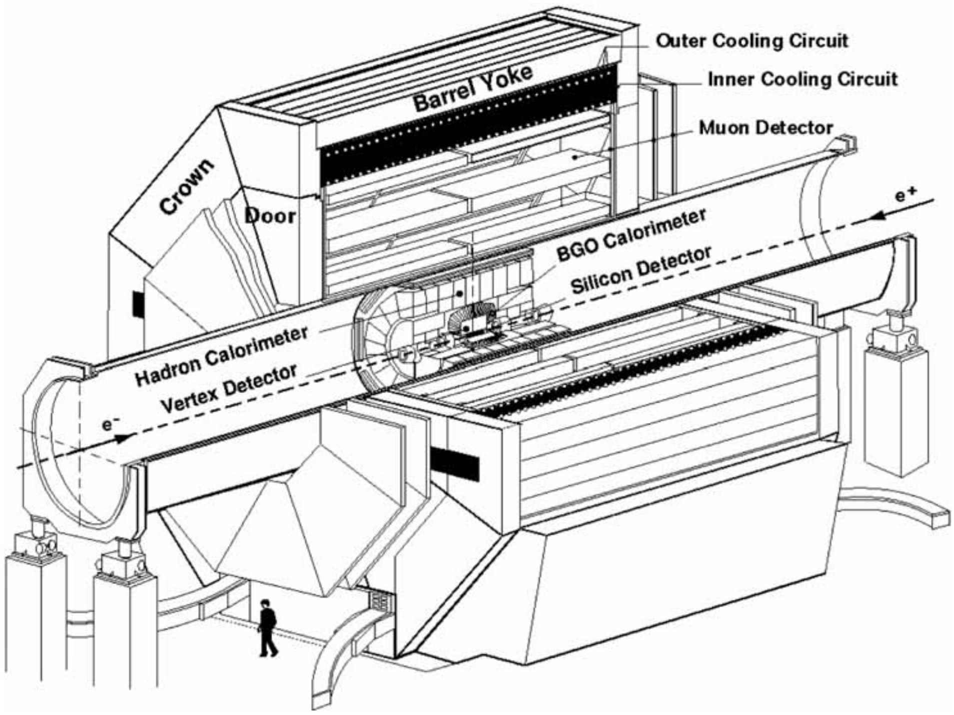

Fig. 1 – A general view of the L3 detector [3].

The detected channels in this energy region are:

$$e^+e^- \to e^+e^-(\gamma)$$
$$e^+e^- \to \mu^+\mu^-(\gamma)$$
$$e^+e^- \to \tau^+\tau^-(\gamma)$$
$$e^+e^- \to q\overline{q}$$
$$e^+e^- \to e^+e^-\tau^+\tau^-$$
$$e^+e^- \to e^+e^-e^+e^-$$
$$e^+e^- \to W^+W^-$$

In the present analysis we are interested in an as pure as possible sample of two charged lepton events.

We followed the method of selecting only events in which leptons share the most part of center of mass energy. The quantity computed for performing this selection is $\sqrt{s'}$ [4, 5] where:

$$s' = s - 2E_\gamma\sqrt{s} + E_\gamma^2 - \vec{p}_\gamma^{\,2}$$

with

$$p_\gamma = \frac{\sqrt{s}\left|\sin\left(\theta_1+\theta_2\right)\right|}{\sin\theta_1+\sin\theta_2+\left|\sin(\theta_1+\theta_2)\right|},\ \theta_1,\ \theta_2 \text{ being the lepton polar angles.}$$

The selection criterion for this "high energy" sample was $\sqrt{s'} > 0.85\sqrt{s}$. In order to separate hadronic channels, the following cuts are applied:

$2 \le \mathrm{NGTK} \le 6$ NGTK is the number of good detected tracks.

NCLCA <12 NCLCA is the number of clusters in hadronic calorimeter.

$E_{vis} > 30$ GeV E_{vis} is the visible energy.

In the data base of detected events leptons are defined by jets and tracks. A jet has one (or three) leading track(s) defined in the track chamber or muon chambers and the energy lost in electromagnetic and hadronic calorimeters. For each jet, a jet energy E_j, an electromagnetic calorimeter energy E_{bg} and a hadronic calorimeter energy E_{hc} are given.

Another quantity given for each lepton is its total energy $E_{lep}(i)$.

The preselection criteria aim to the separation of two lepton channels. The preselection has been applied on a Monte Carlo simulation sample. The programs KORALZ, BHWIDE, TEEGO, KK2f have been used. The simulated events have been reconstructed in the detectors using the program GEANT.

Table 1 shows the two lepton channels separated after preselection, for MC simulated events and experimental events normalized at the same total number of events after preselection.

Table 1

Monte Carlo and experimental events after different cuts

	CHANNEL					
	ee→ee	**ee→μμ**	**ee→ττ**	**ee→eμ**	**ee→eτ**	**ee→μτ**
ee→ee **(MC)** after preselection	6992	0	3.2	0	375	0
ee→ee **(MC)** after particle selection	—	—	—	0	10.01	0
ee→ee **(MC)** after **LFV** selection	—	—	—	**0**	**0.89**	**0**
ee→μμ **(MC)** after preselection	2.2	5404	21.56	58.52	13.64	579
ee→μμ **(MC)** after particle selection	—	—	—	0	0	1.32
ee→μμ **(MC)** after **LFV** selection	—	—	—	**0**	**0**	**0.44**
ee→ττ **(MC)** after preselection	295	102	725	342	948	505
ee→ττ **(MC)** after particle selection	—	—	—	0	0.88	0
ee→ττ **(MC)** after **LFV** selection	—	—	—	**0**	**0**	**0**
Experimental data after preselection	7600	5607	731	191	813	2795
Experimental data after particle selection	—	—	—	0	39	1
Experimental data after **LFV** selection	—	—	—	**0**	**1**	**1**

Monte Carlo generated events show that channel assignation after reconstruction and preselection is biased. Reconstruction mixes particles, especially taus as electrons and muons. For LFV analysis the particle identification is crucial.

In order to solve this problem we should use the energy of leptons deposited into electromagnetic and hadronic calorimeter.

3. SELECTION CRITERIA FOR LFV ANALYSIS

The L3 detector identifies the electron by its high energy deposited in the electromagnetic calorimeter [4] and a small energy in the hadronic calorimeter: $E_{bg} > 30$ GeV and $E_{hc} < 0.4$ GeV.

The tau is identified by its hadronic decay into one or three hadrons. The energy deposit in the electromagnetic calorimeter should be small and that deposited in the hadronic calorimeter, high: $E_{bg} < 30$ GeV and $E_{hc} > 5.0$ GeV.

The muon has a small deposit in both electromagnetic and hadronic calorimeters: $E_{bg} < 30$ GeV and $E_{hc} < 1.0$ GeV.

Applying these cuts we found the number of events "after particle selection" in Table 1. These cuts are not sufficient to separate two lepton channels (ee, μμ, ττ) because they do not use any correlations between particles. Further we apply only cuts which could separate the LFV signal.

We analyzed in [6] the energy distribution of the electrons and muons from the tau decay into leptons. Most decay leptons have small energy. Consequently a cut on the lepton energy will eliminate leptons from tau decay. A cut on electron and muon energy at $0.96 * E_{beam}$ has been applied. Taking into account the lifetime of the tau we can cut on SDCA (smallest distance of closest approach) at about 100 μm, the r.m.s. error on SDCA being of about 90 μm.

As we have seen in Introduction, the LFV signal is a part of supersymmetric sparticle production at the weak scale.

The possibility to find such a signal at LEP2 is related to the limits on sparticle masses in a MSSM. The typical signature of SUSY events is a pair of acollinear leptons, acollinear jets or a lepton-jet pair, recoiling against missing transverse energy ($\not{E}_T$).

The cuts to be applied for the detection of a LFV signal depend on the scenario of superparticle production [8]. For example for $\tilde{l}$ pair production above W^+W^- threshold, a cut on $\theta_{acopl} < 2.55$ rad and $\not{E}_T > 10$ GeV would select selectron pair electroproduction with a very small W^+W^- background and consequently a high signal to background ratio.

We tried different cuts on accoplanarity. We present in Table 1 the number of events left after a cut on accoplanarity $\theta_{acop} < 3.12$. The MC background has been normalized to the experimental data after preselection.

Table 2 gives 95% CL upper limit [9] of the LFV cross section for the whole energy range and an integrated luminosity of 453 pb^{-1}.

In the same energy region the OPAL Collaboration [10] gives for LFV cross section upper limits compatible with our results.

Table 2

Cross section upper limits for LFV

Channel	**Number of events (95% CL – upper limits) [8]**	**Background**	**Selection Efficiency (ε)**	$\sigma = \frac{N}{\varepsilon L}\,(fb)$
$ee \to e\mu$	3.09	0	100%	6.82
$ee \to e\tau$	4.24	0.89	97%	9.65
$ee \to \mu\tau$	4.70	0.44	99.7%	10.41

4. CONCLUSIONS

LFV signal has been searched for in the energy range 192–208 GeV at an integrated luminosity of 453 pb^{-1} using the LEP2 data taken in the L3 experiment. Experimental data have been selected by applying cuts suggested by Monte Carlo simulated events on two lepton channels. Upper limits for LFV have been found.

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