PROCEEDINGS OF SCIENCE

Search for Branons at LEP

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Branons are natural dark-matter candidates predicted by theories with extra dimensions. They correspond to the fluctuation of a three-dimensional brane along the extra dimensions and could be the first manifestation of this new physics in scenarios where gravitons are not accessible at high-energy colliders. Two searches performed with the L3 detector at LEP for branon production in the single-Z and single-photon channels are discussed. Their results allow to derive the most stringent limits on the possible existence of branons.

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1. Introduction

The scale of gravitational phenomena, $m_{Pl} \approx 10^{19}$ GeV, is immensely larger than the scale of the electroweak interactions, $m_{ew} \approx 10^2$ GeV, leading to the so-called hierarchy problem. Some recent theoretical ideas introduce mechanisms to reduce the scale of gravity to a new scale, M_F, of the order of m_{ew} [1]. This natural solution of the hierarchy problem postulates the existence of extra space dimensions. These could manifest themselves as deviations from the Newton law in short-range tests of gravity or in new phenomena at high-energy colliders mediated by gravitons. No such deviations have been observed so far.

In a different scenario, the presence of a three-dimensional brane as an additional physical body in a theory with extra dimensions implies additional degrees of freedom associated to its fluctuation along the extra dimensions [2]. These degrees of freedom manifest as branons: new scalar particles, $\tilde{\pi}$, described by an effective theory with couplings of the same order as the brane tension, f. Branons are natural dark-matter candidates [3].

To some extent, searches for gravitons and branons are complementary [4]. For $f \gg M_F$, the first evidence for extra dimensions would be the discovery of gravitons. For $f \ll M_F$, gravitons might not be accessible at high-energy colliders and branons would provide the first signal of extra dimensions.

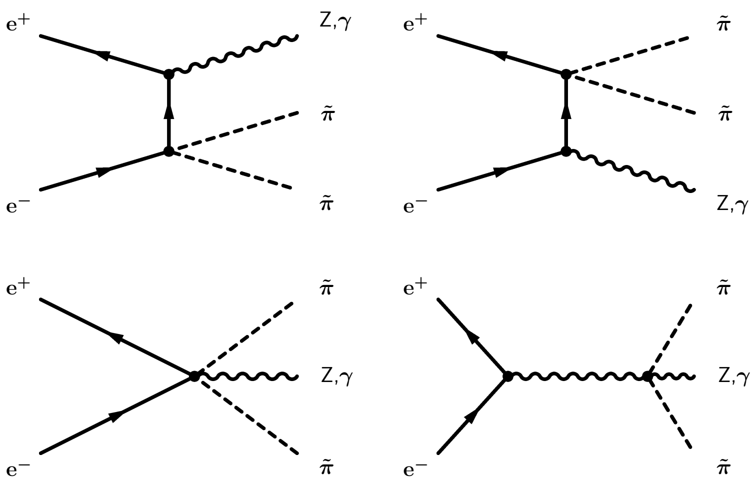

Figure 1: Feynman diagrams describing branon production at LEP through the $e^+e^- \to \tilde{\pi}\tilde{\pi}Z$ and $e^+e^- \to \tilde{\pi}\tilde{\pi}\gamma$ processes.

2. Branon manifestations at LEP

Branons couple to Standard Model particles in pairs and could be produced in e^+e^- collisions at LEP through the Feynman diagrams shown in Figure 1. They do not interact in the detector giving a signature of missing energy and momentum associated with either a single photon or a single Z-boson.

The L3 Collaboration searched for branon production at LEP in a data sample of about 0.6 fb^{-1} collected at centre-of-mass energies $\sqrt{s} = 189 - 209$ GeV [5], with an average value $<\sqrt{s}>=$

198 GeV. Events with a single Z-boson decaying into hadrons and missing energy and momentum are selected to tag the $e^+e^- \to \tilde{\pi}\tilde{\pi}Z \to \tilde{\pi}\tilde{\pi}q\bar{q}$ process, while events with a single photon and missing energy and momentum are used to search for the $e^+e^- \to \tilde{\pi}\tilde{\pi}\gamma$ process. The methods and results of these analyses are discussed in the following sections.

3. Search in the single-Z channel

The analysis selects unbalanced hadronic events with a visible mass compatible with that of a Z boson. The main background sources are: $e^+e^- \to q\bar{q}\gamma$ events with an undetected low-angle high-energy photon; pair-production of W bosons with a semileptonic final state where a lepton escapes detection; Z boson pair-production followed by the decay of a Z boson into hadrons and the other into neutrinos; single W-boson production.

A requirement on the missing momentum vector to point in the detector strongly suppresses background from the $e^+e^- \to q\bar{q}\gamma$ process. Other backgrounds are reduced by selection criteria on event-shape and jet-shape variables. A total of 455 events is observed in data, while 470 events are predicted by Standard Model processes. A branon signal with $M = 0$ GeV and $f = 40$ GeV would be selected with a 55% efficiency and contribute with 123 events to this sample.

The two variables most sensitive to a possible branon signal are the reduced energy of the reconstructed Z boson, $x_Z = E_Z/\sqrt{s}$, and the cosine of its polar angle, θ_Z. The distribution of these variables for data and Standard Model Monte Carlo are shown in Figures 2a and 2b, respectively, together with the predictions in presence of a branon signal. No excess is observed.

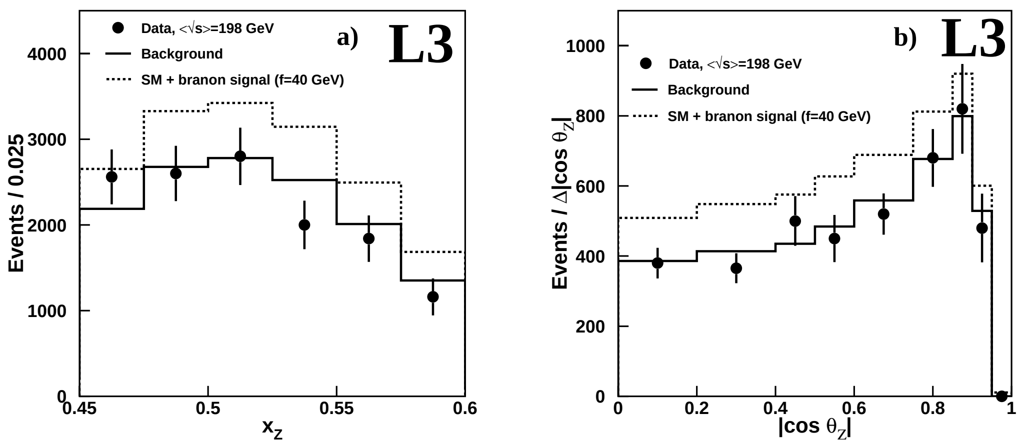

Figure 2: Distributions of a) the reduced energy and b) the cosine of the polar angle of single Z-boson candidates. Data and Standard Model Monte Carlo are shown together with the expected signal for massless branons with $f = 40$ GeV

4. Search in the single-photon channel

The L3 Collaboration published a high-precision study of events with a single photon and missing energy [6] in two different energy regions, according to the value of the transverse momentum of the photon, p_t, relative to the beam energy, E_{beam}. A high-p_t study covers the range $0.04 < p_t/E_{beam} < 0.60$ in the barrel and endcap regions of the high-precision BGO electromagnetic calorimeter, $|\cos\theta_\gamma| < 0.73$ and $0.8 < |\cos\theta_\gamma| < 0.97$, respectively. A low-$p_t$ selection allows the study of events with $0.016 < p_t/E_{beam} < 0.04$ in the barrel region.

The high-p_t selection observes 838 events in data while 811 events are expected from Standard Model processes, corresponding to a $e^+e^- \to \nu\bar{\nu}\gamma$ signal with a purity of 99% and an efficiency of 80%. Figure 3a compares the observed cross section of the $e^+e^- \to \nu\bar{\nu}\gamma$ process as a function of $x_\gamma = E_\gamma/E_{beam}$ with the prediction of the Standard Model and the possible excess of a branon signal with $M = 0$ GeV and $f = 150$ GeV. The data are in good agreement with the Standard Model prediction.

The low-p_t selection observes 543 events in data whereas 554 events are expected from Standard Model processes, three quarters are from the $e^+e^- \to e^+e^-\gamma$ process and the remaining from the $e^+e^- \to \nu\bar{\nu}\gamma$ process. Figure 3b compares the observed and expected distributions of x_γ. A good agreement is observed. The excess expected in presence of a possible branon signal with $M = 0$ GeV and $f = 150$ GeV is also shown.

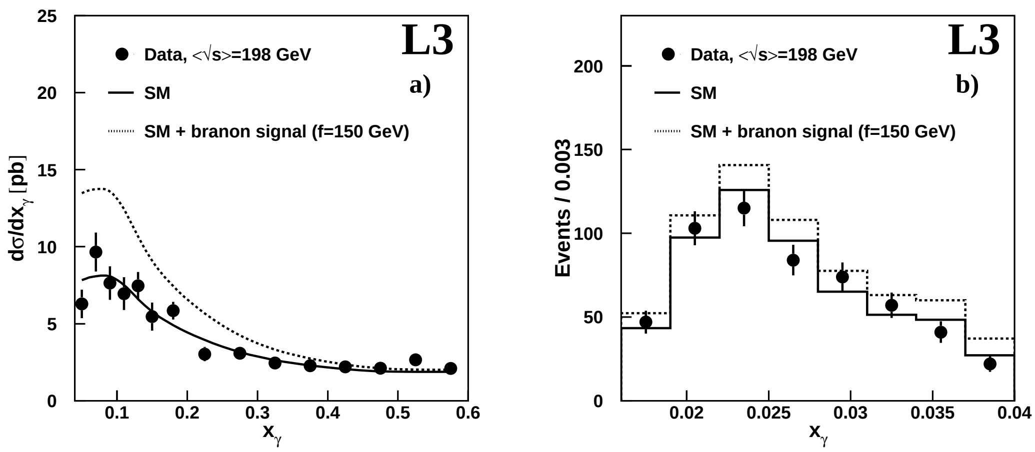

Figure 3: Observed and expected a) cross sections of the $e^+e^- \to \nu\bar{\nu}\gamma$ process from the high-p_t single-photon selection and b) distributions of the reduced photon energy observed by the low-p_t selection. The expected signals for massless branons with $f = 150$ GeV is also shown

5. Results

No evidence for branon production was found either in the $e^+e^- \to \tilde{\pi}\tilde{\pi}Z$ or in the $e^+e^- \to \tilde{\pi}\tilde{\pi}\gamma$ channel. Two-dimensional distributions of x_Z *vs.* $\cos\theta_Z$ for the single-Z channel and of x_γ *vs.* $\cos\theta_\gamma$ for the single-photon channel are compared with the double-differential cross section for branon production [7] and 95% confidence level limits are extracted as a function of M and f, as shown in Figure 4.

The analysis of the $e^+e^- \to \tilde{\pi}\tilde{\pi}Z$ channel results in $f > 47$ GeV for massless branons. There is no sensitivity for branon masses near and beyond the kinematic limit $M \gtrsim (\sqrt{s} - m_Z)/2$ and no bounds on f can be derived for $M > 54$ GeV.

The $e^+e^- \to \tilde{\pi}\tilde{\pi}\gamma$ channel has a larger sensitivity owing to the larger photon-electron coupling and a larger phase space available for a final state photon instead of a massive Z boson. For $M = 0$, a limit $f > 180$ GeV is established. For very elastic branes, $f \to 0$, a lower mass limit is obtained as $M > 103$ GeV.

These bounds are the most stringent to date on the possible existence of branons. They complement and improve those deduced from astrophysical observations [3].

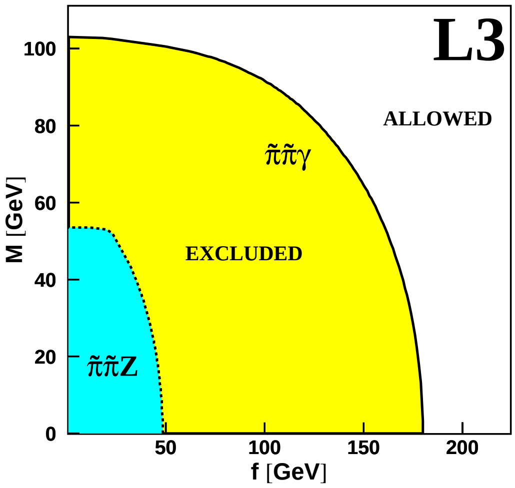

Figure 4: Exclusion regions in the plane of the branon mass, M, and brane tension, f, derived by the $e^+e^- \to \tilde{\pi}\tilde{\pi}Z$ and $e^+e^- \to \tilde{\pi}\tilde{\pi}\gamma$ searches.

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