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Search for Heavy Stable and Long-Lived Particles in e^+e^- Collisions at $\sqrt{s}$=189 GeV

DELPHI Collaboration

Abstract

A search for stable and long-lived heavy charged particles was performed using the data taken by the DELPHI experiment at an energy of 189 GeV. The Cherenkov light detected in the Ring Imaging Cherenkov Detector and the ionisation loss measured in the Time Projection Chamber were used to identify heavy particles passing through the detector. No evidence for the production of such particles has been found, therefore exclusion limits at 95% confidence level were derived on the masses of left and right handed smuons and staus. The results were combined with previous DELPHI searches in this channel. Including previous DELPHI results, masses of left (right) handed stable smuons and staus can be excluded between 2 GeV/c^2 and 88 (87.5) GeV/c^2 at 95% CL.

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1 Introduction

The search for heavy stable and long-lived charged particles in events with low multiplicity was made within the data recorded by the DELPHI detector at LEP at center-of-mass energies of about 189 GeV. The results presented in this paper extend previous DELPHI results from [1] in the leptonic topology to energies of 189 GeV. In most Supersymmetric models (SUSY) the supersymmetric partners of standard particles are unstable and have short lifetimes, except the lightest supersymmetric particle (LSP) which is commonly believed to be neutral and stable. Therefore, in most of the searches it is assumed that the supersymmetric particles decay instantaneously. In some scenarious, however, it is possible that SUSY-particles acquire a long lifetime. They become long-lived or stable, and thus escape from detection by the standard searches. In the Minimal Supersymmetric Standard Model (MSSM) with a very small amount of R-parity violation the LSP can be a charged slepton or squark and decay with a long lifetime into Standard Model particles [2].

In gauge mediated supersymmetric models [3] the gravitino is the LSP and the next to lightest supersymmetric particle (NLSP) can obtain a long lifetime in a very natural way for large values of the SUSY-breaking scale [4]. This is possible for sleptons, for example when the stau is the NLSP. The pair production of such long-lived or stable particles yields a characteristic signature, with typically two back-to-back charged heavy objects in the detector.

In this analysis it was assumed that the long-lived particles decay outside the tracking volume of the detector, which extends to a typical radius of 1.5 m. Furthermore, it was assumed that they do not interact more strongly than ordinary matter particles.

Heavy stable particles were searched for by looking for high momentum charged particles with either anomalous ionisation loss (dE/dx) measured in the Time Projection Chamber (TPC), or the absence of Cherenkov light in the gas and liquid radiators of the Barrel Ring Imaging CHerenkov (RICH). The combination of the TPC and RICH detectors and kinematical cuts provided efficient detection of new heavy particles with a small background.

The data analysed corresponded to 155.3 pb^{-1} at an energy of about 189 GeV. The negative search result was used to set limits at 95% CL on the production cross-section of stable sleptons. They were combined with previous DELPHI results from [1], and mass limits on stable or long-lived smuons and staus were derived.

2 Event selection

A description of the DELPHI apparatus and its performance can be found in ref. [5], with more details on the Barrel RICH in ref. [6]. Charged particles were selected if their impact parameter was less than 5 cm in the azimuthal plane and less than 10 cm in the longitudinal direction, and their polar angles lay between 20° and 160°. The relative errors on the measured momentum[1] were required to be less than 100% and the track lengths larger than 30 cm.

Only events with two or three charged particles were considered. It was further required that at least one charged particle had a momentum above 5 GeV/c reconstructed by the TPC and was inside the acceptance of the Barrel RICH $|\cos\theta| < 0.68$, where θ is the polar angle.

[1] Within this paper, with "momentum" the apparent momentum is meant, defined as the ratio of the momentum and the charge $|q|$.

Cosmic muons were removed by putting tighter cuts on the impact parameter with respect to the average beam-spot position. When the event had two charged particles with at least one identified muon in the muon chambers, the impact parameter in the azimuthal plane was required to be less than 0.15 cm, and less than 1.5 cm in the longitudinal plane.

Charged particles were selected, if they fullfilled a combination of the following criteria:

1. the Gas Veto: no photons were observed in the Gas RICH
2. the Liquid Veto: four or less photons were observed in the Liquid RICH
3. the TPC high ionisation loss: measured normalised energy loss was above 2 units i.e. twice the energy loss for a minimum ionising particle
4. the TPC low ionisation loss: measured normalised energy loss was below 0.3 of that expected for protons

The particle identification using the RICH is described in detail in ref. [7].

For the Gas and Liquid Vetoes it was required that the RICH was fully operational, and that photons from other tracks or ionisation hits were detected inside the drift tube crossed by the track. Due to tracking problems electrons often passed a Gas or Liquid Veto. Therefore it was required that particles that deposit more than 5 GeV in the electromagnetic calorimeter, had hits in the outer tracking detector. Signals from at least 80 wires were required for the measurement of the normalised energy loss in the TPC.

An event was selected if the momentum of a charged particle was above 15 GeV/c and the Gas Veto (1) was confirmed by a Liquid Veto (2) or a low ionisation loss (4) (in boolean notation (1)·(2)+(1)·(4)) or if the momentum of a charged particle was above 5 GeV/c and the Gas Veto was confirmed by a high ionisation loss ((1)·(3)). The event was also accepted if two charged particles were present with both momenta above 15 GeV/c, and both had either a high ionisation loss or a Gas Veto, or both had a low ionisation loss ((1+3)·(1'+3')+(4)·(4')). This additional search window improves the efficiency for large masses by about 10%.

3 Analysis results

One event was selected in the data, in agreement with the expected background of 1.02 $\pm$ 0.13 events. The expected background was evaluated from the data by estimating the probability of accepted particles passing the individual cuts which build up the different search windows. The largest background contribution was expected in the high energy loss search window, 0.54$\pm$ 0.1. A background of 0.34$\pm$0.07 was expected in the combined Liquid and Gas Veto search window, whereas the contribution from the other two windows was small. The candidate event passed both the Gas and Liquid Vetoes. It had two high momentum back-to-back charged particles with associated hits in the muon chambers. Figure 1 shows the measured normalised ionisation loss and the measured Cherenkov angle in the liquid radiator for the data taken at 189 GeV, after applying the Gas Veto.

The efficiency for selecting an event was evaluated for right handed smuons as a function of the mass in 10 GeV/c^2 steps between 10 GeV/c^2 and 90 GeV/c^2. Additional points at 85,91,92 and 93 GeV/c^2 have been added in order to get a better modelling of the efficiency close to the kinematical limit. At each point 1000 events were simulated with SUSYGEN [8], and passed through the detector simulation. The efficiency curve for masses above 45 GeV/c^2 and a centre-of-mass energy of 189 GeV is shown in Figure 2a. Stable or long-lived staus and selectrons are expected to yield the same experimental signature, so the estimated efficiencies hold for these cases as well.

As no evidence for a signal was found, exclusion limits at 95% CL were derived. The new results were combined with previous published results from [1] with a likelihood ratio method to obtain experimental limits on the masses of left and right handed stable or long-lived smuons and staus. For selectrons, no limits were given because in this model the production cross-section can be highly suppressed due to an addition t-channel sneutrino exchange. The candidate event has been taken into account over the full mass range. Figure 2b shows the cross-section for left and right handed smuons in the MSSM at an energy of 189 GeV, calculated with SUSYGEN [8] as a function of the particle mass. The 95% CL cross-section limit is also shown. The production of left (right) handed stable smuons and staus can be excluded with masses up to 88 (87.5) GeV/c^2.

4 Conclusions

A search was made for stable and long-lived heavy charged particles in leptonic final states at energies of 189 GeV, using particles identified by the Cherenkov light in the RICH and the ionisation loss in the TPC.

One event was observed in the data, in agreement with the expectation of 1.02 ± 0.13 background events. The results were combined with previous results of the DELPHI Collaboration[1], which excluded long lived or stable left (right) handed smuons and staus for masses between 2 and 81 (80) GeV/c^2. Including the new data, left (right) handed stable smuons and staus can be excluded with masses between 2 GeV/c^2 and 88 (87.5) GeV/c^2 at 95% CL.

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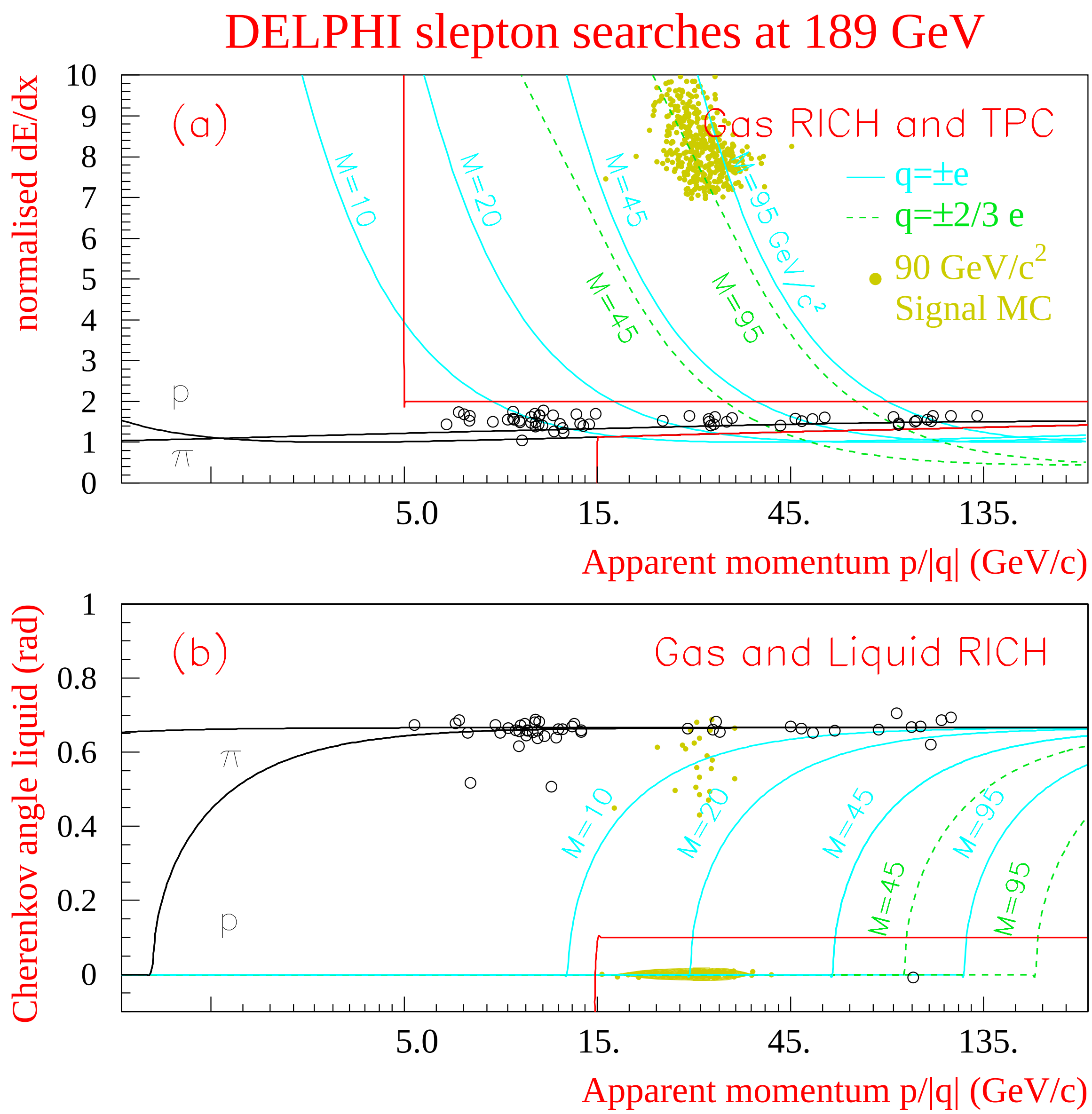

Figure 1: (a) Normalised energy loss as a function of the apparent momentum $p/|q|$ after the Gas Veto for the 189 GeV data. (b) Measured Cherenkov angle in the liquid radiator as a function of the apparent momentum after the Gas Veto: if four photons or less were observed in the liquid radiator, the Cherenkov angle was set equal to zero. The rectangular areas in (a) indicate selections (1)·(2) and (1)·(4), and that in (b) shows selection (1)·(3). The selection criteria are explained in the text. Open circles are data. The small filled circles indicate the expectation for a 90 GeV/c^2 signal with charge $\pm$e, resulting in a large dE/dx (upper plot) and no photons (except for a few accidental rings) in the liquid Cherenkov counter (lower plot).

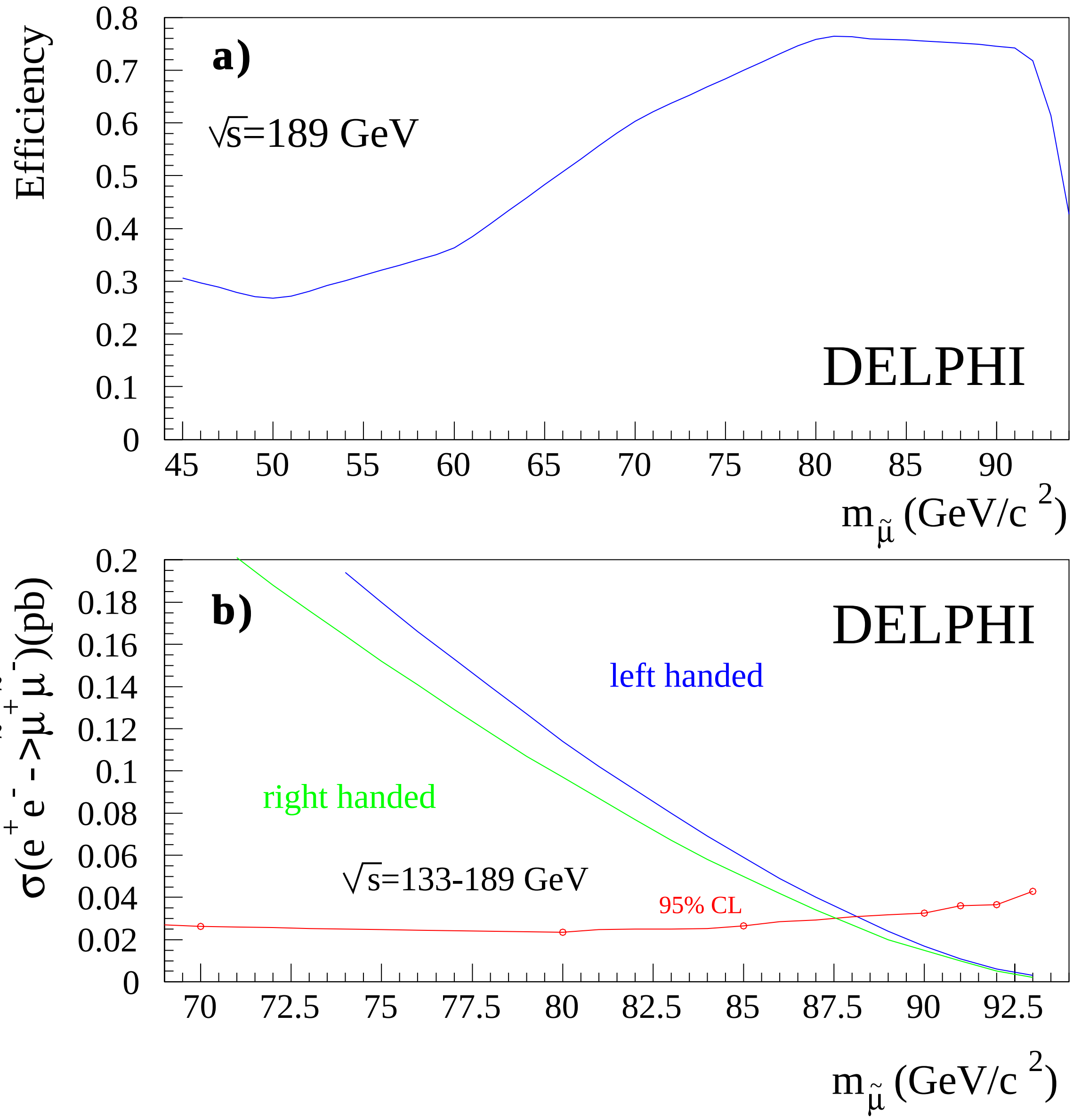

Figure 2: (a) Efficiency for detecting stable and long-lived smuons (staus) as a function of the smuon mass at a centre-of-mass energy of 189 GeV.
(b)Predicted production cross-section for left and right handed smuons (staus) as a function of the smuon (stau) mass. The 95% CL cross-section limit, derived from DELPHI searches between 133 GeV and 189 GeV, is also shown.