EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/95-XXX
July 23, 1997

Search for R–Parity Breaking Sneutrino Exchange at LEP

The L3 Collaboration

Abstract

We report on a search for R–parity breaking effects due to supersymmetric tau–sneutrino exchange in the reactions $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \mu^+\mu^-$ at $\sqrt{s} =$ 91–172 GeV, using the L3 detector at LEP. No evidence for deviations from the Standard Model expectations of the measured cross sections and forward–backward asymmetries for these reactions is found. Upper limits for the couplings λ_{131} and λ_{232} for sneutrino masses up to $m_{\tilde{\nu}_\tau} \leq 190$ GeV are determined from an analysis of the expected effects due to tau sneutrino exchange.

Submitted to *Phys. Lett. B*

Introduction

Supersymmetric theories [1] are considered to be the most promising and natural extensions of the Standard Model (SM). The standard minimal supersymmetric model [2] conserves baryon number B and lepton number L, usually represented as the existence of a multiplicative discrete symmetry called R–parity [3]. R–parity conservation is not ensured by gauge invariance. The most general superpotential even for a minimal supersymmetric model contains interactions violating B and L.

The high–x, high–Q^2 events observed by the H1 [4] and ZEUS [5] collaborations at HERA have revived the interest in theories with broken R–parity. In this case the superpotential contains L–violating trilinear Yukawa couplings of two leptons to scalar sleptons [6, 7]:

$$W^{\mathrm{lll}}_{\not{R}} = \lambda_{\mathrm{ijk}} \mathrm{L}^{\mathrm{i}}_{\mathrm{L}} \mathrm{L}^{\mathrm{j}}_{\mathrm{L}} \bar{\mathrm{E}}^{\mathrm{k}}_{\mathrm{R}} \;, \qquad (1)$$

where L stands for the left–handed doublets of leptons, E for the right–handed singlets of charged leptons, and *ijk* are generation indices. At least two different generations are coupled in the purely leptonic vertices, since $\lambda_{\mathrm{ijk}} \neq 0$ only for $i < j$. Depending on the value of the couplings λ the effects due to sneutrino exchange in leptonic e^+e^- processes at LEP energies can be large [8].

The effects of sneutrino exchange manifest themselves as deviations from the Standard Model expectations of the measured cross sections, σ, and forward–backward asymmetries, A_{fb}, for electron–pair and muon–pair production:

$$e^+e^- \to e^+e^-, \quad e^+e^- \to \mu^+\mu^-. \qquad (2)$$

Mass limits for sneutrinos within the Minimal Supersymmetric Standard Model are derived from the measurement of the invisible width of the Z: $m_{\tilde{\nu}} > 41.8$ GeV, if three sneutrino generations are assumed, and $m_{\tilde{\nu}} > 37.1$ GeV, in case of one sneutrino generation [9]. In theories with broken R–parity the search for sneutrinos is extended over the entire energy range of LEP1 and LEP2.

Measurements of Lepton–Pair Production

Measurements of the cross section and the forward–backward asymmetry for reactions (2) have been performed at centre–of–mass energies around the Z peak [10], at $\sqrt{s} = 130.3$ and 136.3 GeV [11], and at $\sqrt{s} = 161.3$, 170.3 and 172.3 GeV [12]. The selection procedure, the measurements with their statistical and the systematic errors are described in the references. The L3 detector and its performance are described in [13]. In all cases except for the $e^+e^- \to e^+e^-$ cross section measurement the low–statistics results at $\sqrt{s} = 170.3$ GeV are combined with the results at 172.3 GeV to a centre–of–mass energy of 172.1 GeV.

For electron pair production both leptons have to satisfy $44^\circ < \theta < 136^\circ$, where θ is the angle between the incoming electron and the outgoing fermion. For muon–pair production around the Z peak the angular acceptance is given by $|\cos\theta\,| < 0.8$. At higher energies, the angular range is extended to $|\cos\theta\,| < 0.9$.

At the Z resonance and well above 72258 and 1099 electron– and muon–pair events have been selected. These correspond to an integrated luminosity of 40.8 pb^{-1} and 26.2 pb^{-1}, respectively.

For comparison of the measured values with the predictions from the Standard Model or from theories with broken R–parity the measurements are not extrapolated to the full solid angle.

The theoretical expectations are instead computed with the same angular cuts as applied to the data.

Exchange of Tau Sneutrinos

Lepton–pair production in e^+e^- collisions is affected by the R–parity violating exchange of sneutrinos in the s– and/or t–channel. The corresponding diagrams for electron–pair production are shown in Figure 1. For muon– and tau–pair production only the s–channel SM diagram is present. Diagrams with sneutrino, $\widetilde{\nu}_j$, exchange are present if the couplings λ_{ijk} is not zero at both vertices.

Interactions which violate R–parity will introduce at energies well below the mass of the exchanged slepton the usual four–fermion contact interactions. In this letter, the impact of nearby resonances is investigated, which necessitate the inclusion of propagator and non–zero width effects [8].

Lepton number conservation places severe constrains on the couplings λ in the general case. Only if the effective four–fermion Lagrangian does not violate L conservation, the allowed values reach

$$\lambda \leq 0.1 \times (\frac{m_{\widetilde{\nu}}}{200 \ \ \mathrm{GeV}}) \ , \tag{3}$$

where $m_{\widetilde{\nu}}$ is the mass of the exchanged sneutrino.

This is possible if only some of the operators with a particular generation structure are present in Equation (1). Two main options lead to s–channel sneutrino exchange and potentially large effects:

- case (A): one single Yukawa coupling λ is much larger than all the others, so that the latter are negligible; two options are present: the muon sneutrino coupling to electrons λ_{121} is heavily constrained by the R–violating interpretation of the HERA data [8], but the coupling of tau sneutrinos to electrons λ_{131} can be sizeable and is considered further.

- case (B): two Yukawa couplings violating the same lepton flavour are much larger than the others; for s–channel exchange mainly the case where the coupling of tau sneutrinos to electrons, λ_{131}, and to muons, λ_{232}, are not equal to zero is of interest.

The cross section for electron–pair production in case (A) contains both s– and t–channel contributions from the exchange of γ/Z bosons and of tau sneutrinos and anti–sneutrinos. Muon–pair production is not affected. In tau–pair production only very small effects due to t–channel electron sneutrino exchange occur.

In case (B), the reaction $e^+e^- \rightarrow \mu^+\mu^-$ receives large additional contribution from tau sneutrino exchange in the s–channel and effects similar to those in $e^+e^- \rightarrow e^+e^-$ are obtained.

Deviations from the Standard Model predictions are computed with a program provided by the authors of [8]. Initial–state radiation (ISR) changes the effective centre–of–mass energy in a large fraction of the observed events. These effects are taken into account by computing the first order exponentiated cross sections and asymmetries following [14]. Other QED corrections give smaller effects and are neglected.

Examples of calculations before and after the inclusion of initial–state radiation are shown in Figure 2a for $e^+e^- \rightarrow e^+e^-$ and in Figure 2b for $e^+e^- \rightarrow \mu^+\mu^-$. Large effects are observed, especially in case of a radiative return to a nearby resonance. The typical interference curve in electron pair production is smeared after the inclusion of ISR, due to the integration over areas with constructive and destructive interference. The effects of the cut on the effective centre–of–mass energy $\sqrt{s'} > 0.85\sqrt{s}$ are also clearly visible.

Analysis and Results

For each centre–of–mass energy the deviation of the measured cross sections and forward–backward asymmetries from the Standard Model expectations for the same angular cuts are determined. Above the Z peak, the events at high effective centre–of–mass energy are used. They do not include the radiative return to the Z and have the largest sensitivity to a nearby resonance. For electron–pair production the programs ALIBABA [15] and TOPAZ0 [16] are used at the Z peak and at higher energies, respectively. For muon–pair production ZFITTER [17] is used throughout. The error on a deviation consists of three parts, which are combined in quadrature: statistical error, systematic error and theoretical error. The systematic error for cross sections includes the luminosity error of our measurements ranging from 0.25% to 0.6%. Thus the cross section measurements depend on the normalisation. For A_{fb} measurements there is no such dependence, and the statistical errors above the Z peak are still dominant. The measurements of σ and A_{fb} are independent and are combined.

For each centre–of–mass energy the deviations from the Standard Model are computed resulting from tau sneutrino exchange, as a function of the tau sneutrino mass and coupling strength λ. This is done on a two–dimensional grid which contains 200 values for $m_{\tilde{\nu}_\tau}$ between 60 and 260 GeV, and 100 values for λ between 0.01 and 0.20.

No statistically significant deviations from the Standard Model predictions are observed. The maximum likelihood method is used to derive a one sided upper limit on the coupling strength λ at the 90% confidence level for a given value of $\mathrm{m}_{\tilde{\nu}_\tau}$. The likelihood function, L, is constructed by combining the cross section and A_{fb} measurements at the different centre–of–mass energies:

$$-\ln \mathrm{L} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\frac{(\sigma(\mathrm{SM};\lambda,\mathrm{m}_{\tilde{\nu}_\tau}) - \sigma^{\mathrm{meas}})^2}{2\cdot\Delta_\sigma^2} + \frac{(\mathrm{A_{fb}}(\mathrm{SM};\lambda,\mathrm{m}_{\tilde{\nu}_\tau}) - \mathrm{A_{fb}^{meas}})^2}{2\cdot\Delta_{\mathrm{A_{fb}}}^2} \right)_{\mathrm{i}} \tag{4}$$

$$\begin{aligned} \Delta_\sigma &= \mathrm{error}(\sigma(\mathrm{SM};\lambda,m_{\tilde{\nu}_\tau}) - \sigma^{\mathrm{meas}}) \, , \\ \Delta_{\mathrm{A_{fb}}} &= \mathrm{error}(A_{\mathrm{fb}}(\mathrm{SM};\lambda,m_{\tilde{\nu}_\tau}) - A_{\mathrm{fb}}^{\mathrm{meas}}) \, , \end{aligned} \tag{5}$$

where $\sigma(\mathrm{SM};\lambda,\mathrm{m}_{\tilde{\nu}_\tau})$ and $\mathrm{A_{fb}}(\mathrm{SM};\lambda,\mathrm{m}_{\tilde{\nu}_\tau})$ are the expectations for the cross section and the forward–backward asymmetry from the Standard Model combined with the additional effect of sneutrino exchange as a function of the mass and the coupling strength, and σ^{meas} and $A_{\mathrm{fb}}^{\mathrm{meas}}$ are the measured quantities. The index i runs over all energy points. After proper normalisation the likelihood function gives the probability for $\lambda_{ijk} < \lambda_{\mathrm{lim}}$ for any value of λ_{lim} in the physically allowed region.

Finally, the results for the different sneutrino masses are combined in a single exclusion plot in the $(m_{\tilde{\nu}_\tau}, \lambda)$ plane. The results for electron–pair production are shown in Figure 3. The LEP high energy data has larger sensitivity to new physics of this type compared to the high precision measurements at the Z peak. This is due to the fact that the absolute, and not the relative, error is crucial in this search. The results are compared with limits on R–parity breaking interactions from processes at lower energies [7]. The strongest limit on the coupling λ_{131} comes from precise measurements of the ratio $\mathrm{R}_\tau = \Gamma(\tau \to \mathrm{e}\nu\bar{\nu})/\Gamma(\tau \to \mu\nu\bar{\nu})$. Using the latest data [18], a 90% confidence level upper limit is derived and also shown in Figure 3.

For muon–pair production the results are shown in Figure 4, together with the 90% confidence level constrains derived from the lower energy measurements. In this case the strongest limit on λ_{232} comes from precise measurements of the ratio $\mathrm{R}_{\tau\mu} = \Gamma(\tau \to \mathrm{e}\nu\bar{\nu})/\Gamma(\mu \to \mathrm{e}\nu\bar{\nu})$. In order to simplify the presentation of the limit in two dimensions, it is assumed that $\lambda_{131} = \lambda_{232}$. In both cases, large and previously unexplored areas in the $(m_{\tilde{\nu}_\tau},\ \lambda_{131})$ and $(m_{\tilde{\nu}_\tau},\ \lambda_{131} = \lambda_{232})$ planes are excluded.

Acknowledgements

We wish to express our gratitude to the CERN accelerator divisions for the excellent performance of the LEP machine. We acknowledge the contributions of all the engineers and technicians who have participated in the construction and maintenance of this experiment. We are grateful to J. Kalinowski, R. Rückl, H. Spiesberger and P. Zerwas for providing us with their code and for many discussions.

References

[1] J. Wess and B. Zumino, Phys. Lett. **B 49** (1974) 52.

[2] H.P. Nilles, Physics Reports **110** (1984) 1.

[3] G. Farrar and P. Fayet, Phys. Lett. **B 76** (1978) 575.

[4] H1 Collab., C. Adloff *et al.*, Preprint DESY 97-24, DESY, 1997, To be published in Zeit. Phys. C.

[5] ZEUS Collab., J. Breitweg *et al.*, Preprint DESY 97-25, DESY, 1997, To be published in Zeit. Phys. C.

[6] S. Dimopoulos and L. Hall, Phys. Lett. **B 207** (1987) 210.

[7] V. Barger, G. Giudice and T. Han, Phys. Rev. **D 40** (1989) 2987.

[8] J. Kalinowski, R. Rückl, H. Spiesberger and P. Zerwas, Preprint DESY 97-044, DESY, 1997, To be published in Phys. Lett. B.

[9] L3 Collab., O. Adriani *et al.*, Physics Reports **236** (1993) 1.

[10] L3 Collab., M. Acciarri *et al.*, Z. Phys. **C 62** (1994) 551.

[11] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 370** (1996) 195.

[12] L3 Collab., M. Acciarri *et al.*, Preprint CERN-PPE/97-52, CERN, 1997, To be published in Phys. Lett. B.

[13] L3 Collab., B. Adeva *et al.*, Nucl. Inst. Meth. **A 289** (1990) 35;
M. Acciarri *et al.*, Nucl. Inst. Meth. **A 351** (1994) 300;
M. Chemarin *et al.*, Nucl. Inst. Meth. **A 349** (1994) 345;
I.C. Brock *et al.*, Nucl. Inst. Meth. **A 381** (1996) 236;
A. Adam *et al.*, Nucl. Inst. Meth. **A 383** (1996) 342.

[14] R. Kleiss *et al.*, Z Physics at LEP 1, volume 3, (CERN, 1989).

[15] W. Beenakker, F.B. Berends and S.C. van der Marck, Nucl. Phys. **B 349** (1991) 323.

[16] G. Montagna, O. Nicrosini, G. Passarino, F. Piccinini and R. Pittau, Nucl. Phys. **B 401** (1993) 3.

[17] D. Bardin *et al.*, FORTRAN package ZFITTER, and preprint CERN–TH. 6443/92;
D. Bardin *et al.*, Z. Phys. **C 44** (1989) 493;
D. Bardin *et al.*, Nucl. Phys. **B 351** (1991) 1;
D. Bardin *et al.*, Phys. Lett. **B 255** (1991) 290..

[18] R. Barnett *et al.*, Phys. Rev. **D 54** (1996) 1.

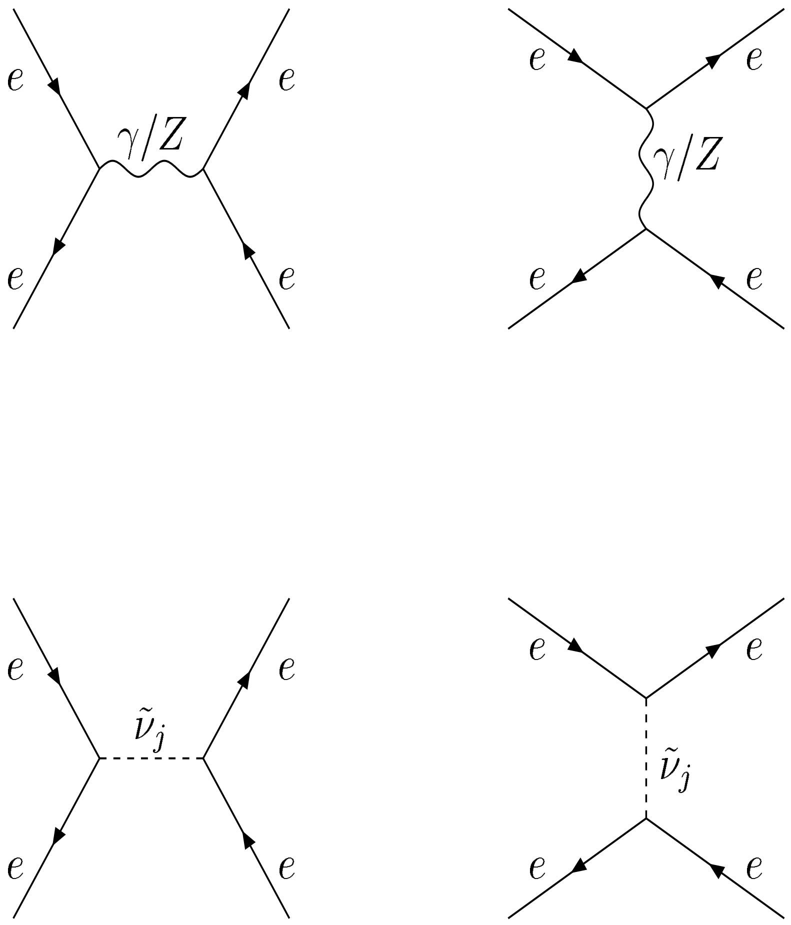

Figure 1: Feynman diagrams for the reaction $e^+e^- \rightarrow e^+e^-$, including the exchange of $\tilde{\nu}_j$ in the s– and t–channel with $\lambda_{1j1} \neq 0$.

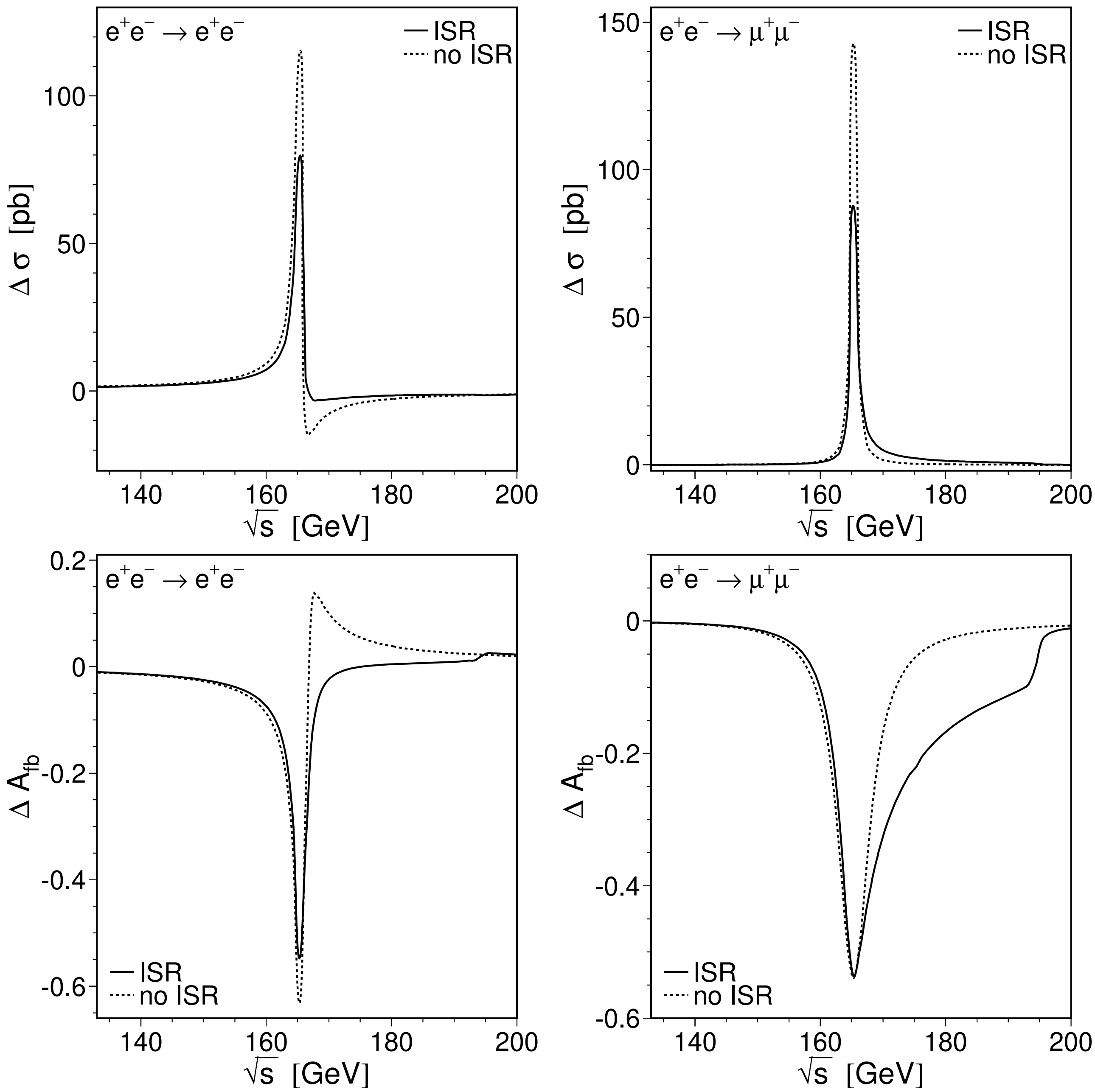

Figure 2: Deviations of the cross section, Δ_σ, and the forward–backward asymmetry, $\Delta A_{\rm fb}$ from the SM expectations due to sneutrino exchange as a function of the centre–of–mass energy: on the left for $e^+e^- \to e^+e^-$ and on the right for $e^+e^- \to \mu^+\mu^-$. The dashed line shows the results before and the solid line after the inclusion of ISR. The parameter values for this calculations are $m_{\tilde{\nu}_\tau} = 165.3$ GeV, $\Gamma_{\tilde{\nu}_\tau} = 1$ GeV, $\lambda_{131} = 0.08$ and $\lambda_{232} = 0.08$.

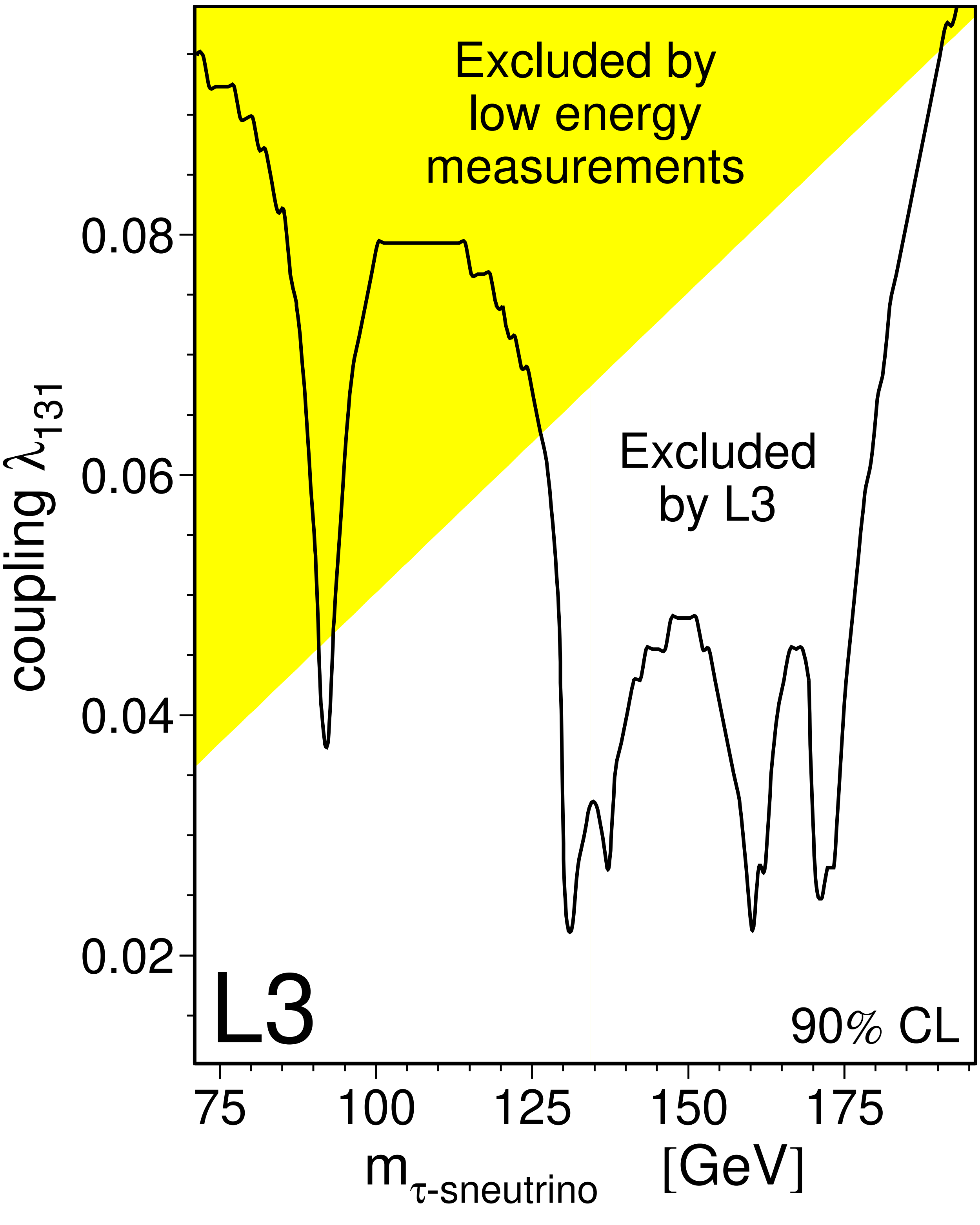

Figure 3: Upper limits on the coupling strength λ_{131} as a function of $m_{\tilde{\nu}_\tau}$ derived from the measurements of electron–pair production. The shaded area above the straight line is excluded by lower energy measurements at 90% confidence level. The jagged curve is the 90% confidence level upper limit from this analysis.

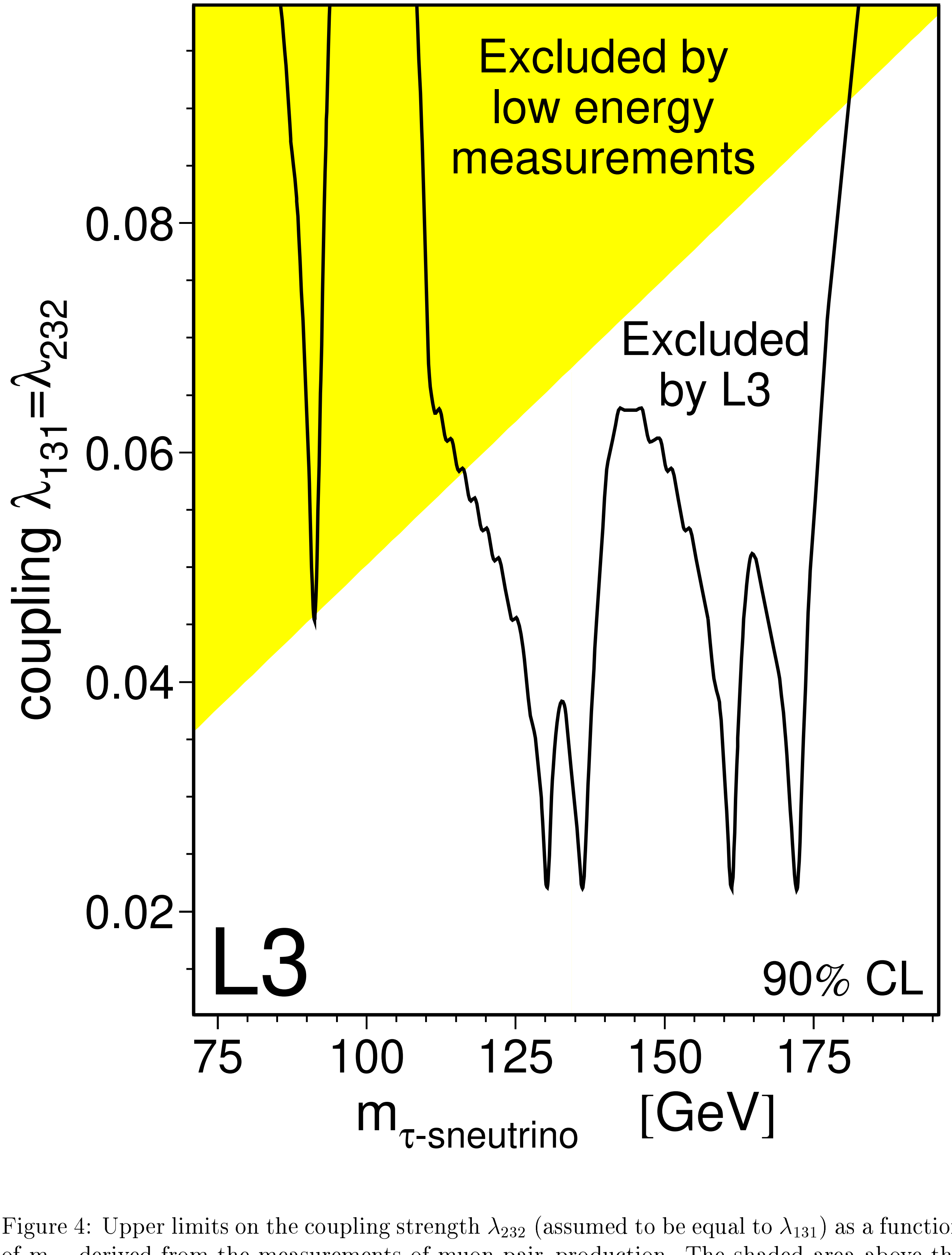

Figure 4: Upper limits on the coupling strength λ_{232} (assumed to be equal to λ_{131}) as a function of $m_{\tilde{\nu}_\tau}$ derived from the measurements of muon pair–production. The shaded area above the straight line is excluded by lower energy measurements at 90% confidence level. The jagged curve is the 90% confidence level upper limit from this analysis.