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DELPHI Collaboration

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Preliminary

DELPHI Collaboration

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Abstract

A search for lepton flavour number violating Z^0 decays in the channels $Z^0 \rightarrow \mu\tau$, $Z^0 \rightarrow e\tau$, and $Z^0 \rightarrow e\mu$, using the DELPHI detector with data collected during the 1991–93 LEP runs, is described. No signal was found. Preliminary upper limits (95% CL) of 1.5×10^{-5}, 3.6×10^{-5}, and 0.40×10^{-5}, respectively, are reported.

1 Introduction

The standard model does not contain first order flavour changing neutral currents. However, several extensions to it allow flavour changing neutral currents with branching ratio predictions of lepton flavour number violating Z^0 decays varying from $\sim 10^{-4}$ to $\sim 10^{-9}$ [1]. For a recent review of lepton flavour violation physics, see ref. [2]. In this note a search for Z^0 decays to $\mu\tau$, $e\tau$, and $e\mu$ with the DELPHI detector is described. A previous DELPHI search based on data from 1990 and 1991 is reported in ref. [3]. Previous searches have also been reported by the other LEP experiments [4].

2 Method

In a search for rare (or absent) processes one is sensitive to detector malfunctions. Therefore strict detector quality requirements were applied, and known dead detector zones were masked off.

2.1 The $\mu\tau$, $e\tau$ analyses.

The $\mu\tau$ ($e\tau$) search looked for a high energy muon (electron) recoiling against a low multiplicity system with the leading charged track being different from a muon (electron). (τ decays to $\mu\nu\bar{\nu}$ ($e\nu\bar{\nu}$) were not accepted.) Efficiencies and backgrounds were determined from Bhabha [5], dimuon [6], and τ-pair [7] Monte Carlo event samples with detector response functions simulated [8] and adjusted to fit real data. For the generation of signals, modified versions of KORALZ [7] were used. In the absence of a signal, 95% CL upper limits were determined by an unbinned likelihood method. The likelihood function was defined as

$$L = \prod_{i=1}^{N_{data}} \left(f_b P_b(x_i) + (1 - f_b) P_s(x_i) \right) \tag{1}$$

where x_i is the muon momentum (electron energy) normalized to the beam energy, f_b is the background fraction in the data, $P_b(x)$ the normalized probability density for the background as determined from Monte Carlo, and $P_s(x)$ the normalized probability density for the signal as determined from Monte Carlo. The background fraction was parametrized in terms of the signal as $f_b = 1 - \frac{BN_Z\epsilon}{N_{data}}$ where B is the signal branching fraction, N_Z the number of Z^0'es produced, ϵ the 4π signal selection efficiency, and N_{data} the number of accepted candidates in data. N_Z was calculated as a sum over the LEP energy points from the total cross section and the corresponding luminosities. The 95% upper limits were derived utilizing the fact that twice the log likelihood ratio statistic is approximately χ^2_1 [9]. (An alternative approach consists in determining the upper limit from the normalized likelihood function. This, however, corresponds to a Bayesian approach with a uniform prior on the signal branching fraction [10]. The current knowledge of this parameter [3, 4] does not lend support to such an assumption.)

2.2 The $e\mu$ analysis.

The $e\mu$ analysis looked for a beam energy electron in one hemisphere together with a beam energy muon in the other one.This analysis was background free due to the double suppression of the τ pair background. The upper limit was taken as the Poissonian upper limit at 95% CL for zero observed events.

3 Detector

Only the barrel part of the DELPHI detector was used in the three analyses. A complete description of the DELPHI detector may be found in [11]. Here only the most relevant parts will be mentioned. The main tracking device is the time projection chamber (TPC) extending radially from 32 to 116 cm and from -135 cm to +135 cm along the beam (covering approximately a polar angle range from 20 to 160 degrees). In addition to providing precise track points, the specific ionization, dE/dx was used for particle identification. The TPC tracking was supplemented by precise space information from the vertex detector (VD) (three layers at radii between 6 and 11 cm) and from the Inner Detector drift chamber (ID) positioned between the VD and the TPC. Finally precise $R\Phi$ information came from the Outer Detector (OD), a five layer drift tube detector at radii from 198 to 206 cm for a polar angle range from 43 to 137 degrees. A momentum resolution of $\sim 4\%$ was measured with dimuons at 45 GeV/c.

Electromagnetic calorimetry was provided by the High density Projection Chamber (HPC), a lead/gas calorimeter with ions drifting in the gas gaps to multiwire proportional chambers. The detector gives 3-dimensional charge distributions in nine radial samplings over 18 radiation lengths with a $\Delta z \Delta \Phi$ granularity of about 4 mm$\times 1^{\circ}$. The polar angle coverage is 43 to 137 degrees. An energy resolution of $\sim 6\%$ was measured with electron pairs at 45 GeV.

Hadronic calorimetry was provided by the Hadron Calorimeter (HCAL), a 20 gaps limited streamer/iron plate detector being read out in four radial samplings with a granularity of about $3^{\circ} \times 3^{\circ}$.

Muons penetrating the iron of the HCAL were detected by the Barrel Muon chambers (MUB), providing three dimensional track points for polar angles between 52 and 128 degrees.

In the three analyses reported here the particle identification was based on the calorimetry, the dE/dx measurements, and the muon chambers.

4 The $\mu\tau$ search

After cuts on the reconstructed impact point in radius, R, and position along the beam, z, to suppress cosmics, the analysis proceeded by searching for a high momentum ($|p|/E_{beam} > 0.5$) muon in one of the hemispheres. If found, strict cuts were applied to the leading charged track in the opposite hemisphere to reject muons. The muon identification required the HCAL response to be compatible with a minimum ionizing particle, and at least one associated MUB hit. In addition non-zero energy in the fourth HCAL layer was required, suppressing hadronic background. Only one charged track in the muon hemisphere was accepted.

The anti mu selection in the opposite hemisphere required the combined HPC and HCAL response not to be compatible with a muon. The event was rejected if any charged track in the hemisphere had associated MUB hits. It was required that the leading charged track in the hemisphere had a momentum large enough for a muon to penetrate the HCAL

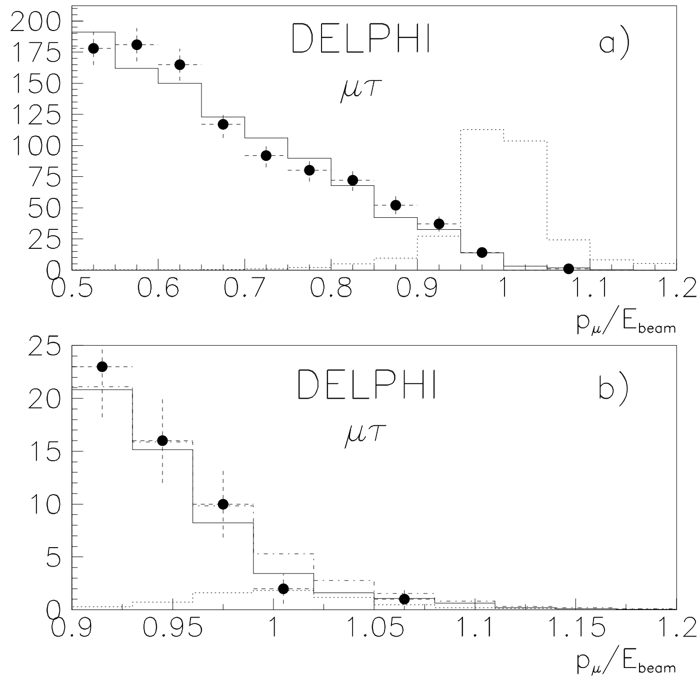

Figure 1: Normalized muon momentum spectra in $\mu\tau$ candidate events. **a):** Histogram: background (from Monte Carlo). Black dots: data. Dotted histogram: signal with arbitrary normalization. **b):** The signal region. Black dots: data. Solid histogram: background corresponding to the 95% upper limit signal fraction. Dotted histogram: Signal corresponding to the 95% upper limit. Dash-dotted histogram: Background plus signal.

all the way to the MUB, $|p| > 2.5 GeV/c$. To ensure high MUB efficiency, candidates pointing towards the detector junction at 90° were rejected requiring $|\theta - 90°| > 2°$. For the same reason tracks closer than 0.6° to the azimuthal sector borders at 15° intervals were rejected. In the case of more than one charged track in the hemisphere, all charged tracks were required to be seen by the VD, thus minimizing the chance of having an electron from a photon conversion as the leading charged track. Furthermore, the leading charged track was required to have a non-zero HCAL response or HPC energy greater than 0.5 GeV. To suppress mu pair background, the event was required to have acolinearity greater than 0.1°. Finally, the leading charged tracks in the two hemispheres were required to have opposite charges.

The efficiency of the $\mu\tau$ event selection was found to be $(16.3 \pm 0.5)\%$, giving an effective number of Z^0 of 358000 ± 12000.

The resulting p/E_{beam} distribution is shown in fig. 1, for background, signal, and data. The resulting log likelihood distribution is shown in fig. 2. The 95% upper limit was found to be $B^{95\%}_{Z^0\to\mu\tau} = 1.5 \times 10^{-5}$.

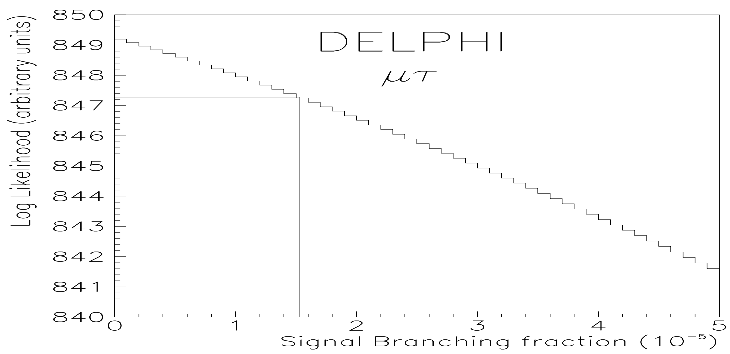

Figure 2: The log likelihood as a function of the $Z^0 \to \mu\tau$ branching fraction. The 95% upper limit is marked by a vertical line.

5 The $e\tau$ search

After cuts on the reconstructed impact point in radius, R, and position along the beam, z, to suppress cosmics, the analysis proceeded by searching for a high energy electron ($E_{em}/E_{beam} > 0.5$ where E_{em} denotes electromagnetic energy associated to the track) in one of the hemispheres. If found, strict cuts were applied to the leading charged track in the opposite hemisphere to reject electrons. In addition to the high electromagnetic energy requirement the electron identification required the electromagnetic energy divided by the track momentum to be consistent with electron response. In addition the energy in HCAL layers 2 through 4 and the number of hits in the muon chambers were required to be zero.

The anti electron selection demanded the leading charged track in the hemisphere to point at least one degree away from HPC detector junctions in the polar angle (at 90°) and in azimuth (every 15 degrees). Furthermore, the event was required to have an acolinearity greater than 0.4°. If at this stage in the analysis the leading charged track had more than 7.5 GeV in HCAL layers 2 through 4, the event was accepted. If not the anti electron candidate was subjected to the following cuts: The electromagnetic energy divided by the momentum had to be inconsistent with the expected electron response. The candidate was rejected if the leading charged track pointed towards a dead or weak HPC module. For tracks below 8 GeV the TPC dE/dx response was required to be inconsistent with that of an electron. Tracks above 8 GeV were required to have nonzero energy deposit in HCAL layers 2 through 4 or at least one associated muon chamber hit.

The efficiency of the $e\tau$ event selection was found to be $(15.7 \pm 0.5)\%$, giving an effective number of Z^0 of 328000 ± 11000. The resulting E_{em}/E_{beam} distribution is shown in fig. 3, for background, signal, and data. The resulting log likelihood distribution is shown in fig. 4. The 95% upper limit was found to be $B^{95\%}_{Z^0 \to e\tau} = 3.6 \times 10^{-5}$.

6 The $e\mu$ search

After cuts on the reconstructed impact point in radius, R, and position along the beam, z, to suppress cosmics, the analysis proceeded by searching for a high momentum muon

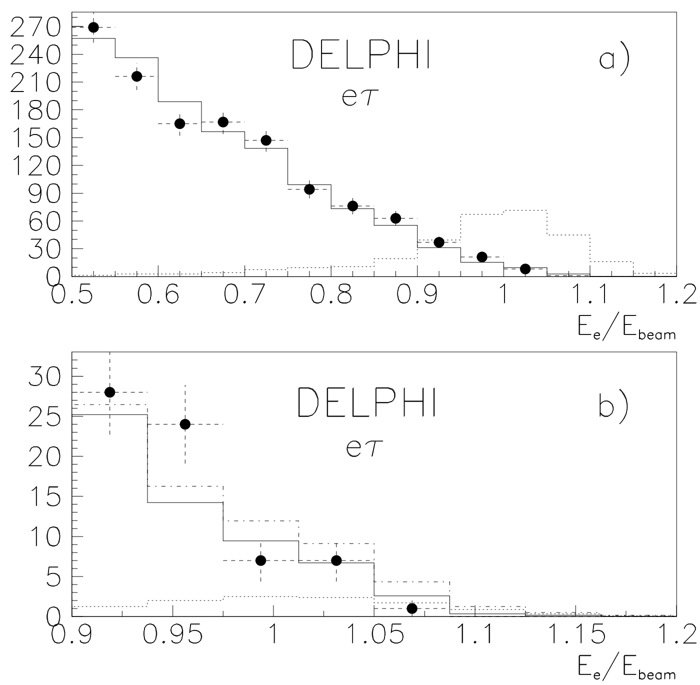

Figure 3: Normalized electron energy spectra in $e\tau$ candidate events. **a):** Histogram: background (from Monte Carlo). Black dots: data. Dotted histogram: signal with arbitrary normalization. **b):** The signal region. Black dots: data. Solid histogram: background corresponding to the 95% upper limit signal fraction. Dotted histogram: Signal corresponding to the 95% upper limit. Dash-dotted histogram: Background plus signal.

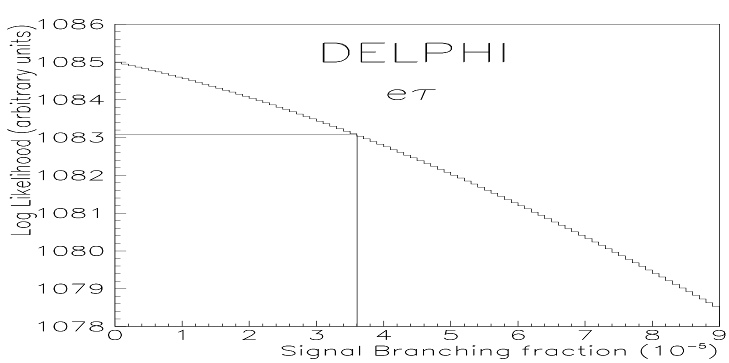

Figure 4: The log likelihood as a function of the $Z^0 \to e\tau$ branching fraction. The 95% upper limit is marked by a vertical line.

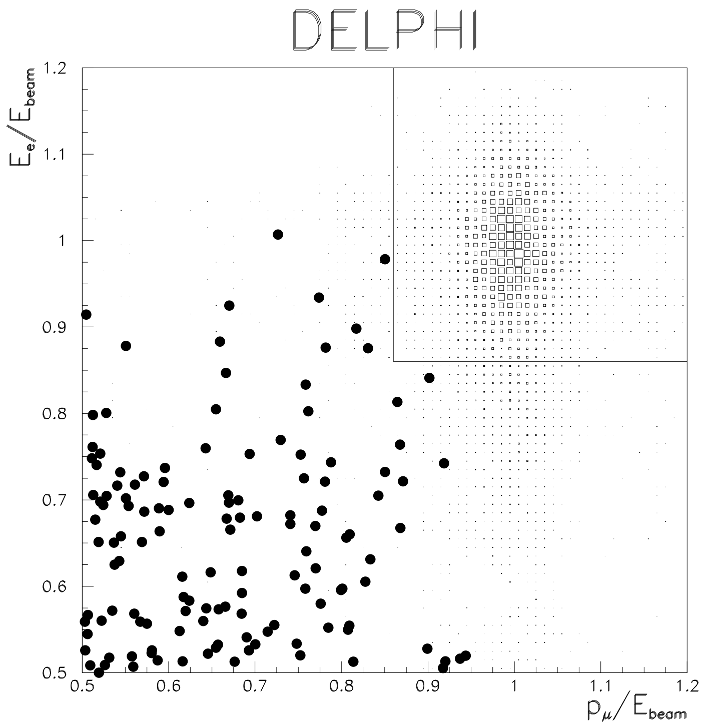

Figure 5: Normalized electron energy versus normalized muon momentum for $e\mu$ candidates. Boxes: Expected signal. Black dots: data.

($|p|/E_{beam} > 0.86$) in one hemisphere together with a high energy electron ($E_{em}/E_{beam} > 0.86$) in the opposite hemisphere. The muon selection accepted only one track in the hemisphere, which had to have at least one associated muon chamber hit and an HCAL response compatible with that of a minimum ionizing particle.

The electron selection also accepted only one charged track in the hemisphere. In addition to the high electromagnetic energy requirement, the track was required to have zero energy in HCAL layers 2 through 4 as well as zero muon chamber hits. A small nonzero energy was accepted in the first HCAL layer to allow for leakage through the HPC.

The efficiency of the $e\mu$ event selection was found to be $(35.5 \pm 1.2)\%$, giving an effective number of Z^0 of 757000 ± 26000. The resulting two-dimensional distribution of the electron E_{em}/E_{beam} versus the muon $|p|/E_{beam}$ is shown in fig. 5, for signal and data. The 95% CL upper limit resulting from zero observed candidates is $B^{95\%}_{Z^0 \to e\mu} = 0.40 \times 10^{-5}$.

7 Summary

A search for lepton number violating Z^0 decays in the channels $Z^0 \to \mu\tau$, $Z^0 \to e\tau$, and $Z^0 \to e\mu$ has been performed using the DELPHI detector at LEP. The data were collected during the 1991–93 LEP runs. No signal was found. The results for the three channels are summarized in table 1.

Channel	Efficiency (%)	Effective number of Z^0	Br.ratio 95% CL Upper Limit (10^{-5})
$Z^0 \to \mu\tau$	16.3±0.5	358000±12000	1.5
$Z^0 \to e\tau$	15.7±0.5	328000±11000	3.6
$Z^0 \to e\mu$	35.5±1.2	757000±26000	0.40

Table 1: Summary of results for the three channels.

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