EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

L3 Note 2759
June 30, 2002

Search for New Physics Phenomena in Fermion-Pair Production in e^+e^- Collisions at Centre–of–Mass Energies up to 209 GeV

The L3 Collaboration

Abstract

The measurements of hadron and lepton–pair production cross sections and leptonic forward–backward asymmetries performed with the L3 detector at centre–of–mass energies between 130 GeV and 209 GeV (all results above 190 GeV are preliminary) are used to search for new physics phenomena such as: contact interactions, exchange of virtual leptoquarks and Z′ bosons, effects of low scale gravity and TeV strings in models of quantum gravity with large extra dimensions. No evidence for these phenomena is found and new preliminary limits on their parameters are set.

Submitted to the 31st *International Conference on High Energy Physics*

Introduction

The study of fermion–pair production, $e^+e^- \rightarrow f\bar{f}$, at centre–of–mass energies well above the Z resonance allows to look for physics beyond the Standard Model. This note updates the results from our previous searches [1–4], using the full LEP2 data set above the Z pole.

The results presented in this paper are based on analyses of our measurements of hadronic and leptonic cross sections and leptonic forward–backward asymmetries [5–8]. The measurements in all channels are used to search for four-fermion contact interactions. The virtual exchange of leptoquarks is investigated using our hadron cross section measurements. Limits on contact interactions, and on leptoquark couplings have been presented also by other LEP collaborations [9–11]. The effects of TeV strings, predicted recently [12, 13] in theories of quantum gravity with extra dimensions [14], are searched for in Bhabha scattering. This is an extension of the searches for low scale gravity in fermion–pair production at LEP [2, 11, 15, 16].

Data and Analysis Method

Measurements of cross sections and forward–backward asymmetries for the reactions $e^+e^- \rightarrow f\bar{f}$ have been performed with the L3 detector [17] at centre–of–mass energies, $\sqrt{s}$, of 130.0 GeV, 136.1 GeV, 161.3 GeV, 172.3 GeV, 182.7 GeV, 188.7 GeV [5–7], and at $\sqrt{s} =$ 191.6–209 GeV [8]. They correspond to an integrated luminosity of 705 pb^{-1}.

For the e^+e^- final state both leptons have to be in the polar angular range $44° < \theta < 136°$, where θ is the angle between the incoming electron and the outgoing lepton. Muon– and tau–pair candidates are selected with both leptons in the fiducial volume given by $|\cos\theta| < 0.9$ and $|\cos\theta| < 0.92$, respectively. Hadron events are selected in the full solid angle. A minimum effective centre–of–mass energy, $\sqrt{s'_{\text{min}}}$, or a maximum acollinearity angle in the Bhabha channel, are required to select events without substantial energy loss due to initial state radiation.

The measurements of total cross sections and leptonic forward–backward asymmetries are analysed in terms of new physics, which will manifest itself as deviations from the Standard Model predictions. The contributions of contact interactions, leptoquarks and scalar quarks are included directly into the improved Born cross section calculated with the program ZFITTER [18] and are convoluted to account for QED radiative corrections. For the analyses including the e^+e^- final state, i.e. contact interactions, scalar neutrinos, TeV strings and form factors, the effects of new phenomena are computed with dedicated programs in the improved Born approximation, taking into account QED radiative corrections. For contact interactions where both approaches are used, the results agree well with each other.

The measurements are compared to the predictions of the Standard Model [19] as calculated using the ZFITTER, TOPAZ0 [20] and BHWIDE [21] programs with the following parameters [22–24]: $m_{\text{Z}} = 91.190$ GeV, $\alpha_s(m_{\text{Z}}^2) = 0.119$, $m_{\text{t}} = 173.8$ GeV, $\Delta\alpha^{(5)}_{\text{had}} = 0.02804$, and $m_{\text{H}} = 150$ GeV. The results of our analyses are not sensitive to small variations of these parameters. The theoretical uncertainties on the Standard Model predictions are estimated to be below 0.5% [25] except for large angle Bhabha scattering where the uncertainty is 1.5% [20, 21, 26].

The measurements show no statistically significant deviations from the Standard Model expectations. In their absence, limits at 95% confidence level on the contributions of new physics are determined by integrating the log-likelihood functions in the physically allowed range of the parameters describing new physics phenomena, assuming a uniform prior distribution. The statistical errors and systematic uncertainties of the measurements [6, 7], as well as the theory uncertainties given above, are combined in quadrature for all analyses.

Four–Fermion Contact Interactions

Four-fermion contact interactions offer a general framework for describing interactions beyond the Standard Model. They are characterised by a coupling strength, g, and by an energy scale, Λ, which can be viewed as the typical mass of new heavy particles being exchanged. At energies much lower than Λ, the exchange of virtual new particles is described by an effective Lagrangian [27]:

$$\mathcal{L} = \frac{1}{1+\delta_{\mathrm{ef}}} \sum_{i,j=\mathrm{L,R}} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} (\bar{\mathrm{e}}_i \gamma^\mu \mathrm{e}_i)(\bar{f}_j \gamma_\mu f_j), \tag{1}$$

where e_i and f_j denote the left– and right–handed initial–state electron and final–state fermion fields. The Kronecker symbol, δ_{ef}, is zero except for the $\mathrm{e}^+\mathrm{e}^-$ final state where it is one. The parameters η_{ij} define the contact interaction model by choosing the helicity amplitudes which contribute to the reaction $\mathrm{e}^+\mathrm{e}^- \to f\bar{f}$. The value of g/Λ determines the size of the expected effects. By convention $g^2/4\pi$ is chosen to be 1 and $|\eta_{ij}| = 1$ or $|\eta_{ij}| = 0$, leaving the energy scale Λ as free parameter. The helicity combinations of the specific models considered are defined in Table 1. Atomic physics parity violation experiments probe with high precision the couplings of electrons to quarks of the first family, and place severe constraints on the scale Λ of the order of 15 TeV [28]. The VV, AA, V0 and A0 models are parity conserving and hence are not constrained by such measurements.

The four–fermion contact interactions for the different types of final–state fermions are tested separately as well as for all flavours combined and lower limits on the scale Λ are derived. The lower limits on Λ obtained from lepton–pair final states are summarised in Table 2 and Figure 1. It is important to note that the pure leptonic case is only accessible at LEP.

For hadronic final states the cases where the contact interactions affect all flavours at the same time, and only one flavour of up–type or down–type quarks, are analyzed. The results are given in Table 3 and depicted in Figure 2, together with the combined results for all charged fermions. Similar limits are obtained from studies of deep inelastic scattering at HERA [29, 30] and proton–antiproton collisions at the TEVATRON [31, 32].

In a new analysis, the results for the measurement of the $\mathrm{b\bar{b}}$ cross section [33] are also included. A separate look to contact interactions that contribute only to $\mathrm{b\bar{b}}$ final states gives the results shown in Table 4.

Leptoquarks

Leptoquarks couple to quark–lepton pairs from the same family, preserving the baryon number B and the lepton number L. Leptoquarks carry fermion numbers, $F = L + 3B$. Following the notation in Reference [34], scalar leptoquarks S_I and vector leptoquarks V_I are indicated based on spin and isospin I. Isomultiplets with different hypercharges are denoted by an additional tilde.

In the process $\mathrm{e}^+\mathrm{e}^- \to$ hadrons leptoquarks of the first generation can be exchanged in the t–channel ($F = 0$) or in the u–channel ($F = 2$). The coupling of leptoquarks to quark–lepton pairs, g, is referred to as $g_{\rm L}$ or $g_{\rm R}$, according to the chirality of the lepton. The contributions of leptoquark exchange to $\rm e^+e^- \rightarrow q\bar{q}$ depend on g^2.

Studying the exchange of different types of leptoquarks separately, limits on $|g|$ are derived depending on the mass, $m_{\rm LQ}$, of the exchanged leptoquark. The states S_0, $S_{1/2}$ and V_0, $V_{1/2}$ couple to both left- and right-handed quarks. Here, only $g_{\rm L}$ or $g_{\rm R}$ is assumed to be non–zero since low energy processes and rare decays of π and K constrain the product $g_{\rm L}\, g_{\rm R}$ [35]. Upper limits on the allowed values for $|g|$ are presented in Figure 3 for scalar leptoquarks and in Figure 4 for vector leptoquarks.

For a coupling of electromagnetic strength, $g = \sqrt{4\pi\alpha}$, where α is the fine-structure constant, mass limits can be derived. The results for these lower bounds on leptoquark masses are given in Table 5. In case of $\tilde{S}_{1/2}(\rm L)$ exchange, i.e. coupling to left-handed fermions, the assumption $g_{\rm L} = \sqrt{4\pi\alpha}$ yields a very small contribution to the hadron cross section that is not observable with the precision of our measurements.

The results at LEP complement the leptoquark searches at HERA. In most cases the indirect limits on leptoquark masses and couplings obtained in our analysis are more stringent than the corresponding limits presented by the H1 collaboration [30]. The indirect search covers regions at high leptoquark masses above the reach of direct leptoquark searches [36].

Extra Z Bosons

Additional heavy gauge bosons, Z′ are predicted by many theories. Popular models result from an $\rm E_6$ GUT or from left–right symmetries [37, 38],

$$J^\mu_{Z'} = J^\mu_\chi \cos\Theta_6 + J^\mu_\psi \sin\Theta_6; \qquad J^\mu_{Z'} = \alpha_{LR} J^\mu_{3R} - \frac{1}{2\alpha_{LR} J^\mu_{B-L}}. \tag{2}$$

Specific cases are the χ, ψ and η model ($\Theta_6 = 0; \pi/2; -\arctan\sqrt{5/3}$) and Left-Right models ($\sqrt{2/3} \le \alpha_{LR} \le \sqrt{\cot^2\theta_W - 1}$). For the analyses the ρ-parameter at tree-level, ρ_0, is assumed to be zero.

Since no indication for the existence of a Z′ is found bounds on the Z′ parameters can be determined. A ZZ′ mixing modifies the couplings of the Z boson to fermions. Precision measurements on the Z peak are sensitive to the couplings and, hence, to the ZZ′ mixing, θ_M. Including the results of the L3 measurements on the Z resonance [39] bounds in the $m_{\rm Z'} - \theta_M$ plane are derived. For Z′ masses above the direct search limits from Tevatron [40] the L3 measurements shrink the ZZ′ mixing angle to

$$|\theta_M| < 4 \cdot 10^{-3}, \tag{3}$$

compatible with vanishing ZZ′ mixing ($\theta_M = 0$).

Fixing θ_M to zero, lower bounds on the Z′ mass, $m^{min}_{\rm Z'}$ are derived as summarized in Table 6. It also includes the Sequential Standard Model, SSM, where a Z′ with Standard Model couplings is postulated. A comparison of these limits with the results of direct searches at Tevatron [40] is given. Lower limits $m_{\rm Z'}$ at the 95% confidence level for all $\rm E_6$ and left-right symmetric models are determined as shown in Figure 5 for the parameters Θ_6 and α_{LR}.

A more general approach does not fix the Z′ model, i.e. the $\rm Z'f\bar{f}$ couplings are free parameters. But far away of a Z′ resonance the measurements of cross sections and asymmetries of fermion–pair production are only sensitive to the ratio of Z′ couplings and Z′ mass. Best information can be reached considering leptonic cross section and asymmetry measurements and assuming lepton universality. In this case the Z′ couplings to the leptons in the initial and final state agree and together with the Z′ mass they are the only unknown parameters.

The resulting Z′ couplings to leptons, v'_l and a'_l, derived in a model-independent Z′ search are shown at the 95% confidence level in Figure 6 for three different Z′ masses. The values $v'_l = a'_l = 0$ are included; no hint for an existence of an extra Z′ boson is found.

Low Scale Gravity

The cross section and asymmetry measurements from 192–209 GeV are used to extend our search [2] for effects of quantum gravity in theories with extra dimensions. We update the results for the Bhabha channel, which is the most sensitive at LEP2 energies [15]. The results from the fit are:

$$\mathrm{M_s} > 1.04 \ \ \mathrm{TeV}, \ \lambda = +1 \tag{4}$$

$$\mathrm{M_s} > 1.05 \ \ \mathrm{TeV}, \ \lambda = -1 \tag{5}$$

and are shown in Figure 7. They improve on our published results and will improve further when we analyze the differential cross section. Scales of the order of ~ 1 TeV are already excluded.

TeV Strings

Recently, it has been realized that in a string theory of quantum gravity [12, 13] there are new phenomenological consequences. For instance, massive string mode oscillations can lead to contact interactions, which may have stronger effects than those caused by the virtual exchange of gravitons.

The effects of TeV scale strings on Bhabha scattering are computed [13] by multiplying the leading-order scattering amplitudes by a common form factor, which depends on the string scale M_S and the Mandelstam variables s and t. The Standard Model cross section for Bhabha scattering is modified as follows:

$$\frac{d\sigma}{d\cos\theta} = \left(\frac{d\sigma}{d\cos\theta}\right)_{SM} \left| \frac{\Gamma(1-\frac{s}{M_S^2})\Gamma(1-\frac{t}{M_S^2})}{\Gamma(1-\frac{s}{M_S^2}-\frac{t}{M_S^2})} \right|^2 , \tag{6}$$

where Γ is the gamma function.

The cross sections and forward-backward asymmetries measured between 130 and 209 GeV are used to derive a lower limit on the string scale M_S of 0.55 TeV.

Conclusions

The measurements of fermion–pair cross sections and forward–backward asymmetries, performed with the L3 detector at centre–of–mass energies between 130 GeV and 209 GeV, are used to search for effects of new physics phenomena. No hint of manifestations of physics beyond the Standard Model is found.

The sensitivity of the searches, performed at energies above the Z pole, has improved substantially compared to our previous publications with the analysis of the full LEP2 data set.

Preliminary limits on the energy scale Λ of four–fermion contact interactions in the range 4.7 – 20.2 TeV for leptons, and in the range 2.2 – 11.3 TeV for quarks are obtained. The effects of the exchange of leptoquarks are studied. Upper limits on the coupling constants, $|g_{\rm L}|$ and $|g_{\rm R}|$ are determined as a function of the particle masses. Lower limits on the mass of leptoquarks between 112 GeV and 557 GeV, depending on the leptoquark type, are derived assuming $g = \sqrt{4\pi\alpha}$. Additional heavy neutrol gauge bosons, Z′, are excluded for masses below 280 GeV - 1020 GeV depending on the model ivenstigated. Extra dimension, as described by quantum gravity models, are excluded at scales below ~ 1 TeV . In addition, new searches are performed for the effects of TeV strings, predicted in quantum gravity models, and a lower limit on the string scale M_S of 0.55 TeV is set.

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 the engineers and technicians who have participated in the construction and maintenance of this experiment.

References

[1] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 414** (1997) 373; L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 433** (1998) 163; L3 Collab., M. Acciarri *et al.*, Phys. Lett. **489** (2000) 81.

[2] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 464** (1999) 135; L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 470** (1999) 281.

[3] The L3 collaboration, L3 Note 2543, L3, CERN, June 29, 2000.

[4] The L3 collaboration, L3 Note 2647, L3, CERN, March 2, 2001.

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

[6] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 407** (1997) 361.

[7] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 479** (2000) 101.

[8] The L3 collaboration, L3 Note 2763, L3, CERN, July 1, 2002.

[9] ALEPH Collab., R. Barate *et al.*, E. Phys. J. **C 12** (2000) 183.

[10] DELPHI Collab., P. Abreu *et al.*, Phys. Lett. **B 485** (2000) 45.

[11] OPAL Collab., G. Abbiendi *et al.*, E. Phys. J. C13(2000)553.

[12] E. Accomando, I. Antoniadis and K. Benakli, preprint hep-ph/9912287.

[13] S. Cullen, M. Perelstein and M. Peskin, preprint hep-ph/0001166.

[14] N. Arkani-Hamed, S. Dimopoulos and G. Dvali, Phys. Lett. **B 429** (1998) 263; I. Antoniadis *et al.*, Phys. Lett. **B 436** (1998) 257; N. Arkani-Hamed, S. Dimopoulos and G. Dvali, Phys. Rev. **D 59** (1999) 086004.

[15] D. Bourilkov, J. High Energy Phys. **08** (1999) 006.

[16] D. Bourilkov, Phys. Rev. **D 62** (2000) 076005.

[17] L3 Collab., B. Adeva *et al.*, Nucl. Inst. Meth. **A 289** (1990) 35; F. Beissel *et al.*, Nucl. Inst. Meth. **A 332** (1993) 33; 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.

[18] ZFITTER version 6.21 is used.
D. Bardin *et al.*, preprint hep-ph/9908433; Z. Phys. **C 44** (1989) 493; Nucl. Phys. **B 351** (1991) 1; Phys. Lett. **B 255** (1991) 290. For the comparison with our measurements, the following ZFITTER flags have been changed from their default values: `FINR` = 0, `INTF` = 0, and `BOXD` = 2.

[19] S.L. Glashow Nucl. Phys. **22** (1961) 579; S. Weinberg, Phys. Rev. Lett. **19** (1967) 1264; A. Salam, *Elementary Particle Theory*, ed. N. Svartholm, Stockholm, Almquist & Wiksell (1968) 367.

[20] TOPAZ0 version 4.4 is used.
G. Montagna *et al.*, Nucl. Phys. **B401** (1993) 3; Comp. Phys. Comm. **76** (1993).

[21] S. Jadach and W. Placzek and B. Ward, Phys. Lett. **B 390** (1997) 298.

[22] L3 Collab., M. Acciarri *et al.*, Z. Phys. **C 62** (1994) 551; L3 Collab., O. Adriani *et al.*, Physics Reports **236** (1993) 1; S. Eidelmann and F. Jegerlehner, Z. Phys. **C 67** (1995) 585.

[23] Particle Data Group, C. Caso *et al.*, E. Phys. J. **C 3** (1998) 1.

[24] CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **82** (1999) 2808; DØ Collab., S. Abachi *et al.*, Phys. Rev. Lett. **79** (1997) 1197; we use the average top mass as given in Reference [23].

[25] D. Bardin, private communication.

[26] Reports of the Working Groups on Precision Calculations for LEP2 physics; Two-fermion Production in Electron-positron Collisions, CERN-YR-2000-009, hep-ph/0007180.

[27] E. Eichten, K. Lane and M. Peskin, Phys. Rev. Lett. **50** (1983) 811.

[28] C.S. Wood *et al.*, Science **275** (1997) 1759; V. Barger *et al.*, Phys. Lett. **B 404** (1997) 147; N. Di Bartolomeo and M. Fabbrichinesi, Phys. Lett. **B 406** (1997) 237.

[29] ZEUS Collab., J. Breitweg *et al.*, E. Phys. J. **C**(2000) http://dx.doi.org/10.1007/s100520000336.

[30] H1 Collab., C. Adloff *et al.*, preprint DESY 00-027, accepted by Phys. Lett. B.

[31] CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **79** (1997) 2198.

[32] DØ Collab., B. Abbott *et al.*, Phys. Rev. Lett. **82** (1999) 4769.

[33] L3 Collab., M. Acciarri *et al.*, preprint CERN-EP-2000-054, hep-ex/0005023, accepted by Phys. Lett. B; L3 Collab., M. Acciarri *et al.*, L3 Note 2640, L3, CERN, March, 2001.

[34] A. Djouadi *et al.*, Z. Phys. **C 46** (1990) 679; B. Schrempp, Proceedings, *Physics at HERA* (Hamburg 1991), eds. W. Buchmüller and G. Ingelman.

[35] M. Leurer, Phys. Rev. **D 49** (1994) 333; *ibid.* **D 50** (1994) 536; S. Davidson, D. Bailey and D. Campbell, Z. Phys. **C 61** (1994) 613; M. Hirsch, H.V. Klapdor–Kleingrothaus and S.G. Kovalenko, Phys. Rev. **D 54** (1996) R4207.

[36] H1 Collab., C. Adloff *et al.*, E. Phys. J. **C 11** (1999) 447; ZEUS Collab., J. Breitweg *et al.*, preprint DESY 00-023, accepted by E. Phys. J. C; CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **79** (1997) 4327; DØ Collab., B. Abbott *et al.*, Phys. Rev. Lett. **80** (1998) 2051.

[37] For a review see *e.g.* J.L. Hewett, T.G. Rizzo Phys. Rev. **183** (1989) 193.

[38] L.S. Durkin, P. Langacker, Phys. Lett. **B 166** (1986) 436; for a review see *e.g.* R.N. Mohapatra, *Unifications and Supersymmetries*, Springer, New York 1989.

[39] L3 Collab., M. Acciarri *et al.*, E. Phys. J. **C 16** (2000) 1.

[40] CDF Collab., F. Abe *et al.*, Phys. Rev. Lett. **79** (1997) 2191.

Model	LL	RR	LR	RL	VV	AA	V0	A0	LL−RR
$\eta_{\rm LL}$	±1	0	0	0	±1	±1	±1	0	±1
$\eta_{\rm RR}$	0	±1	0	0	±1	±1	±1	0	∓1
$\eta_{\rm LR}$	0	0	±1	0	±1	∓1	0	±1	0
$\eta_{\rm RL}$	0	0	0	±1	±1	∓1	0	±1	0

Table 1: Models of contact interaction considered. The parameters η_{ij} $(i,j = \mathrm{L,R})$ define to which helicity amplitudes the contact interactions contribute.

Model	e^+e^-		$\mu^+\mu^-$		$\tau^+\tau^-$		$\ell^+\ell^-$	
	Λ_-	Λ_+	Λ_-	Λ_+	Λ_-	Λ_+	Λ_-	Λ_+
LL	7.6	6.2	4.6	12.1	6.0	6.9	6.8	12.6
RR	7.5	6.1	4.4	11.5	5.7	6.6	6.7	12.1
LR	7.9	7.3	2.1	7.9	1.9	4.2	8.6	8.6
RL	7.9	7.3	2.1	7.9	1.9	4.2	8.6	8.6
VV	15.0	13.8	7.9	19.1	11.6	9.7	13.9	20.2
AA	7.7	7.5	7.6	14.9	6.7	10.8	8.4	17.1
V0	10.6	8.9	6.5	16.6	8.4	9.4	9.5	17.5
A0	11.1	10.6	2.2	10.9	2.0	5.7	12.2	12.2
LL−RR	3.9	3.8	4.4	5.7	3.4	4.0	4.7	5.9

Table 2: The one–sided 95% confidence level lower limits on the parameter Λ of contact interaction derived from fits to lepton–pair cross sections and asymmetries. The limits Λ_+ and Λ_- given in TeV correspond to the upper and lower signs of the parameters η_{ij} in Table 1.

Model	$q\bar{q}$		$u\bar{u}$		$d\bar{d}$		$f\bar{f}$	
	Λ_-	Λ_+	Λ_-	Λ_+	Λ_-	Λ_+	Λ_-	Λ_+
LL	3.5	5.0	5.2	6.3	6.5	4.7	7.5	11.4
RR	4.8	3.6	4.6	4.9	2.2	3.5	6.3	12.8
LR	4.5	3.9	3.6	2.2	2.5	3.0	8.1	8.5
RL	5.9	3.0	3.1	2.5	3.5	2.3	7.9	11.2
VV	6.9	5.0	7.6	8.8	2.8	5.6	13.1	21.3
AA	4.8	7.2	6.3	6.9	8.0	6.0	9.5	15.1
V0	4.8	5.2	6.8	8.2	7.8	5.5	9.4	16.9
A0	6.3	3.7	4.2	2.6	3.6	3.0	11.0	14.1
LL−RR	3.5	5.7	4.0	2.7	2.6	4.2	4.4	6.8

Table 3: The one–sided 95% confidence level lower limits on the parameter Λ of contact interaction derived from fits to hadron cross sections, and for all fermions combined. The limits Λ_+ and Λ_- given in TeV correspond to the upper and lower signs of the parameters η_{ij} in Table 1.

	$b\bar{b}$	
	Λ_-	Λ_+
LL	9.4	7.2
RR	2.2	5.0
LR	2.9	4.0
RL	5.0	2.4
VV	2.7	8.4
AA	11.3	9.2
V0	11.2	8.7
A0	4.8	3.5

Table 4: The one–sided 95% confidence level preliminary lower limits on the parameter Λ of contact interaction derived from fits to the $b\bar{b}$ cross sections. The limits Λ_+ and Λ_- given in TeV correspond to the upper and lower signs of the parameters η_{ij} in Table 1.

LQ type	m_{LQ}[GeV]	LQ type	m_{LQ}[GeV]
$S_0(\mathrm{L}) \to \mathrm{eu}$	375	$V_{1/2}(\mathrm{L}) \to \mathrm{ed}$	255
$S_0(\mathrm{R}) \to \mathrm{eu}$	266	$V_{1/2}(\mathrm{R}) \to \mathrm{eu},\ \mathrm{ed}$	216
$\tilde{S}_0(\mathrm{R}) \to \mathrm{ed}$	121	$\tilde{V}_{1/2}(\mathrm{L}) \to \mathrm{eu}$	166
$S_1(\mathrm{L}) \to \mathrm{eu},\ \mathrm{ed}$	270	$V_0(\mathrm{L}) \to \mathrm{e\bar{d}}$	557
$S_{1/2}(\mathrm{L}) \to \mathrm{e\bar{u}}$	112	$V_0(\mathrm{R}) \to \mathrm{e\bar{d}}$	159
$S_{1/2}(\mathrm{R}) \to \mathrm{e\bar{u}},\ \mathrm{e\bar{d}}$	158	$\tilde{V}_0(\mathrm{R}) \to \mathrm{e\bar{u}}$	378
$\tilde{S}_{1/2}(\mathrm{L}) \to \mathrm{e\bar{d}}$	–	$V_1(\mathrm{L}) \to \mathrm{e\bar{u}},\ \mathrm{e\bar{d}}$	523

Table 5: Lower limits on the mass of leptoquarks at 95% confidence level derived from hadronic cross section measurements assuming $g = \sqrt{4\pi\alpha}$.

Z' model	$m_{\mathrm{Z}'}^{min}$(L3)	$m_{\mathrm{Z}'}^{min}$(CDF)
χ	474	595
ψ	280	590
η	335	620
LR	394	630
SSM	1020	690

Table 6: Comparison of lower limits (95% C.L.) on the Z′ mass determined with the L3 experiment and with the CDF experiment. The limits are given in GeV and are preliminary for the L3 experiment.

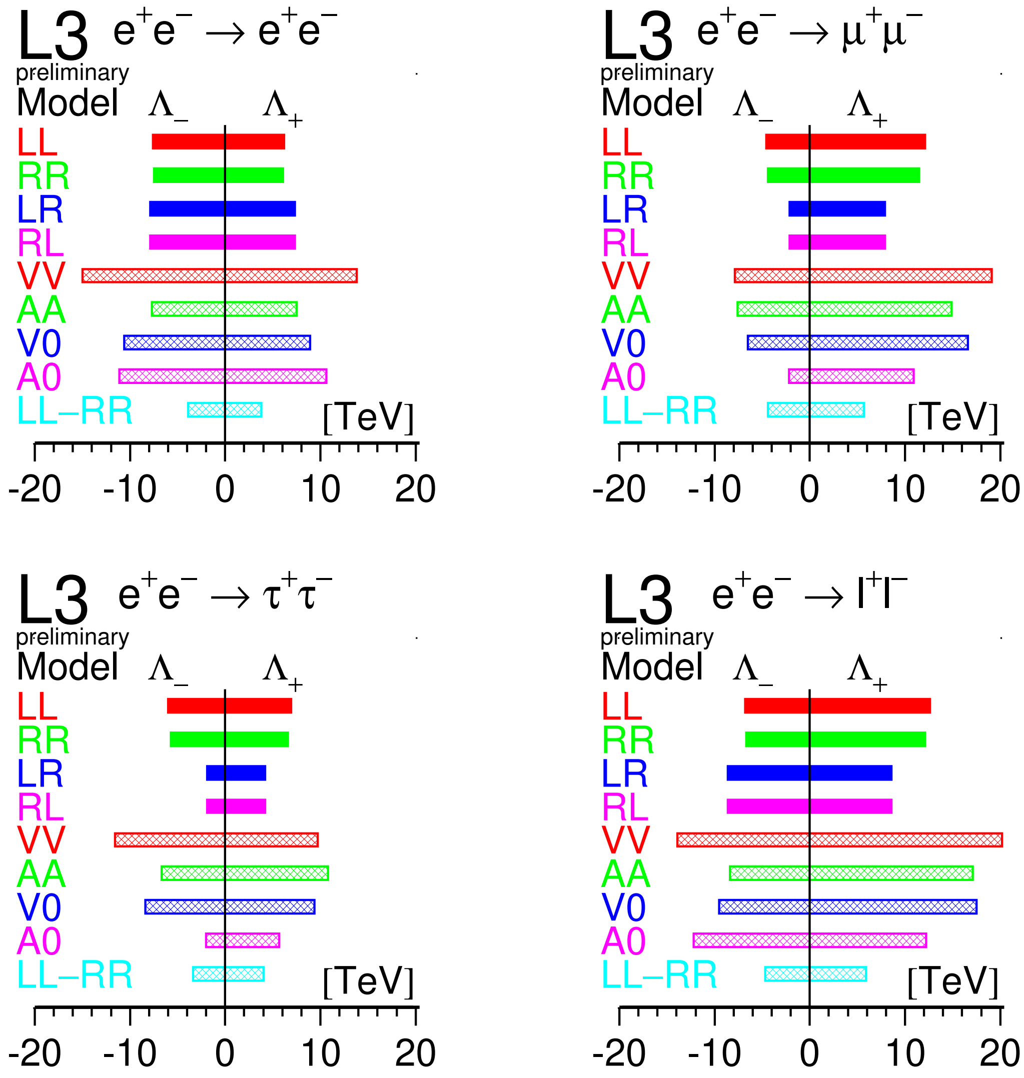

Figure 1: One–sided 95% confidence level lower limits on the scales Λ_+ and Λ_- for contact interactions in leptonic channels. The limits correspond to the values given in Table 2.

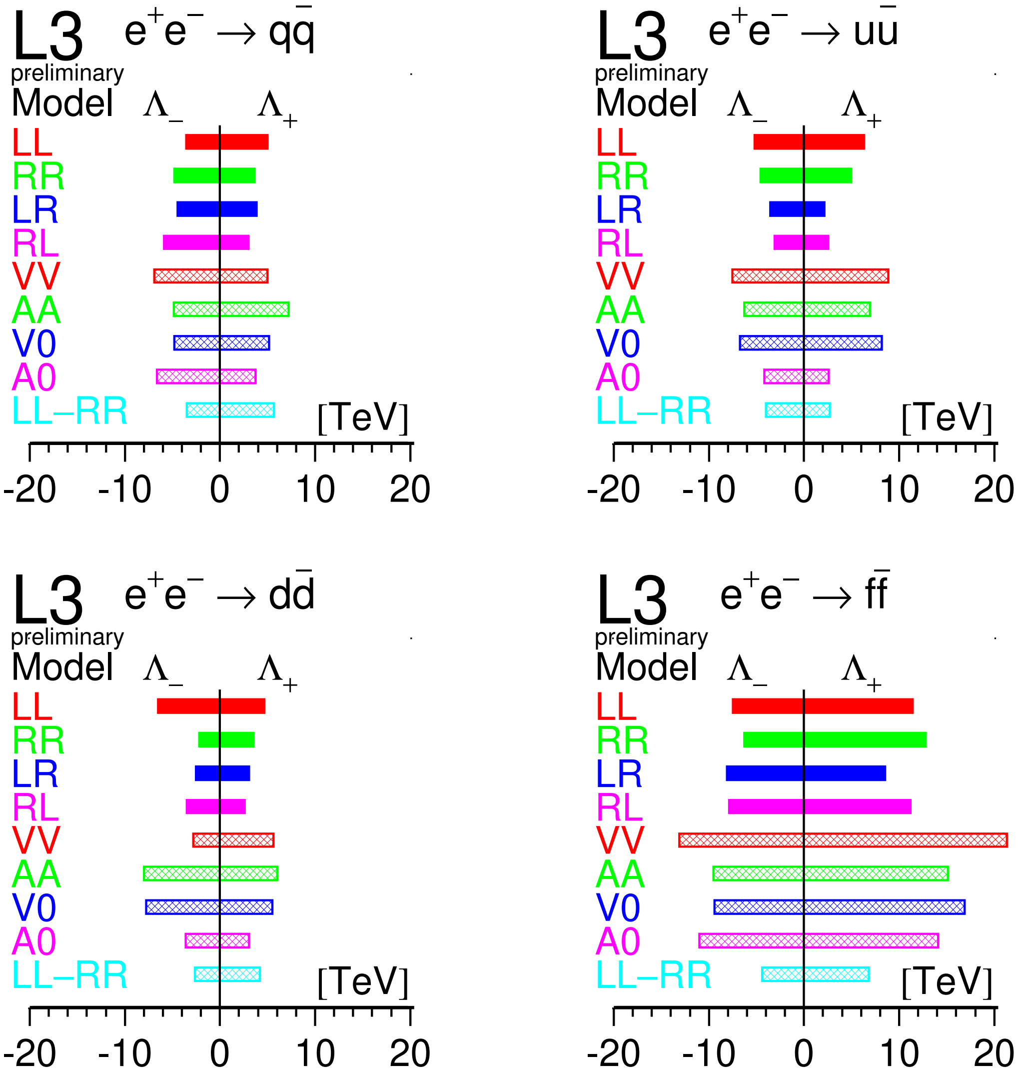

Figure 2: One–sided 95% confidence level lower limits on the scales Λ_+ and Λ_- for contact interactions in hadronic channels and in all channels combined. The limits correspond to the values given in Table 3.

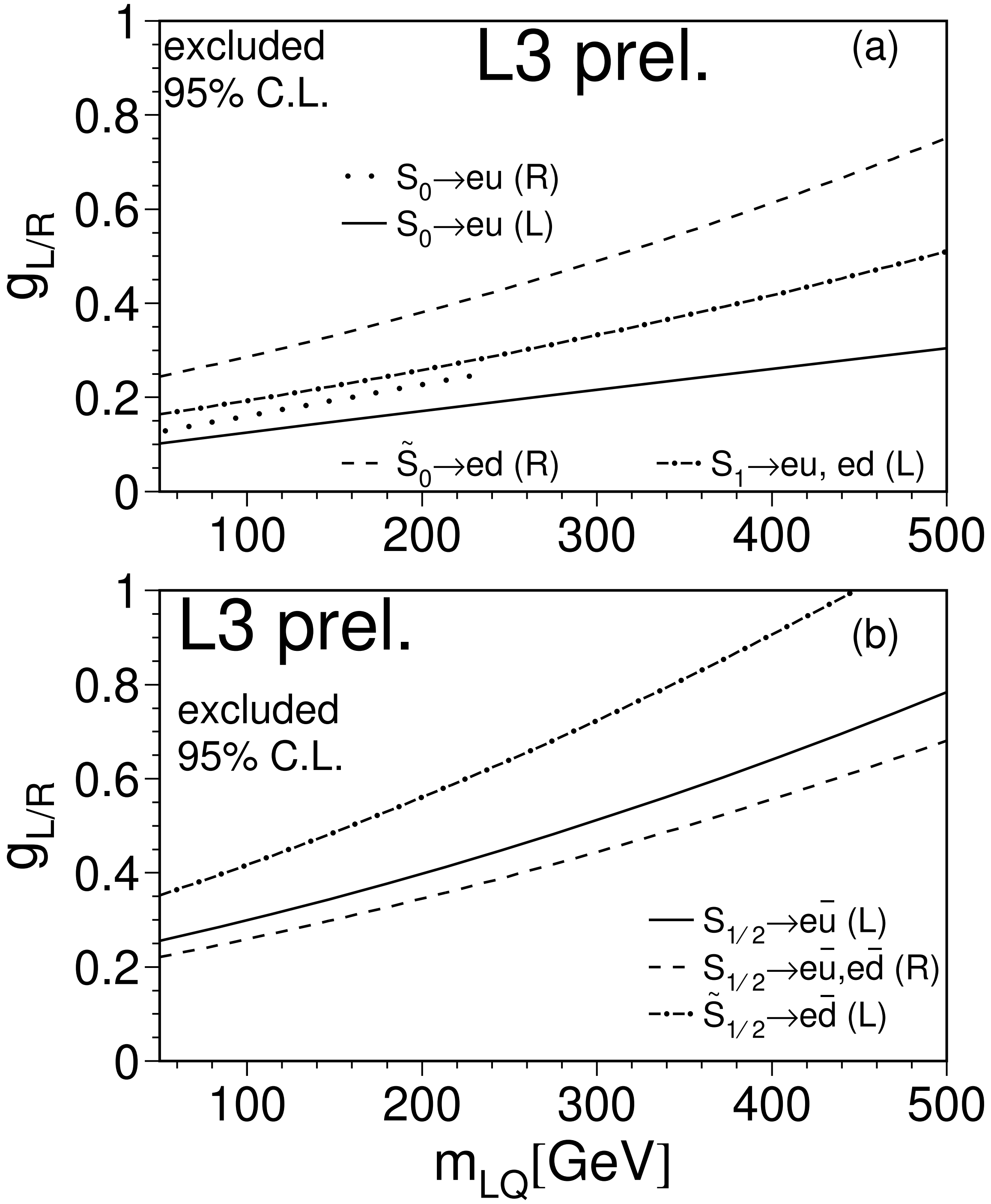

Figure 3: The 95% confidence level upper limits on $|g_L|$ or $|g_R|$ as a function of $m_{\rm LQ}$ for various scalar leptoquarks derived from hadronic final state cross sections. Limits are shown for fermion number F=2 (a) and for F=0 (b). Bounds on the R–parity violating couplings $|\lambda'_{1jk}|$ for the exchange of scalar down–type quarks in the u–channel and scalar up–type quarks in the t–channel correspond to limits on $|g_{\rm L}|$ for the S_0(L) and $\tilde{S}_{1/2}$ leptoquark exchange, respectively.

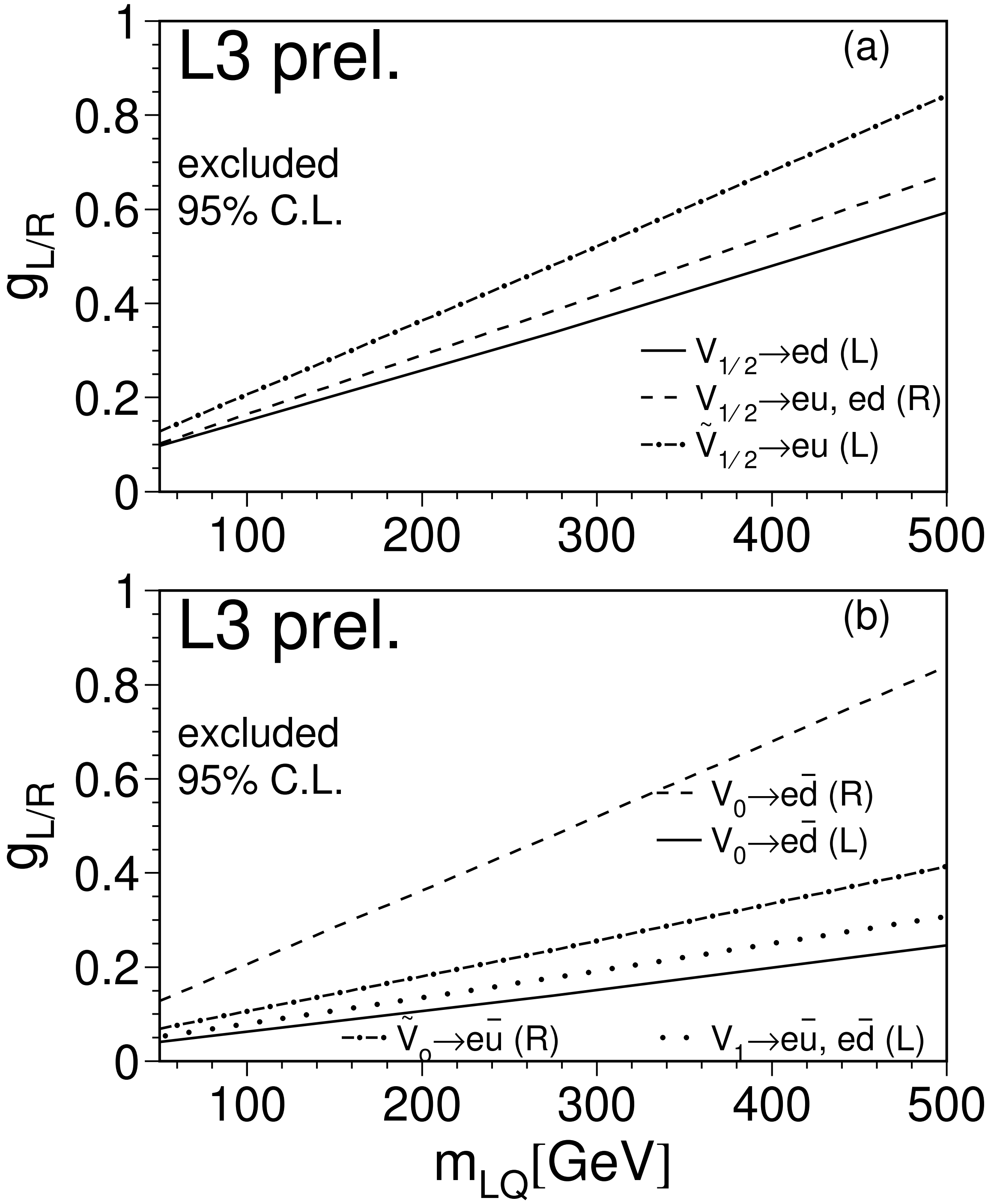

Figure 4: The 95% confidence level upper limits on $|g_L|$ or $|g_R|$ as a function of m_{LQ} for various vector leptoquarks derived from hadronic cross sections. Limits are shown for fermion number F=2 (a) and for F=0 (b).

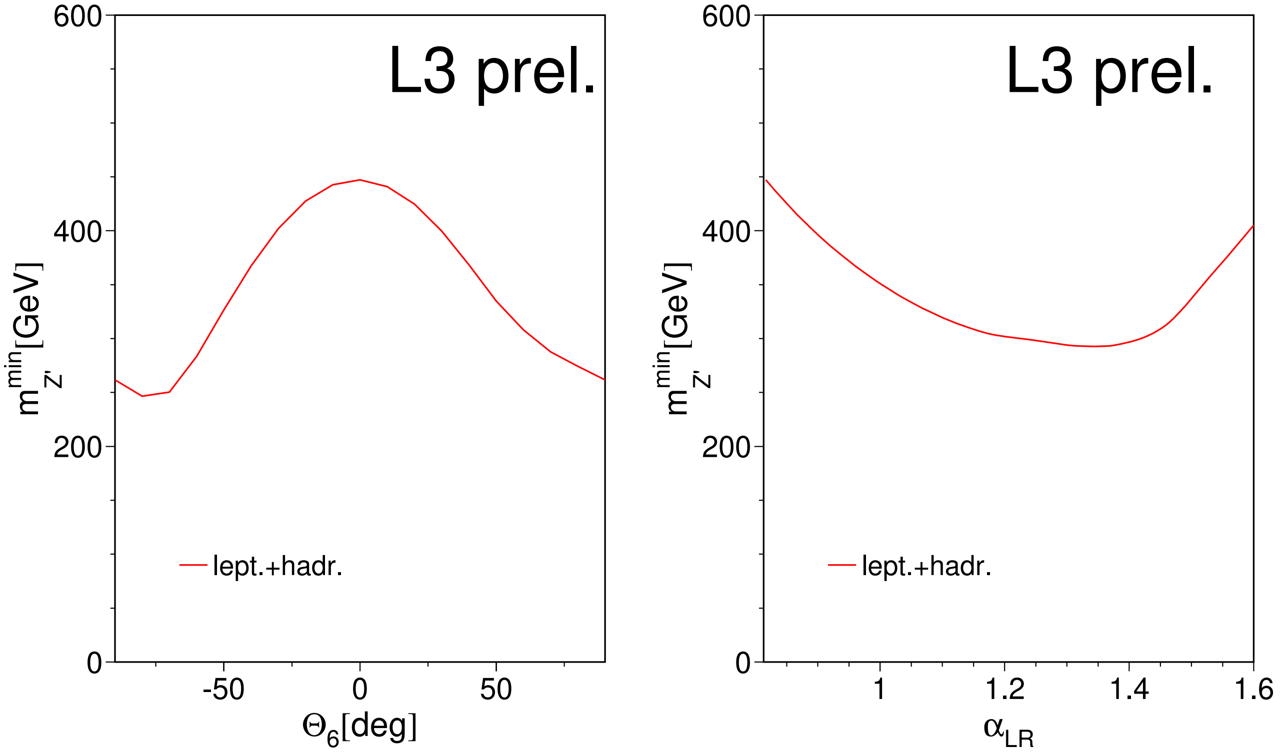

Figure 5: The 95% C.L. limits (preliminary) on $m_{Z'}$, $m_{Z'}^{min}$, as a function of the model parameter Θ_6 for E_6 models and α_{LR} for left–right symmetric models. We assume no Z–Z′ mixing by fixing $\theta_M = 0$.

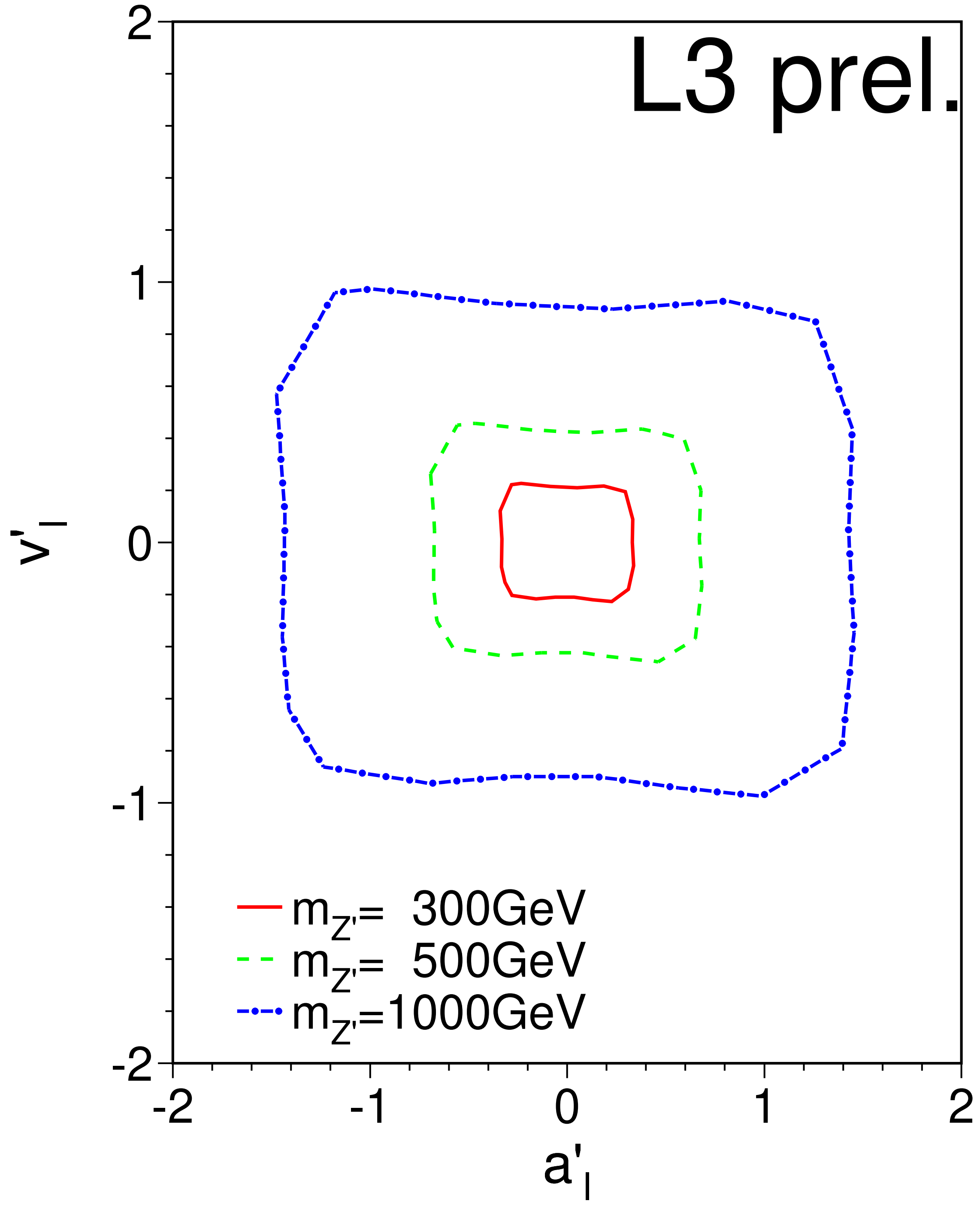

Figure 6: The 95% C.L. upper bounds (preliminary) on $Z'\ell^+\ell^-$ couplings for $m_{Z'}$ =300 GeV, 500 GeV, 1000 GeV. We assume no Z–Z′ mixing by fixing $\theta_M = 0$.

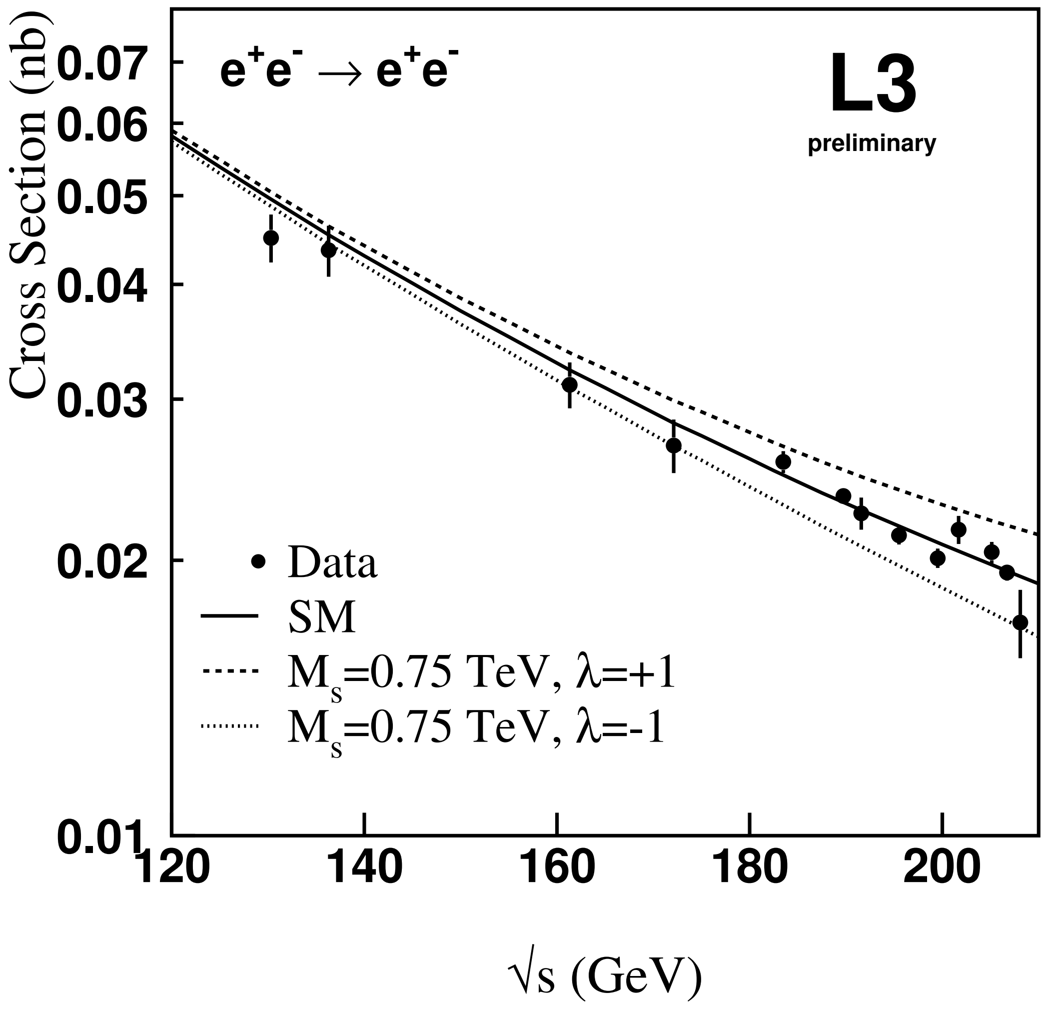

Figure 7: Bhabha cross section and search for low scale gravity effects. The results are preliminary.