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Search for extra spatial dimensions at LEP

The L3 Collaboration

Abstract

Extra spatial dimensions are proposed by recent theories that postulate the scale of gravity to be of the same order as the electroweak scale. A sizeable interaction between gravitons and Standard Model particles is then predicted. Effects of these new interactions in Bhabha scattering and Z boson pair production are searched for in the data sample collected at centre–of–mass energies above the Z pole by the L3 detector at LEP. No hints for the existence of these effects are found and lower limits in excess of 1.2 TeV are derived on the scale of this new theory of gravity. These results are preliminary.

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1 Introduction

Present collider experiments have successfully tested the Standard Model of electroweak interactions (SM) [1] at its characteristic distance M_{ew}^{-1}, where $M_{ew} \sim 10^2$ GeV represents the electroweak scale. On the contrary, the experimental study of the gravitational force extends only down to distances of the order of a centimetre [2], thirty three orders of magnitude above the distance M_{Pl}^{-1}. The Planck scale ($M_{Pl} \sim 10^{19}$ GeV) denotes the characteristic scale of the gravitational interaction.

Deviations from the expected behaviour of gravity are expected in theories that introduce n extra spatial dimensions of size R that can be as large as a fraction of a millimetre [3]. This follows from postulating a new scale M_S for the gravitational interaction, and imposing it to be of the same order of M_{ew}. This Low Scale Gravity (LSG) is related to the macroscopic expectations of gravity in terms of the gravitational constant and hence to M_{Pl} by the application of the Gauss' theorem in the extra dimensions:

$$M_{Pl}^2 \sim R^n M_S^{n+2}. \tag{1}$$

In the LSG scenario, spin–two gravitons couple with SM particles and contribute to the pair production of bosons and fermions in e^+e^- collisions. These effects were searched for in all the possible final states at centre–of–mass energies $\sqrt{s}$ up to 188.7 GeV [4–6]. The present analysis extends those investigations to the 232 pb^{-1} of data collected by the L3 detector [7] at LEP in 1999 at centre–of–mass energies of 191.6 GeV, 195.6 GeV, 199.6 GeV and 201.7 GeV. The Bhabha scattering and Z boson pair production processes present the highest sensitivity to deviations induced by LSG and are the object of the experimental studies described here.

LSG effects are described in terms of the parameter M_S [8], interpreted as a cutoff of the theory. It appears as $1/M_S^4$ in the LSG and SM interference terms and as $1/M_S^8$ in the pure graviton exchange process. These terms are multiplied by the factors λ and λ^2, respectively, which incorporate the dependence on the unknown full LSG theory and are of order unity [8]. For numerical results on the scale M_S, this analysis assumes $\lambda = \pm 1$ to allow for different signs in the interference between the SM and LSG contributions. Throughout this analysis the radiative corrections to SM and LSG processes are assumed to factorise.

2 Z Boson Pair Production

The contribution of virtual graviton exchange to the pair production of Z bosons affects both the total cross section and the distribution of the Z production angle [9]. The same discriminating variables used to measure the ZZ cross sections at each of the center–of–mass energies under study and to limit a possible ZZγ or ZZZ vertex [10] are investigated to search for LSG effects. They are the reconstructed Z mass of $\mathrm{ZZ} \rightarrow \mathrm{q\overline{q}}\ell^+\ell^-$ events, the output of a neural network for the $\mathrm{ZZ} \rightarrow \mathrm{q\overline{q}q'\overline{q}'}$ and $\mathrm{ZZ} \rightarrow \mathrm{q\overline{q}}\nu\overline{\nu}$ final states and the sum of the visible and recoil masses in the $\mathrm{ZZ} \rightarrow \ell^+\ell^-\ell'^+\ell'^-$ and $\mathrm{ZZ} \rightarrow \ell^+\ell^-\nu\overline{\nu}$ channels. A fit to these distribution for the data is performed, modelling the SM expectation with Monte Carlo events generated with EXCALIBUR [11]. Possible LSG effects are included by reweighting these Monte Carlo events with the corresponding matrix element [9]. The free parameter of the fit is λ/M_S^4 and the two hypotheses $\lambda = +1$ and $\lambda = -1$ are tested separately. The data are found to be consistent with the SM expectations and a 95% confidence level (CL) lower limits on M_S is extracted as:

$$M_S > 1.2 \text{ TeV}, \quad \lambda = \pm 1.$$

This limit includes the results from the study of Z boson pair production at 183 GeV [4, 12] and 189 GeV [5, 13].

3 Bhabha Scattering

Contrary to boson pair production, where effects of extra dimensions are mainly expected in the total cross section, in the case of fermion pair production important distortions of the angular distributions occur [8,14]. Part of this information is retained in the forward–backward asymmetry of the e^+e^- final state that is investigated here together with the $e^+e^- \rightarrow e^+e^-$ cross–section. The values of these two quantities measured from the data at the four centre–of–mass energies under investigation [15] are compared [16] with the SM predictions [17] and possible additional contributions expected from LSG [18]. No deviations from the SM expectations are found, yielding the 95% CL limits on M_S:

$$M_S > 1.0 \text{ TeV}, \quad \lambda = +1,$$

$$M_S > 0.9 \text{ TeV}, \quad \lambda = -1.$$

The calculation of these limits includes also the results obtained by the study of the differential cross sections at lower centre–of–mass energies [4,5]. The experimental systematic uncertainties as well as those on theory predictions are included in the fit.

4 Combined Results

The results of the search for the effects of extra spatial dimensions in the Bhabha scattering and Z pair production processes can be combined within the following two hypotheses: no higher order operators give sizeable contributions to the investigated processes, apart from those considered here [9, 18] and the meaning of the cutoff parameter is the same for both of them.

The simultaneous fit of the data for the two channels does not present any possible statistically significant effect of LSG, and 95% CL lower limits on M_S are derived as:

$$M_S > 1.3 \text{ TeV}, \quad \lambda = +1,$$

$$M_S > 1.2 \text{ TeV}, \quad \lambda = -1.$$

These results, summarised in Table 1, confirm the high sensitivity of the Z boson pair production to LSG effects, despite of its low cross section and hence small statistics, and are expected to improve with the inclusion of the full angular information for the Bhabha scattering and, to a lesser extent, with further information from the study of other boson and fermion pair final states.

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Process	M_S (TeV) $\lambda = +1$	M_S (TeV) $\lambda = -1$
$e^+e^- \rightarrow ZZ$	1.2	1.2
$e^+e^- \rightarrow e^+e^-$	1.0	0.9
Combined	1.3	1.2

Table 1: Lower limits at 95 % CL on the cutoff M_S for different processes and values of λ and their combination.

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