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Unstoppable, sbottomless sfermion searches

Searches for scalar partners of fermions (excluding stops and sbottoms)

Isabel Trigger

CERN, e-mail: Isabel.Trigger@cern.ch

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Abstract. Results are presented from searches by the LEP collaborations for scalar partners of leptons and light quarks in the context of the Minimal Supersymmetric Standard Model (MSSM). Examples shown are searches by OPAL for events with two leptons and significant missing transverse momentum and events with anomalous dE/dx, L3 searches for mass-degenerate squarks and for single electrons, and a DELPHI search for staus of mass less than $M_{Z^0}/2$. No evidence is observed for any signal indicating physics beyond the Standard Model (SM). Limits are shown in the context of a constrained MSSM (CMSSM).

1 Introduction

Supersymmetric models predict that for every fermion there exists a corresponding scalar boson (sfermion). The four LEP experiments (ALEPH, DELPHI, L3 and OPAL) have searched for the scalar partners of right- and left-handed charged leptons (sleptons, $\tilde{\ell}$) and quarks (squarks, $\tilde{q}$). Searches for the partners of top and bottom quarks ($\tilde{t}, \tilde{b}$) are covered in a separate contribution [1].

Many searches for supersymmetry look for charginos ($\tilde{\chi}^{\pm}$), fermionic partners of the W and $H^{\pm}$ bosons, as these have the most striking signature in most models. If, however, there are $\tilde{\nu}_e$ with mass less than a few hundred GeV, t-channel $\tilde{\chi}^+\tilde{\chi}^-$ processes in e^+e^- collisions can interfere destructively with the standard s-channel processes and the cross-section may be suppressed. Moreover, if there are light $\tilde{\nu}$, a chargino can decay to $\tilde{\nu}$ and a very soft lepton, making the $\tilde{\chi}^{\pm}$ decays effectively invisible. In such cases, $\tilde{\ell}$ is also light, so it is possible to search directly for $\tilde{\ell}^+\tilde{\ell}^-$ pair-production. If the production is s-channel with a virtual γ/Z^0 propagator, then the sleptons must be either $\tilde{\ell}_R\bar{\tilde{\ell}}_R$ or $\tilde{\ell}_L\bar{\tilde{\ell}}_L$; in the t-channel through $\tilde{\chi}^0_1$ exchange it is also possible to produce $\tilde{e}_L\bar{\tilde{e}}_R$. The s-channel cross-section for $\tilde{\ell}_R\bar{\tilde{\ell}}_R$ is smaller than for $\tilde{\ell}_L\bar{\tilde{\ell}}_L$, so limits on $\tilde{\ell}_R\bar{\tilde{\ell}}_R$ are conservative.

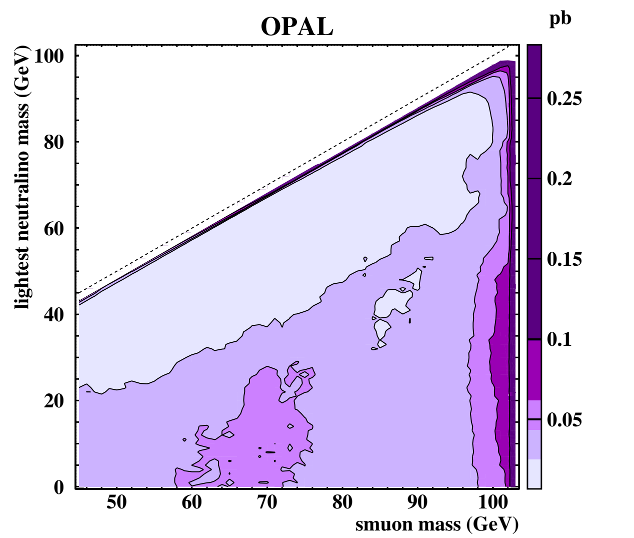

Fig. 1. Cross-section limits at 95% confidence-level for $\tilde{\mu}^+\tilde{\mu}^-$ production in e^+e^- collisions at OPAL [2]

2 Direct searches for slepton pair-production

Sleptons are expected to decay to the corresponding SM ℓ and the lightest supersymmetric particle (LSP), which is stable in the R-parity conserving models considered here, and therefore invisible. The LSP is generally assumed to be the lightest neutralino ($\tilde{\chi}^0_1$, fermionic partner of the neutral gauge and Higgs bosons). The signature for $\tilde{\ell}^+\tilde{\ell}^-$ pair-production is therefore expected to be two oppositely charged leptons of the same flavour with significant missing transverse momentum carried away by the LSP. The main background is SM W^+W^- production where both bosons decay to leptons of the same flavour.

The OPAL $\tilde{\mu}$ (smuon) search is taken as an example [2]. The background depends on the masses of the $\tilde{\mu}$ and the LSP. Signals are generated for a grid of $\tilde{\mu}$ and LSP masses, and compared with the SM backgrounds. A maximum likelihood technique is used to distinguish signal from background at each point on this grid, and as no indication of a

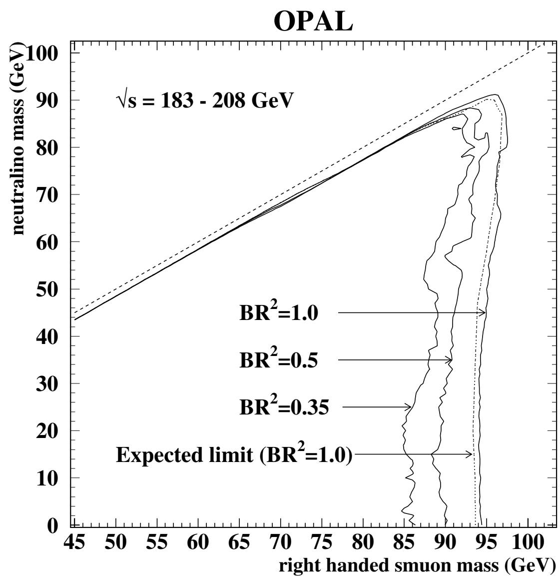

Fig. 2. Model-independent $\tilde{\mu}_R$ mass limits from OPAL[2]

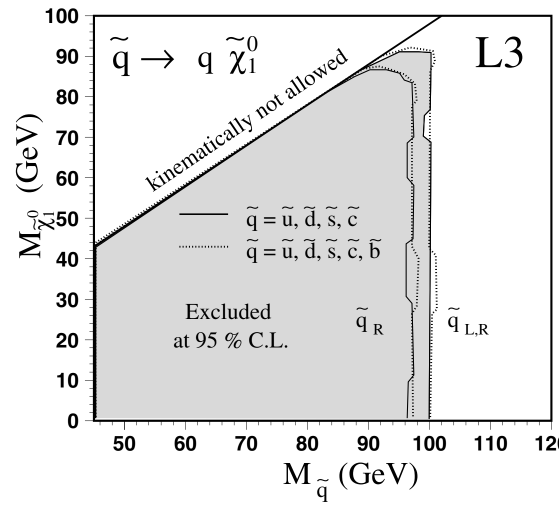

Fig. 3. L3 95% confidence-level CMSSM $\tilde{\text{q}}$ mass limits [3]

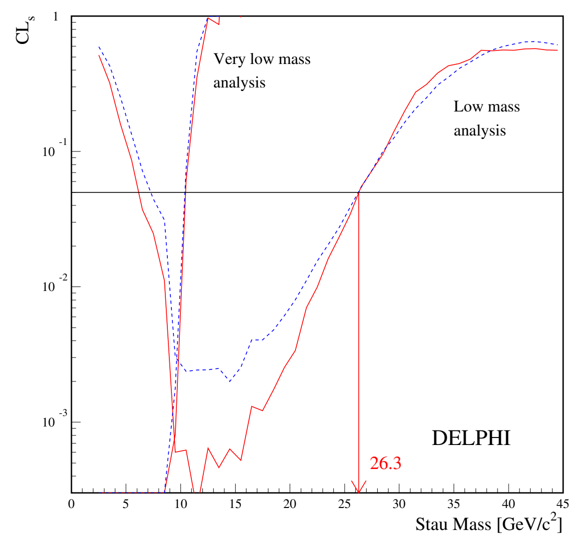

Fig. 4. Confidence levels for $\tilde{\tau}$ signal in DELPHI low-mass analyses [4]. All masses below 26.3 GeV can be excluded by combining the two analyses shown

signal is seen, an extended maximum likelihood technique is used to calculate the cross-section below which 95% of the likelihood function for the data lies (Fig. 1). Similar results have been obtained for $\tilde{\text{e}}$ and $\tilde{\tau}$ production, and the results from all four LEP experiments have been combined to provide limits slightly more stringent than those obtained by OPAL alone, and consistent with expectations for SM background only. Because $\tilde{\mu}^+\tilde{\mu}^-$ and $\tilde{\tau}^+\tilde{\tau}^-$ can only be produced in the s-channel, mass limits are almost model-independent. Limits from OPAL are shown in Fig. 2. The only dependence is on the branching ratio of the slepton decay to lepton and lightest neutralino – if the LSP is in fact one of the $\tilde{\nu}$ or if the $\tilde{\chi}^0_2$ or one of the $\tilde{\nu}$ is close in mass to the LSP, the branching ratio may not be 100%. Because the τ is relatively massive, there may be mixing between $\tilde{\tau}_R$ and $\tilde{\tau}_L$; this mixing also affects the limits.

The L3 experiment also searched for scalar partners of quarks [3] by looking for events with jets and significant missing transverse momentum; results are shown in Fig. 3. These are a reinterpretation of the search for $\tilde{\text{t}}$ and $\tilde{\text{b}}$ described elsewhere in these proceedings[1].

3 Searches for sneaky sleptons

Direct searches for lepton pairs with missing transverse momentum revealed no hint of a signal, but that does not completely exclude the possibility that sleptons with masses below half the maximum LEP centre-of-mass energy of 209 GeV might exist. Scenarios with R-parity violation or gauge-mediated supersymmetry breaking, which would lead to different final states, are beyond the scope of this paper; however, within the MSSM there are a number of possible ways for light $\tilde{\ell}$ to hide. Two that are considered here are mixing between $\tilde{\tau}_R$ and $\tilde{\tau}_L$, and $\tilde{\ell}$ almost mass-degenerate with the LSP.

3.1 Stau mixing

Because the τ is relatively massive, there can be significant mixing between the super-partners of its right- and left-handed flavour eigenstates. This mixing might be tuned to just the value where the lightest stau mass eigenstate decouples from the Z^0, so that constraints from LEP 1 which are assumed when setting all the limits shown above would no longer apply. DELPHI performed a special search for $\tilde{\tau}$ with masses between the τ mass and $M_{Z^0}/2$ (Fig. 4).

3.2 Single electron search

If $\tilde{\text{e}}_R$ is almost mass-degenerate with the LSP, it can decay to electrons too soft to be detected. In this case, even if $\tilde{\text{e}}_L$ is too massive to be pair-produced at LEP 2, it might nevertheless be possible to detect $\tilde{\text{e}}_R\bar{\tilde{\text{e}}}_L$ production. The

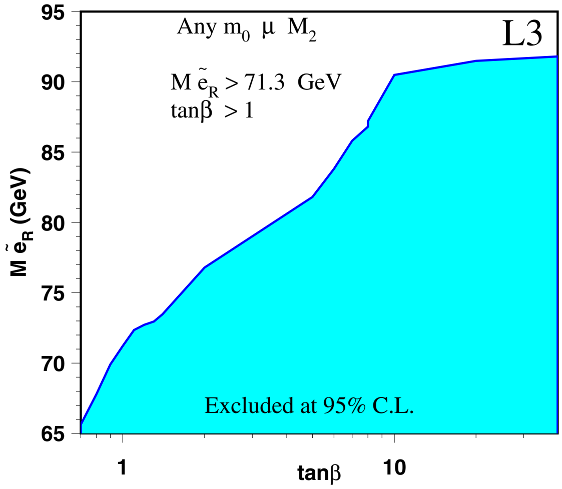

Fig. 5. Mass limits for $\tilde{e}_R$ from L3 single electron analysis [3]

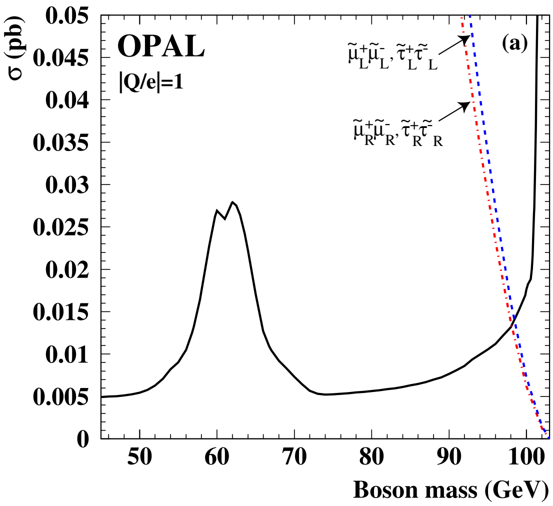

Fig. 6. 95% confidence-level limits on stable charged bosons [6]. *Dotted curves* show expected signals

signature event would be a single stiff electron. ALEPH [5] and L3 [3] have done such searches (Fig. 5).

3.3 Stable sleptons

If the mass difference between $\tilde{\ell}$ and the LSP is less than the corresponding ℓ mass, $\tilde{\ell}$ may not decay inside the detector. OPAL searches for pair-production of massive charged bosons with anomalous dE/dx. Stable $\tilde{\ell}$ can be excluded almost to the LEP 2 kinematic limit (Fig. 6).

3.4 Interpretation in the constrained MSSM

Slepton search results may be combined with $\tilde{\chi}^{\pm}, \tilde{\chi}^0$ and Higgs search results to constrain the allowed parameter space of the models studied (Fig. 7). Slepton limits exclude regions of the CMSSM parameter space where the unified scalar fermion mass (m_0) is small; these regions are generally not excluded by other searches.

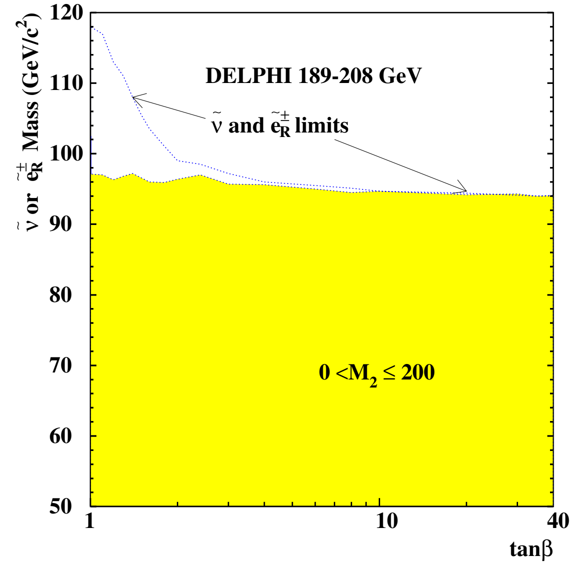

Fig. 7. Limits on $\tilde{\nu}$ and $\tilde{e}_R$ in the CMSSM from DELPHI [4]

4 Conclusions

Data from all $\tilde{\ell}$ and $\tilde{q}$ searches reported here are consistent with the SM background; no evidence for sfermions has been seen at LEP. From the data, it is possible to set absolute limits on the $\tilde{\ell}$ masses in the CMSSM, and even some absolute limits on $\tilde{\ell}$ masses in the more general context of the MSSM. Constraints can be placed on the allowed parameter space in the CMSSM. It is difficult to search for $\tilde{\ell}$ at other existing colliders, although the TeVatron is an ideal place to search for $\tilde{t}$ and $\tilde{b}$. It will therefore be necessary to wait for the LHC, where the prospects of observing sleptons in cascade decays are excellent.

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