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**A Search for Heavy Charged and Neutral Leptons
from Z^0 Decays**

The L3 Collaboration

ABSTRACT

We have searched for charged and neutral leptons. We exclude stable Dirac neutrinos below 42.8 GeV and stable Majorana neutrinos below 34.8 GeV. From a search for unstable neutrinos we exclude masses below 46.4 GeV (Dirac) and below 45.1 GeV (Majorana). We exclude all masses of sequential charged and neutral leptons, except if both masses are larger than 42.8 GeV (for stable Dirac neutrinos). All mass limits correspond to 95% C.L.

Introduction

The L3 detector at the e^+e^- collider LEP is ideal for the search for new leptons, because production cross sections at the Z^0 resonance are large, and final state particles can be identified cleanly. In this study we present a search for heavy leptons. For the original method for the search for heavy leptons see [1], and for the discovery of the τ lepton see [2]. Previous results on this subject by other LEP and SLC experiments can be found in [3].

Our search includes sequential heavy charged leptons, L^\pm , and neutral leptons (heavy neutrinos), L^0 , of the Dirac or Majorana type. We consider in our analysis the production of lepton pairs from Z^0 decays, $Z^0 \rightarrow L^+ L^-$, $Z^0 \rightarrow L^0 \bar{L}^0$. We study the cases of stable and unstable heavy leptons.

We obtain a limit on heavy lepton masses from the measurement of the total decay width of the Z^0 , and in case of a heavy stable neutrino from the invisible decay width of the Z^0 . Even higher mass limits, close to the beam energy, are obtained from a direct search for heavy leptons.

We study the case of a stable heavy charged lepton, which is expected if the fourth generation neutrino is heavier than the charged lepton, and if flavor is conserved in the decay. The event signature is similar to $e^+e^- \rightarrow \mu^+\mu^-$, with the difference that the momenta of the stable leptons are smaller and the time-of-flight is longer.

The case where the neutrino is lighter than the charged lepton is studied in two ways:

- 1) We perform a search for heavy charged lepton decays via the charged current process $L^\pm \rightarrow L^0 + W^{\pm*}$ in looking for events with isolated muons and missing energy.
- 2) We perform a search for heavy neutral lepton decays via the charged current process $L^0 \rightarrow \ell^\pm + W^{\mp*}$, ($\ell = e, \mu, \tau$). This decay is only possible if mixing between lepton flavors exists. The search is based on event topologies of hadronic jets with at least one isolated lepton.

Data Collection

The L3 detector at LEP and its performance are described in detail elsewhere [4]. It consists of a central vertex chamber (TEC), an electromagnetic calorimeter (BGO), a ring of scintillation counters, a hadron calorimeter made of uranium, brass and proportional wire chambers and a high precision muon chamber system. Luminosity is measured by detecting small angle Bhabha events in two forward electromagnetic calorimeters. The BGO covers the polar angle from 42.3° to 137.7° , the muon chambers from 36° to 144° , and the hadron calorimeter from 5.5° to 174.5° .

The data used in these searches were collected during an energy scan of the Z^0 resonance at center of mass energies between 88.2 and 94.2 GeV. The integrated luminosity used in this analysis is about 2.23 pb^{-1} collected between March and June 1990.

Mass Limits from the Z^0 Decay Width

Heavy leptons are assumed to couple to the photon and the Z^0 in the same way as ordinary leptons. An additional type of leptons increases the total decay width of the Z^0 by the following amount:

$$\Gamma_{L^+L^-} = \frac{G_F M_Z^3}{12\pi\sqrt{2}} [\beta(3-\beta^2)g_V^2 + 2\beta^3 g_A^2] \quad \text{for sequential charged leptons, (1)}$$

$$\Gamma_{L^0\bar{L}^0} = \frac{G_F M_Z^3}{12\sqrt{2}\pi} \frac{1}{4} \beta(3 + \beta^2), \quad \text{for Dirac neutrinos, (2)}$$

$$\Gamma_{L^0\bar{L}^0} = \frac{G_F M_Z^3}{12\sqrt{2}\pi} \beta^3, \quad \text{for Majorana neutrinos, (3)}$$

where $g_A = I_3 = -1/2$ and $g_V = I_3 - 2Q_L \sin^2\theta_W = -1/2 + 2 \sin^2\theta_W$ for charged sequential leptons and $\beta = \sqrt{1 - 4m^2/s}$ is the velocity of the lepton.

From a previous measurement with the L3 detector we have determined the following Z^0 parameters [5]:

$$M_Z = 91.161 \pm 0.013(\text{experiment}) \pm 0.030(\text{LEP}) \text{ GeV}$$

$$\Gamma_Z = 2.492 \pm 0.025 \text{ GeV and}$$

$$\Gamma_{\text{invisible}} = 0.502 \pm 0.018 \text{ GeV for the decay width into invisible particles.}$$

The errors on Γ_Z and $\Gamma_{\text{invisible}}$ contain statistical and systematic errors of the measurement. This should be compared to the Standard Model expectation $\Gamma_Z = 2.492 \text{ GeV}$ and $\Gamma_{\text{invisible}} = 0.501 \text{ GeV}$ for the same Z^0 mass, for 3 families of leptons and quarks, and $M_{\text{top}} = 150 \text{ GeV}$, $M_{\text{Higgs}} = 100 \text{ GeV}$ and $\alpha_s = 0.115$ (this set of parameters is in good agreement with our measurement [5],[6]). Using these values we set a 95% C.L. limit of $\Delta\Gamma_Z \leq 41 \text{ MeV}$ and derive the following mass limits for heavy leptons.

$$M_{L^\pm} > 27.9 \text{ GeV (for sequential charged leptons)}$$

$$M_{L^0} > 43.2 \text{ GeV (for Dirac neutrinos)}$$

$$M_{L^0} > 35.4 \text{ GeV (for Majorana neutrinos).}$$

For a conservative limit on the heavy lepton masses we use the values $M_{\text{top}}=90 \text{ GeV}$, $M_{\text{Higgs}}=1000 \text{ GeV}$ and $\alpha_s=0.10$, which are compatible with our measurements and give a lower value for Γ_Z in the Standard Model ($\Gamma_Z=2.462 \text{ GeV}$). Using these values we set a one-sided 95% C.L. limit of $\Delta\Gamma_Z \leq 71 \text{ MeV}$.

Figure 1a displays the increase in the total width of the Z^0 as a function of the heavy lepton mass. We derive the following limits (95% C.L.) for heavy lepton masses:

$$\begin{aligned} M_{L^\pm} &> 14.2 \text{ GeV (for sequential charged leptons)} \\ M_{L^0} &> 38.8 \text{ GeV (for Dirac neutrinos)} \\ M_{L^0} &> 30.0 \text{ GeV (for Majorana neutrinos)}. \end{aligned}$$

These limits are derived from the production of heavy leptons, and are thus independent of any assumptions about the decay properties. They apply equally for stable and unstable leptons.

A stable heavy neutrino will be invisible in the detector. From our measurement of the invisible width and the standard parameters ($M_{\text{top}} = 150 \text{ GeV}$, $M_{\text{Higgs}} = 100 \text{ GeV}$ and $\alpha_s = 0.115$) we obtain a one-sided 95% C.L. limit $\Delta\Gamma_{\text{invisible}} < 30 \text{ MeV}$. This gives the following mass limits for new stable neutrinos.

$$\begin{aligned} M_{L^0} &> 44.2 \text{ GeV (for Dirac neutrinos)} \\ M_{L^0} &> 37.6 \text{ GeV (for Majorana neutrinos)}. \end{aligned}$$

For conservative mass limits we have again chosen the parameters $M_{\text{top}}=90 \text{ GeV}$, $M_{\text{Higgs}}=1000 \text{ GeV}$ and $\alpha_s=0.10$, which yield $\Gamma_{\text{invisible}} = 0.497 \text{ GeV}$ in the Standard Model. Using these parameters we have repeated our analysis in [5], and find $\Gamma_{\text{invisible}} = 0.512 \pm 0.018 \text{ GeV}$. We obtain a conservative 95% C.L. limit of $\Delta\Gamma_{\text{invisible}} < 45 \text{ MeV}$ as indicated in Figure 1b. This gives the following mass limits for new stable neutrinos.

$$\begin{aligned} M_{L^0} &> 42.8 \text{ GeV (for Dirac neutrinos)} \\ M_{L^0} &> 34.8 \text{ GeV (for Majorana neutrinos)}. \end{aligned}$$

The differences between these limits and those given earlier indicate systematic errors due to the uncertainties in M_{top} , M_{Higgs} and α_s .

Search for Unstable Neutral Leptons

In the following analysis we consider the case that the charged lepton is heavier and the associated neutrino lighter than $M_Z/2$. Then the neutrino will be produced in pairs in Z^0 decays. Limits on stable heavy neutrinos have been given earlier from the measurement of the invisible width. In the following we consider the case of unstable heavy neutrinos.

Heavy neutrinos can only decay via the charged current process $L^0 \rightarrow \ell^\pm + W^\mp$ if flavor mixing exists between leptons. The decay amplitude contains a mixing

parameter V_{ℓ,L^0} for the transition from L^0 to the light charged lepton ℓ . The neutral lepton decay width (for Dirac type) is given by:

$$\Gamma(L^0 \rightarrow \ell^\pm + W^{\mp*}) = 9|V_{\ell,L^0}|^2 \frac{G_F^2 M_{L^0}^5}{192\pi^3}$$

The decay width is a factor two larger for Majorana leptons, since the transitions $L^0 \rightarrow \ell^+$ and $L^0 \rightarrow \ell^-$ occur with equal probability. The factor 9 takes into account the $W^{\pm*}$ decay channels into $\mu\nu, e\nu, \tau\nu, ud, cs$. The mean decay path of the heavy neutral lepton is given by

$$l_{L^0} = \beta \gamma c \tau_{L^0} \propto \beta |V|^{-2} M_{L^0}^{-6},$$

where $|V|^2 = |V_{e,L^0}|^2 + |V_{\mu,L^0}|^2 + |V_{\tau,L^0}|^2$.

We require the mean decay path of heavy leptons to be smaller than 1 cm to obtain a high detection and reconstruction efficiency. This corresponds to a lifetime smaller than 60 ps for $M_{L^0} = 40$ GeV. It implies that the limits of the direct search for neutral lepton decays are only valid for mixing parameters $|V|^2 > 6.2 \times 10^{-8}$ at $M_{L^0} = 20$ GeV and $|V|^2 > 5.1 \times 10^{-10}$ at $M_{L^0} = 40$ GeV.

We have generated heavy neutral lepton events assuming the same couplings to the Z^0 as for light neutrinos. We have included standard matrix elements for the charged current decays and first order corrections for initial state radiation. The fragmentation of quark jets from the decay has been simulated with the JETSET 7.2 program [7]. Heavy neutral lepton production has been simulated for masses larger than 20 GeV and for decays into $e+W^*$, $\mu+W^*$, and $\tau+W^*$. The response of the L3 detector for these events is simulated with a program which includes energy loss, multiple scattering and electromagnetic and nuclear interactions in the detector components [8]. The simulated events are reconstructed in a manner analogous to real data.

We have searched for heavy neutral lepton events with isolated leptons, not compatible with $\mu^+\mu^-$, e^+e^- or $\tau^+\tau^-$ or heavy quark decays. The following selection criteria have been used:

- (1) The energy measured in calorimeters should exceed 30 GeV.
- (2) Transverse energy imbalance $E_T/E_{vis} < 0.7$ and longitudinal energy imbalance $|E_{||}/E_{vis}| < 0.4$.
- (3) We require the thrust value to be less than 0.9.
- (4) At least one muon or electron is required with $p > 8$ GeV, and $|\cos\theta| < 0.7$, where θ is the angle with respect to the beam line.
- (5) No charged track (apart from the lepton) with momentum larger than 0.25 GeV should be present in the TEC chamber in the range $\Delta\phi = \pm 15^\circ$ around the lepton track.

- (6) The total calorimetric energy in a cone around the muon with half opening angle of 30 degrees should be smaller than 6.5 GeV. This includes the energy loss of the muon in the calorimeter of typically 2 GeV. For electrons we require that the angle to the nearest jet (with energy larger than 10 GeV) should be larger than 30°.

After all cuts no candidates were found. With Monte Carlo simulations we have determined the number of expected events from neutral lepton decays after the above cuts. The selection efficiencies for neutral leptons are about 46% for decays into electrons and muons, and 14% for decays into taus. They vary less than 4% in the mass range from 20 GeV to 44 GeV. Systematic errors have been taken into account by lowering the number of expected events by 5%, this includes the error on the luminosity, selection and Monte Carlo simulation.

Figure 2 shows the expected number of events for the cases that the neutral lepton decays predominantly into electrons, muons or taus. The result is shown separately for (a) Dirac type and (b) Majorana type lepton. As we have no candidates we derive the 95% C.L. limit on the neutral lepton mass based on three expected events. Combining this limit with our results from the Z^0 width we obtain the mass limits for Dirac leptons for various dominant decay modes:

$$\begin{aligned} M_{L^0} &> 46.5 \text{ GeV for } L^0 \rightarrow e + W^* \\ M_{L^0} &> 46.5 \text{ GeV for } L^0 \rightarrow \mu + W^* \\ M_{L^0} &> 46.4 \text{ GeV for } L^0 \rightarrow \tau + W^* \end{aligned}$$

For Majorana leptons the mass limits are:

$$\begin{aligned} M_{L^0} &> 45.5 \text{ GeV for } L^0 \rightarrow e + W^* \\ M_{L^0} &> 45.5 \text{ GeV for } L^0 \rightarrow \mu + W^* \\ M_{L^0} &> 45.1 \text{ GeV for } L^0 \rightarrow \tau + W^* \end{aligned}$$

The combined results of the search for heavy neutrinos are given in Figure 3 for (a) Dirac neutrinos and (b) Majorana neutrinos. Excluded masses for heavy neutrinos are given as function of the mixing parameter $|V|^2$. Contour (a) is excluded from the direct search for unstable neutrinos, which is valid for an average decay length smaller than 1 cm. This corresponds to a lifetime smaller than 60 ps for a 40 GeV lepton. Contour (b) which extends down to $|V|=0$ is derived from our measurement of $\Gamma_{\text{invisible}}$. A heavy neutrino with decay length larger than 3 m is not accepted in the trigger and therefore it contributes to the measured invisible width of the Z^0 . The limits indicated in contour (b) correspond to an average decay length of 5 m. Contour (c) gives the mass limit from Γ_Z , which is independent of $|V|^2$.

Search for Heavy Charged Leptons

We have generated charged heavy lepton pair production at various masses with the TIPTOP Monte Carlo [9], which includes initial and final state radiation, mass and spin effects. We have used the KORALZ Monte Carlo [10] to simulate the background from pair production of muons and taus and also to simulate stable heavy charged leptons. These events have been simulated [8] in the L3 detector and reconstructed in a manner analogous to real data.

In the search for heavy charged leptons we divide the study into a search for stable and unstable leptons.

Stable charged lepton

Pair production of new stable charged heavy leptons would appear as two back to back charged tracks of low momenta in the muon chambers. As the mass of the particles increases, the dE/dx energy loss in the inner detector increases. Only for masses up to about 38 GeV the heavy lepton is able to reach the outer muon chambers and for masses larger than 43 GeV it will not be able to penetrate the BGO detector. In the mass region below 38 GeV we obtain limits in searching for an excess in the $e^+e^- \rightarrow \mu^+\mu^-$ production. In the mass region above 38 GeV we have looked for events with two back to back tracks in the vertex chamber having either a time of flight compatible with a low velocity particle or a large energy loss in the electromagnetic calorimeter.

We search for heavy leptons in the mass region below 38 GeV by repeating the muon pair selection [11] with modified cuts on the particle momentum and time-of-flight. We lower the momentum cut from $0.5\sqrt{s}$ to $0.06\sqrt{s}$ for the sum of both momenta. The cut on the scintillator mean time has been raised from 3.0 ns to 10.0 ns. From Monte Carlo studies we find that the acceptance for heavy stable lepton pairs for $M_{L\pm} < 38$ GeV is 58%, independent of lepton masses.

With these cuts we accept 6.6% more events compared to the $\mu^+\mu^-$ cuts. This increase is compatible with a higher background from $e^+e^- \rightarrow \tau^+\tau^-$ events ($3.5 \pm 0.3\%$) and $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ events ($2.1 \pm 0.7\%$). We follow the same analysis procedure [11] as for $e^+e^- \rightarrow \mu^+\mu^-$, and obtain a modified partial width of $\Gamma_{\mu\mu} = 83.4 \pm 3.1$ MeV. For a conservative mass limit for heavy leptons we use $M_{\text{top}} = 90$ GeV and $M_{\text{Higgs}} = 1000$ GeV, which gives $\Gamma_{\mu\mu} = 83.1$ MeV for our measured Z^0 mass. From these numbers we obtain a one-sided 95% C.L. limit on the production of a heavy lepton of $\Gamma_{LL} < 5.4$ MeV. This rules out stable heavy leptons below 38 GeV.

The search for stable charged leptons heavier than 38 GeV is carried out by looking for two back-to-back tracks in the TEC with large energy loss in the detector. The trigger for such events requires 2 tracks in the TEC with acoplanarity smaller than 60° and momentum larger than 300 MeV. We have determined the trigger and reconstruction efficiency for these events to be $82.4 \pm 2.0\%$ by studying

muon pair events, which have been triggered independently by the muon trigger. The event selection criteria are listed below.

- (1) We require two and only two tracks in the TEC with an acoplanarity of less than 5° .
- (2) The total visible energy in the detector is required to be less than 60 GeV and the energy deposited in the BGO is required to be less than 8 GeV.
- (3) The event thrust has to be greater than 0.8.

These three cuts strongly suppress Z^0 decays to electrons, muons, taus and hadrons. In addition, we impose the following cuts to select particles with small velocity or large dE/dx .

- (4a) If there is a scintillator hit matching each track, we calculate the speed β of the particles from the measured time-of-flight. We require $\beta < 0.7$ for both tracks. In addition, for the time difference between both scintillator hits we require $|\Delta t| < 3.0$ ns.
- (4b) If no scintillators are hit, as expected for leptons heavier than 43 GeV, we require that the energy deposited in the hadron calorimeter is less than 2 GeV and that there is no track in the muon chambers. The two TEC tracks are required to have matched BGO clusters with at least 0.5 GeV energy and an acollinearity of less than 5° . In addition, the BGO clusters are required to consist of less than 4 crystals, to remove low energy tau decays to electrons.

No event is found. This is consistent with the expected background events from dilepton production and two photon events of 0.4 ± 0.4 .

From a study of Monte Carlo events, the acceptance was found to depend on the mass. The acceptance varied from 49% at 38 GeV to 33 % at 44.5 GeV. We take systematic errors in the simulation and reconstruction for large lepton masses into account by lowering the expected number of events by 5%. We expect 158, 78, 16 events at $M_L = 38.0$ GeV, $M_L = 41.0$ GeV, and $M_L = 44.0$ GeV, respectively. Basing our 95% C.L. limit on three expected events we exclude the mass range $38.0 < M_L < 44.6$ GeV in this study. Combined with the limit given earlier we exclude therefore a new stable charged lepton with $M_L < 44.6$ GeV at 95% confidence level, thus improving previously published limits [3].

Unstable charged lepton

In our search for unstable charged leptons we study the charged current decay $L^\pm \rightarrow L^0 + W^{\pm*}$ assuming that the associated neutral lepton is stable. We look for events with isolated muons and missing energy transverse to the beam direction by imposing the following selection criteria:

- (1) We require at least one reconstructed muon in the detector fulfilling the following criteria:
 - (i) $|\cos\theta_\mu| < 0.7$, where θ_μ is the polar angle of the muon track;

- (ii) the reconstructed muon momentum should be greater than 5 GeV;
 - (iii) within a cone of half angle 25° around the muon track, the energy in the BGO is required to be less than 2 GeV.
- (2) If the muon track has an associated scintillator hit, the time of the hit relative to the bunch crossing must be consistent with a particle produced at the interaction point, *i.e.* the measured time after correcting for time of flight should be less than 3.0 ns. For muon pair events, we require the time difference between the two hits to be less than 3.0 ns.
 - (3) The total energy in the range $|\cos\theta| > 0.73$ is required to be less than 30 GeV and $|\cos\theta_{\text{thr}}| < 0.95$ where θ_{thr} is the polar angle of the thrust axis.
 - (4a) If there are two isolated muons in the event we require the number of BGO shower peaks to be less than 10.
 - (4b) For single muon events we require at least one cluster (jet or isolated particle) outside the cone of half angle 25° around the muon track with either one of the following characteristics:
 - (i) more than 3 GeV deposited in the hadron calorimeter or,
 - (ii) an associated charged track in the TEC if the shower profile in the BGO is consistent with that of an electron.

Heavy lepton events tend to be acoplanar with large missing energy. For events with two muons, the acollinearity and acoplanarity are calculated using the directions of the two reconstructed muon tracks. For events with one isolated muon, the above quantities are calculated from the direction of the muon track and the momentum sum of the two most energetic clusters outside a cone of 25° half opening angle around the muon. For the selection of heavy leptons we use then the additional criteria:

- (5) Acollinearity $> 10^\circ$.
- (6) Acoplanarity $> 20^\circ$.
- (7) Transverse energy imbalance $E_T/E_{\text{vis}} > 0.1$.

Figure 4 shows the transverse energy imbalance vs. acoplanarity for (a) the data and (b) the Monte Carlo simulation assuming a 40 GeV heavy lepton after cuts (1)-(5). Many events with large acoplanarity and missing transverse energy are expected in the simulation, but are not seen in the data. After applying the final cuts (6) and (7) no event is found.

The selection efficiency for heavy leptons (for its associated neutrino being massless) ranges from 19.4% at $M_L = 20$ GeV to 39.1% at $M_L = 44$ GeV for events containing at least one muon. If the associated neutrino is massive, the efficiency is lower for the same charged lepton mass due to the lower average momentum of the muon and lower average missing transverse momentum.

The error in the efficiency calculation consists of $\sim 10\%$ from the Monte Carlo statistics. The efficiencies are insensitive to variation of the cuts except when the

associated neutrino mass is close to the charged lepton mass, where they are sensitive to the muon momentum cut and the acoplanarity cut. To take this into account, we have varied the momentum cut by ± 0.5 GeV and the acoplanarity cut by $\pm 2^\circ$ and assigned the variation in the efficiencies as a systematic error. We assign a total systematic error of 5% from the luminosity measurement, production cross section and event selection.

Summary for Sequential Leptons

The combined result on sequential leptons is displayed in Figure 5. The excluded 95% C.L. contour in the $M_{L^\pm} - M_{L^0}$ mass plane is shown (for Dirac neutrinos) from (a) the measurement of the Z^0 width and (b) the invisible width. Contour (c) shows the result of the search for stable charged leptons, and contour (d) displays the direct search for unstable charged leptons. We exclude all masses of charged and neutral leptons, except if both masses are large, $M_{L^\pm} > 40.2$ GeV, $M_{L^0} > 38.8$ GeV, independent of neutrino decay and $M_{L^\pm} > 42.8$ GeV, $M_{L^0} > 42.8$ GeV if the neutrino is stable.

Conclusions

We have searched for charged and neutral leptons. We exclude stable Dirac neutrinos below 42.8 GeV and stable Majorana neutrinos below 34.8 GeV. From a direct search for unstable neutrinos we exclude masses below 46.4 GeV (Dirac) and below 45.1 GeV (Majorana). From a search for heavy stable charged leptons we exclude masses below 44.6 GeV. In a direct search we exclude unstable charged lepton masses from 10 GeV to 44.3 GeV for a wide range of neutrino masses. Combining these results we exclude all masses of sequential charged and neutral leptons, except if both masses are larger than 42.8 GeV (for stable Dirac neutrinos). All mass limits correspond to 95% C.L.

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Figure Captions

- Figure 1* : a) Expected increase in Γ_Z as a function of the masses of the charged leptons, L^\pm , and neutral leptons, L^0 , of Dirac and Majorana type. The horizontal line indicates the 95% C.L. limit obtained from our measurement. This mass limit is independent of the decay properties of the leptons. b) Same for $\Gamma_{\text{invisible}}$, the mass limit is valid for stable neutral leptons.
- Figure 2* : Expected number of events as function of mass from the direct search for unstable neutral leptons. The result for (a) Dirac and (b) Majorana neutrinos is shown for decays into electrons, muons or taus. The mass limits are valid for a neutrino lifetime less than 16 ps at $M_{L^0} = 20$ GeV and less than 60 ps at $M_{L^0} = 40$ GeV.
- Figure 3* : Excluded masses for heavy neutrinos vs. the mixing parameter $|V|^2$ for Dirac and Majorana neutrinos. Contour (a) is excluded from the direct search for unstable neutrinos; contour (b) which extends down to $|V|=0$ is derived from the measurement of the invisible width of the Z^0 ; and contour (c) gives the mass limits from Γ_Z , which are independent of $|V|^2$.
- Figure 4* : Distribution of acoplanarity vs. transverse energy imbalance for (a) data and (b) charged heavy lepton Monte Carlo. The applied cuts are explained in the text.
- Figure 5* : Mass region in the $M_{L^\pm} - M_{L^0}$ plane excluded by our analysis with 95% C.L. for Dirac neutrinos, contour (a) is derived from the measurements of Γ_Z ; contour (b) indicates the mass limit for a stable neutrino; contour (c) is excluded from the direct search for stable charged leptons and contour (d) from the search for unstable charged leptons.

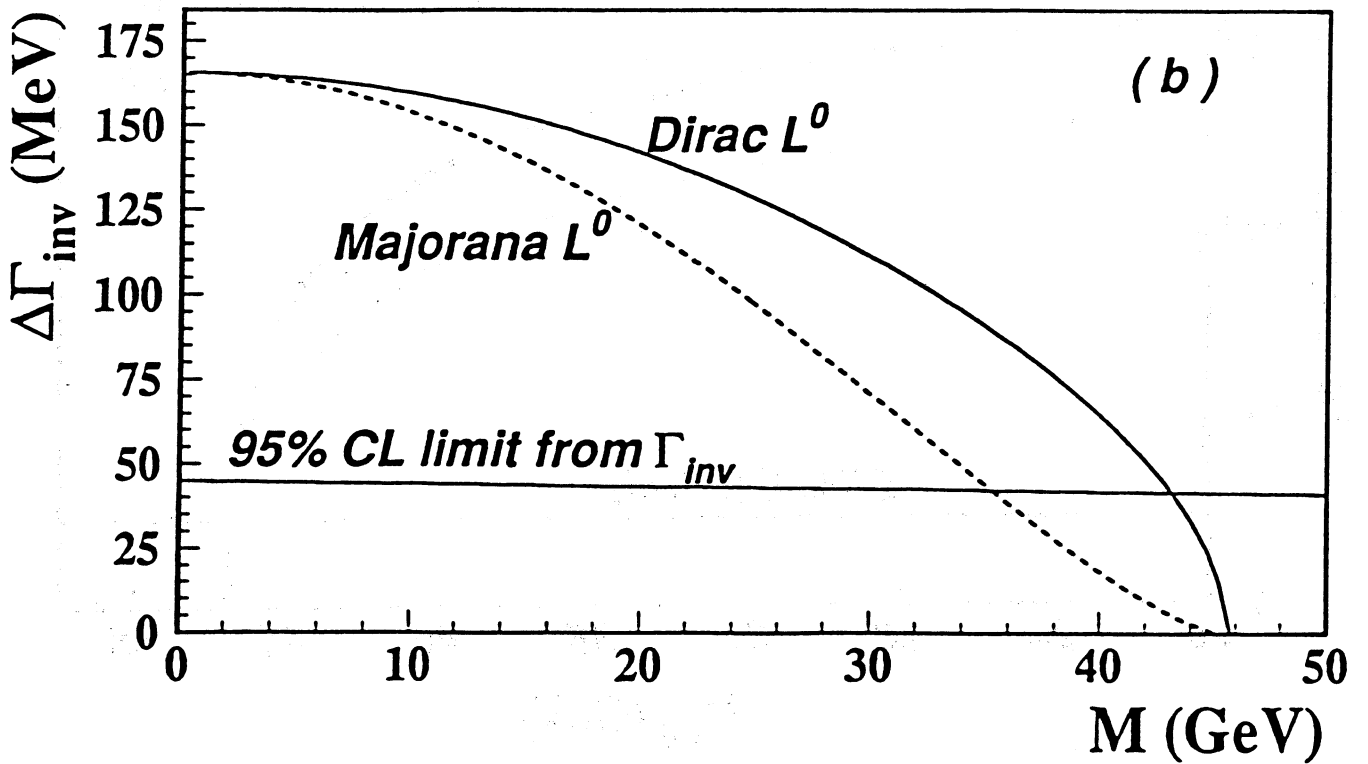
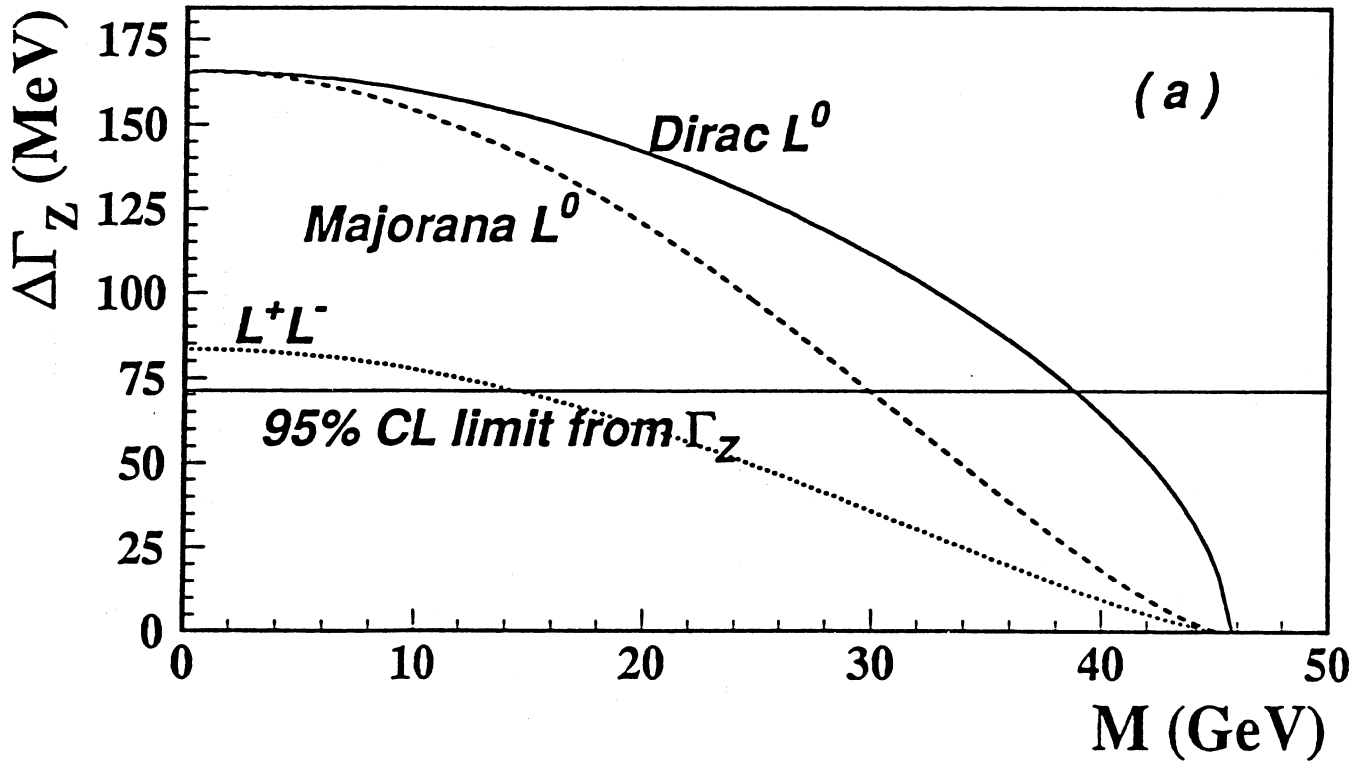


Figure 1

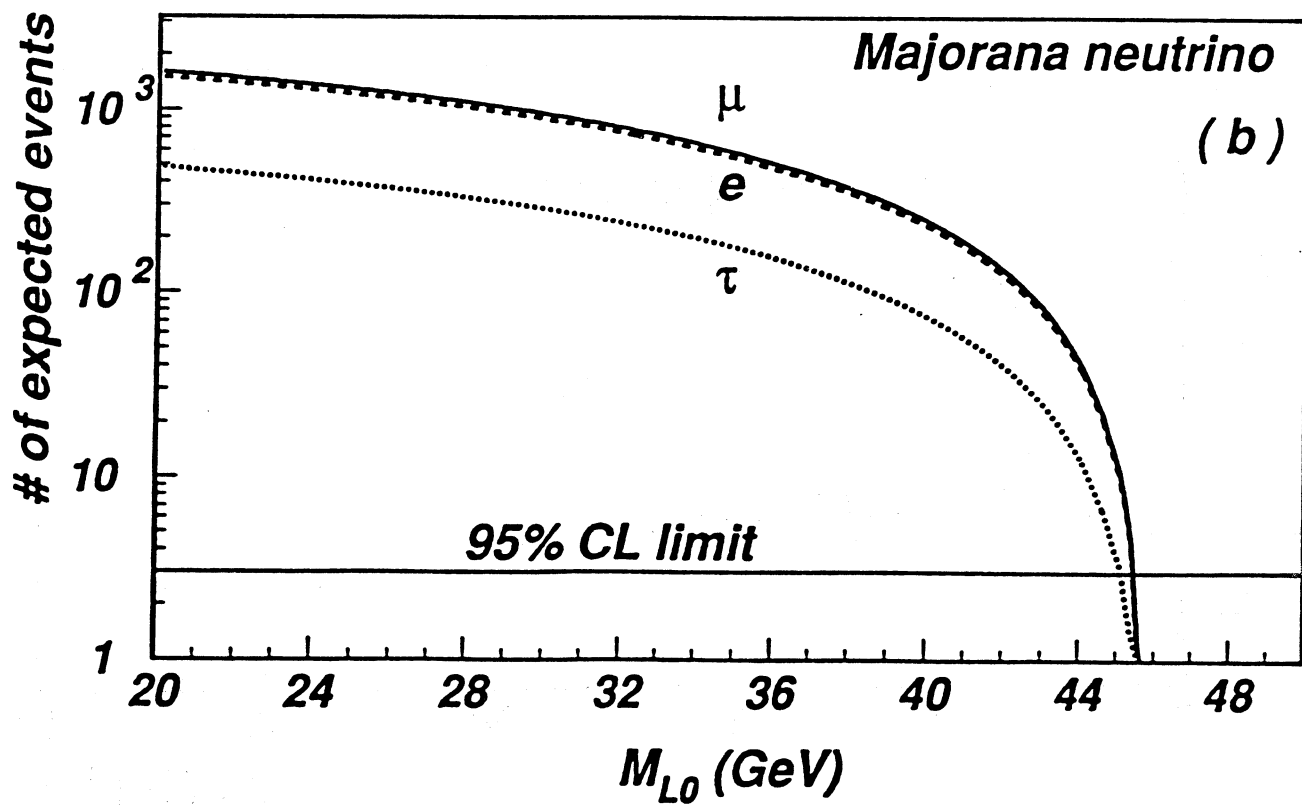
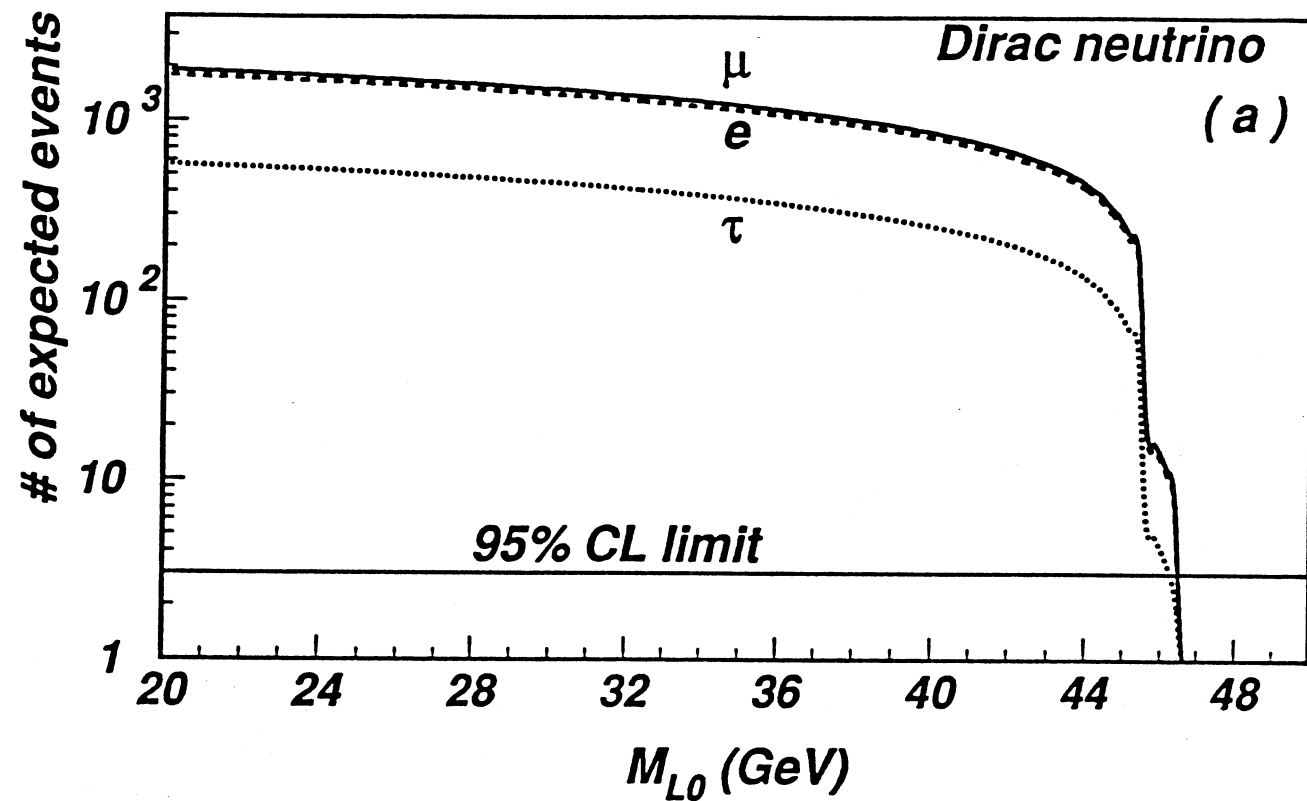


Figure 2

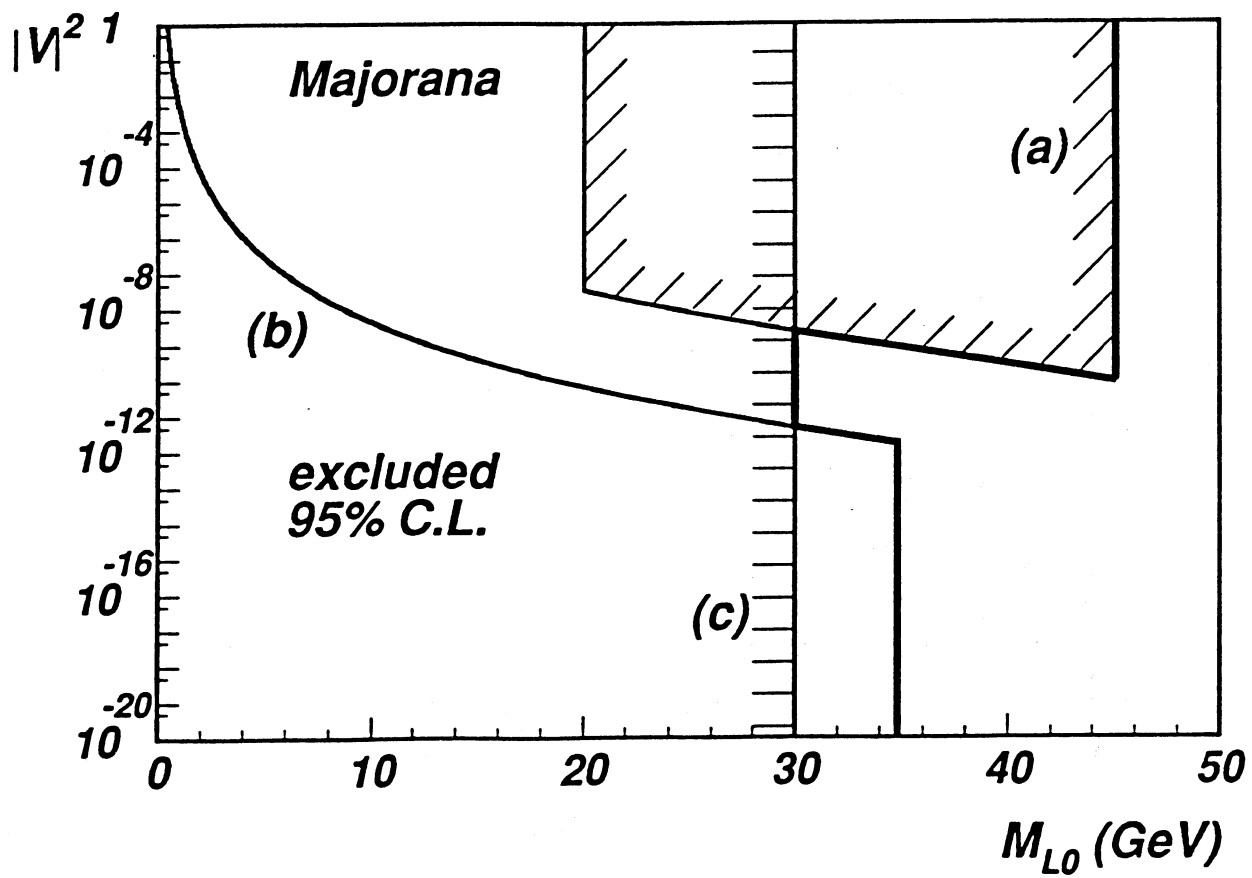
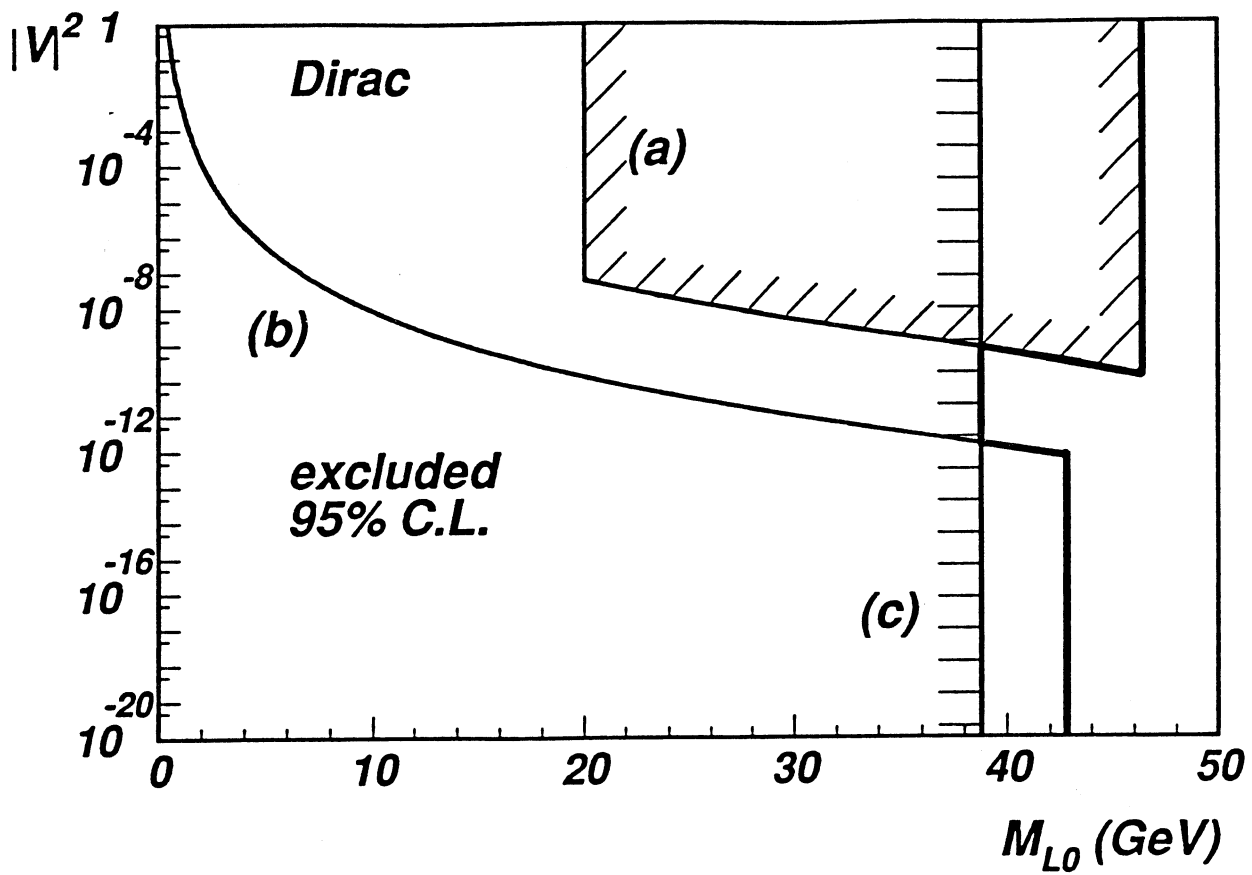


Figure 3

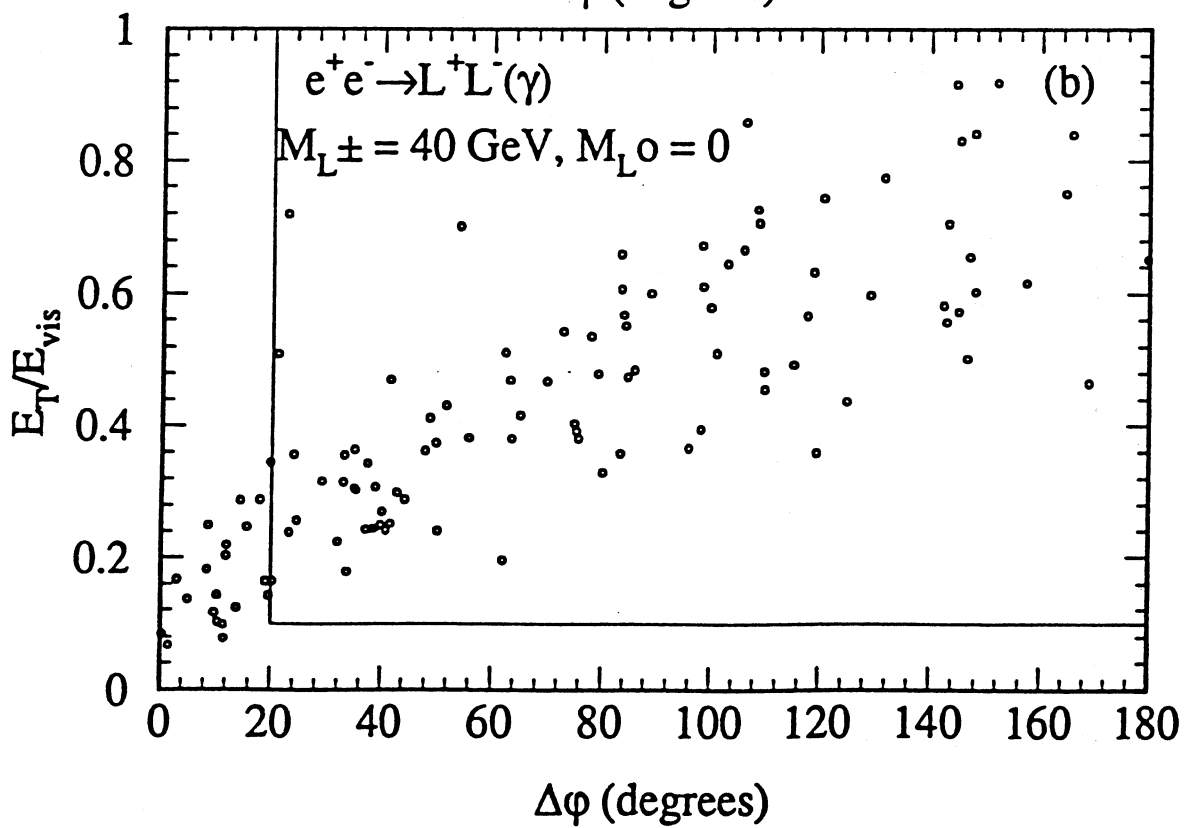
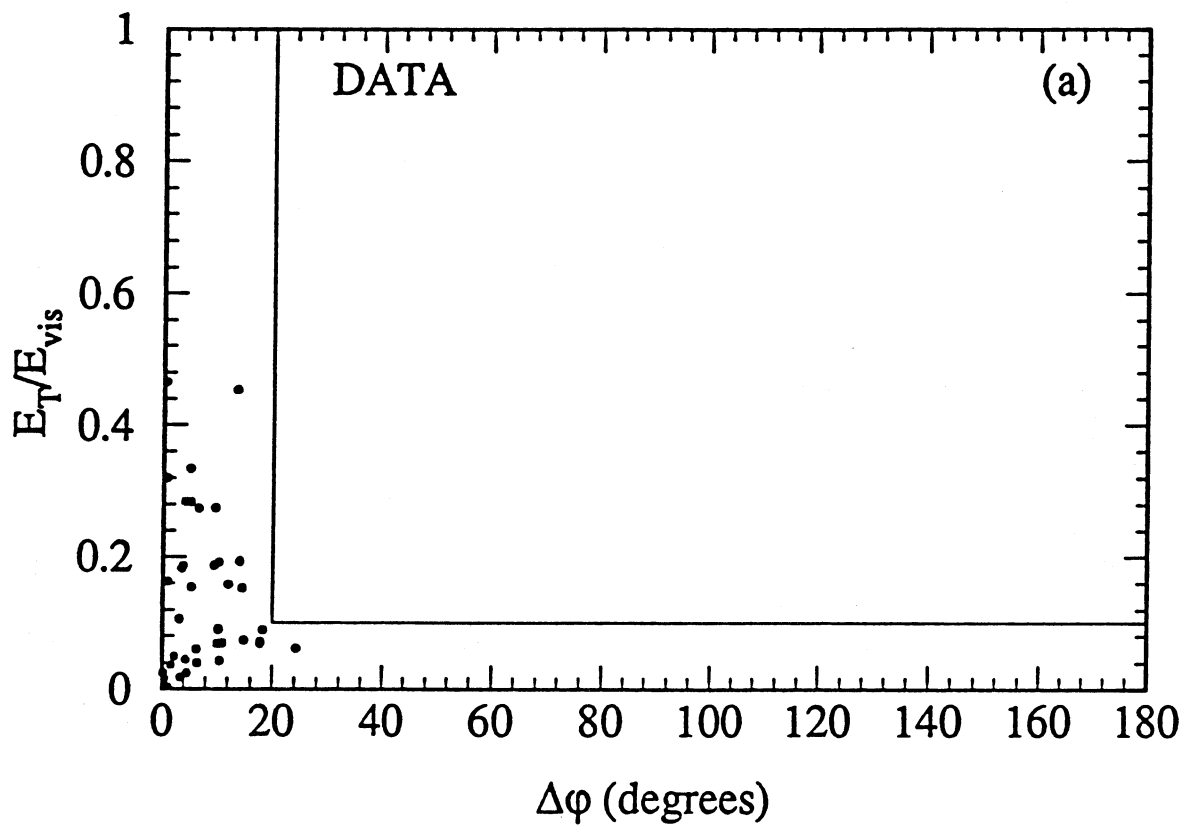


Figure 4

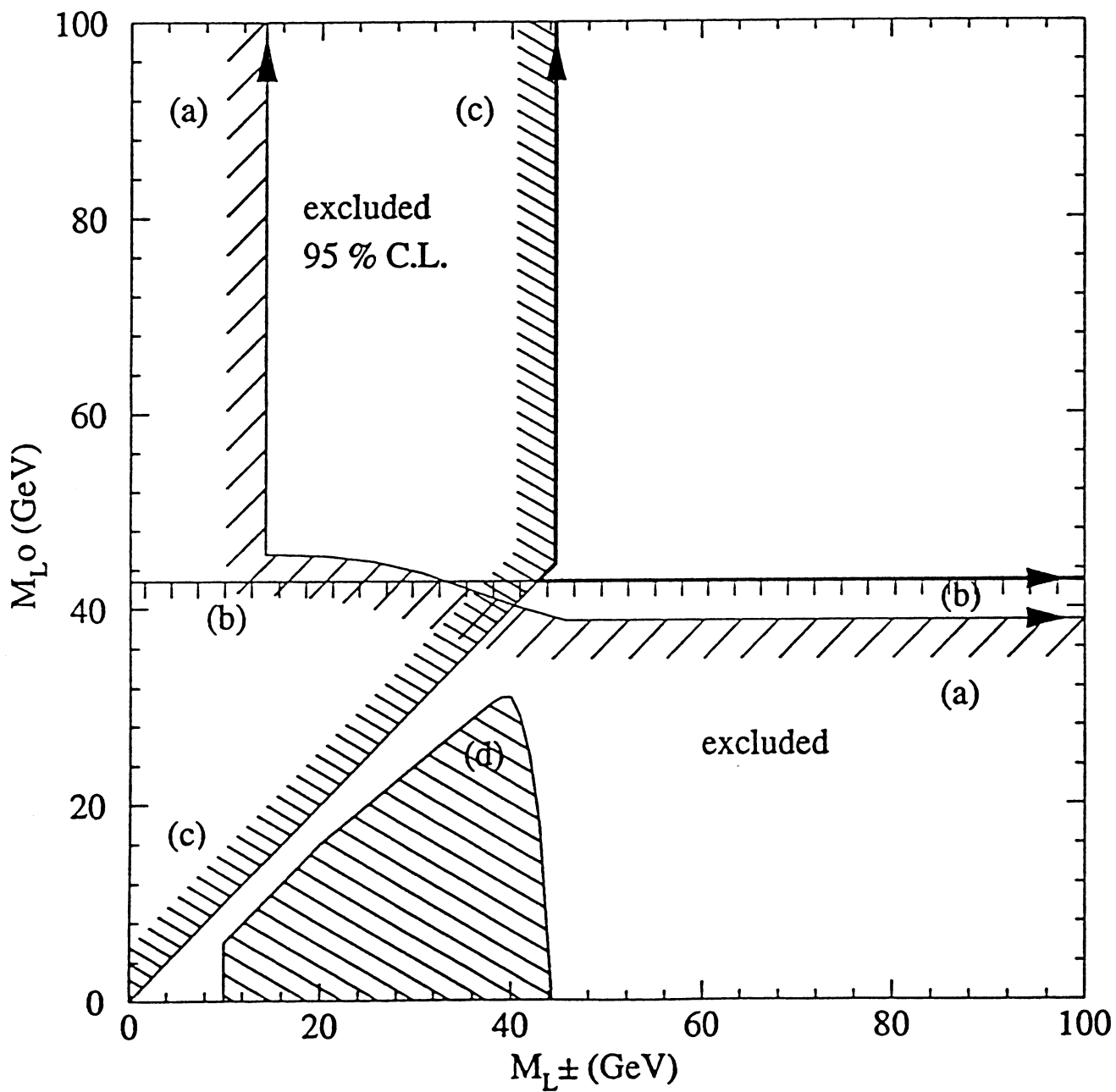


Figure 5