SUSY Searches: Lessons and Loopholes from LEP

Rob A. McPherson
University of Victoria, Victoria, B.C. Canada
and
Institute of Particle Physics Fellow

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Abstract

Searches for signatures of the production of particles predicted by theories with supersymmetry at LEP are reviewed. The searches are discussed primarily from the standpoint of their different experimental topologies, with emphasis on new signatures suggested by alternative theoretical models. No evidence for supersymmetric particle production is observed. The null search results are used to constrain the allowed parameter space of models with supersymmetry, and to exclude supersymmetric particle masses within the context of these restrictive models.

1 Introduction

Supersymmetry [1] (SUSY), where all Standard Model (SM) particles have a partner whose spin differs by a half unit, provides an elegant method of solving the problem of fine-tuning the Higgs mass. Since it is known that SUSY particles, if they exist, do not have the same masses as their SM partners, SUSY must be a broken symmetry. The minimal SUSY extension to the Standard Model, the MSSM, contains an additional 105 parameters [2], many of which parametrize our ignorance of the unknown nature of SUSY breaking. Much of the parameter space of this general MSSM can be excluded by low energy phenomenology, such as the strong suppression of flavour changing neutral currents observed in nature. Many simpler models have been constructed to reduce the large number of free parameters and to avoid constraints. These models often make assumptions about the nature of SUSY breaking.

Null search results can be used in turn to constrain the possible remaining parameter space of the different SUSY breaking models. Popular, and theoretically consistent, models of SUSY breaking include in particular "gravity-mediated" and "gauge-mediated" SUSY breaking. The minimal versions of these models can be denoted mSUGRA (minimal supergravity) and GMSB, respectively. In either model, it is possible to assume the conservation of a quantum number called "R-parity" (RPC), which results in a stable lightest SUSY particle (LSP) and the classic SUSY "missing energy" signature. While SUSY with R-parity violation (RPV) introduces many additional severe phenomenological problems, RPV provides many new possible signatures and thus has been considered by experiments. While many different facilities have searched for SUSY signatures, by far

Stage	$\sqrt{s}$ (GeV)	Years	Integrated Luminosity Per Expt. (pb^{-1})
LEP 1	$\sim M_Z$	1989-1995	175
LEP 1.5	130–140	1995	5
	~161	1996	10
	~172	1996	10
	~183	1997	55
	~189	1998	180
	192–202	1999	230
	200–209	2000	220

Table 1: Approximate integrated luminosity collected by each LEP experiments during the 12 years of LEP running. An example of a much more detailed breakdown can be seen in [3].

the most constraining results on the parameters in mSUGRA and GMSB models come from the Large Electron Positron Collider (LEP).

LEP ran from 1989–2000 with four experiments (ALEPH, DELPHI, L3 and OPAL). In the "LEP I" phase, a data set of about 180 pb^{-1} was collected by each experiment at centre-of-mass energies, $\sqrt{s}$, near M_Z. Both direct searches and precision electro-weak measurements from LEP I severely constrain any new physics with a scale below about $M_Z/2$, unless the new physics decouples from the Z-boson. In the "LEP II" phase, a data set of about 700 pb^{-1} was collected by each experiment at centre-of-mass energies from 130–209 GeV, with about 250 pb^{-1} having $\sqrt{s} > 200$ GeV. The LEP experiments reported many new results in 2002, and are in the process of finalizing many of their searches for new physics. The LEP data sets are summarized in Table 1. A detailed breakdown of luminosity taken at different centre-of-mass energies can be seen, for example, in [3].

2 Searches for SUSY Particle Production

Since there is no compelling reason to believe in any particular SUSY model, experiments attempt to search for signs of SUSY using the most general, or least model dependent, methods possible. Inevitably, there is some model dependence associated with the searches, and experimentalists attempt to consider as many different models predicting as wide a variety of signatures as possible. A set of examples will be considered, highlighting the variety of different searches used to attempt to detect SUSY particles at LEP.

2.1 Searches for Charginos

Charginos ($\tilde{\chi}^{\pm}$) are the mixtures of the SUSY partners of the W-boson ($\tilde{\mathrm{W}}$) and charged Higgs bosons ($\tilde{\mathrm{H}}^{\pm}$). The are two $\tilde{\chi}^{\pm}$ mass eigenstates, denoted $\tilde{\chi}^{\pm}_1$ and $\tilde{\chi}^{\pm}_2$ for the lighter and heavy states, respectively. The cross-section for the processes $e^+e^- \rightarrow \tilde{\chi}^+_1\tilde{\chi}^-_1$ is usually large and depends on the "field content", the fraction of $\tilde{\mathrm{W}}$ (or gaugino) and $\tilde{\mathrm{H}}^{\pm}$

(or higgsino) components. In the 100% higgsino case, the process $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ has a relatively model-independent cross-section. In the 100% gaugino case, the cross-section depends strongly on the mass of the scalar partner of the electron neutrino ($\tilde{\nu}_e$), which usually contributes destructively to the production cross-section. Example production cross-sections for the process $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ are shown in Figure 1. As can be seen from the figure, at LEP the chargino pair production cross-section is usually several picobarns, even near the kinematic limit.

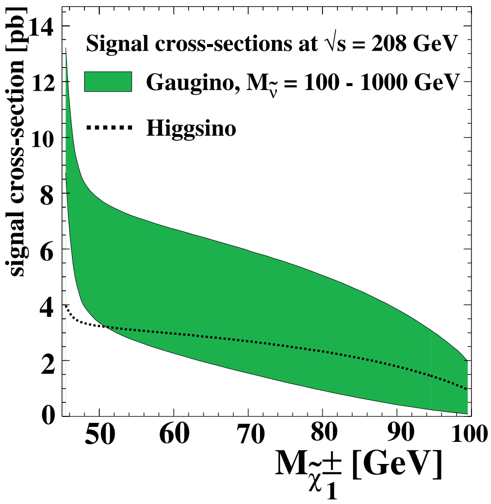


Figure 1: Example cross-section for the process $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$.

Many different searches have been performed by the LEP experiments for chargino pair production. All experiments search for the "classic mode", $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$, followed by the decays $\tilde{\chi}^\pm \to \tilde{\chi}_1^0 W^{(*)}$. The W, which may be virtual, can decay either leptonically or hadronically, while the lightest neutralino LSP ($\tilde{\chi}_1^0$) escapes detection resulting in missing energy in the event. Simple selections can readily exclude cross-sections of a few picobarns, thus excluding charginos in the LEP mass reach in the context of most typical SUSY models. Higher sensitivity searches can probe to smaller cross-sections, particularly possible in non-minimal models.

The detailed signal properties depend most strongly on the chargino mass ($M_{\tilde{\chi}^\pm}$) and on the mass difference between the chargino and lightest neutralino (Δm). Increasingly refined searches have been done by all the LEP experiments, including optimizing the selections for a few different Δm ranges, or using "sliding cuts" depending on Δm. The most sensitive approach actually defines a likelihood for arbitrary $M_{\tilde{\chi}^\pm}$ and Δm in a continuous manner using a sophisticated interpolation of quantities that give separation between signal and background. An example cross-section limit using this technique is shown in Figure 2, taken from [4], where cross-sections for $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ larger than 0.1 pb are excluded for much of the kinematically accessible region assuming a 100% $W^{(*)}$ branching fraction.

The constraints are less restrictive for large $M_{\tilde{\chi}^\pm}$ approaching the kinematic limit. In this region, where each experiment has less data, a combination of the data taken with $\sqrt{s} > 207.5$ GeV by the four experiments has been performed, resulting in the cross-section limits also shown in Figure 2 [5]. Using the combined LEP data set, cross-sections above 1 pb can be excluded even very close to the kinematic limit of $M_{\tilde{\chi}^\pm} \approx 104$ GeV.

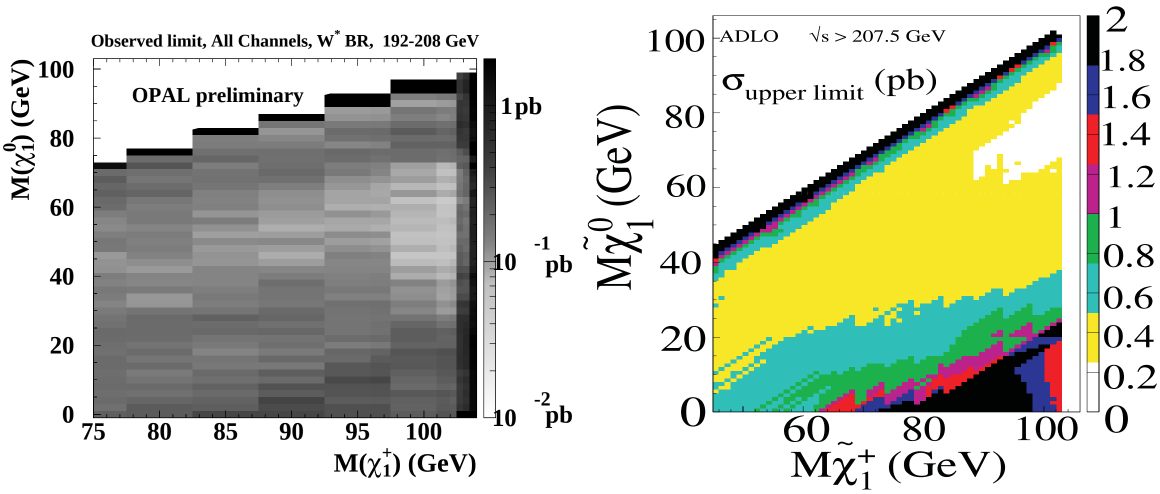


Figure 2: Excluded cross-sections at the 95% C.L. for the process $\mathrm{e^+e^-} \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$, assuming a 100% branching fraction for $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0\mathrm{W}^{(*)}$. On the left are results from OPAL using data taken with $\sqrt{s} = 192 - 209$ GeV, and on the right are results from a combination of the four LEP experiments using data taken with $\sqrt{s} > 207.5$ GeV.

The above constraints do not apply for very small mass differences between the chargino and lightest neutralino, $\Delta m < 3$ GeV. In this region, the lifetime of the chargino can also play an important role. Typical chargino lifetimes as a function of Δm are shown in Figure 3. For $\Delta m < M_\pi$, the chargino is long lived, and would be detected as a heavy stable charged particle using its anomalous ionization energy loss in the detectors' central tracking chambers. Examples of this $\mathrm{d}E/\mathrm{d}x$ distribution are shown in Figure 4, along with excluded cross-sections for heavy stable charged particle production from a combination of the data from the four LEP experiments [6]. In particular, cross-sections as low as 3 fb can be excluded, making this the most sensitive search from LEP.

For slightly larger mass differences, $M_\pi < M_{\tilde{\chi}^\pm} < 3$ GeV, the situation is more difficult. In that region, the visible energy of the signal events is very small, and the background from the so-called "two-photon" process $\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-}\gamma\gamma \rightarrow \mathrm{e^+e^-}X$ is very large. This background can be greatly reduced by requiring that an ISR photon be present in the event, $\mathrm{e^+e^-} \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma_{\mathrm{ISR}}$. While the cross-section is lower with this requirement, the large chargino pair production cross-section and large integrated luminosities acquired at LEP make the search viable. The two-photon background can be essentially completely eliminated with this trick, because the process $\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-}\gamma\gamma \rightarrow \mathrm{e^+e^-}X\gamma_{\mathrm{ISR}}$ contains an additional visible electron in the events which can be used as a veto. Excluded cross-sections for this mass region combining the data of the four LEP experiments are shown in Figure 5 [7]. Even in this difficult Δm region, cross-sections larger than 1 pb can be excluded.

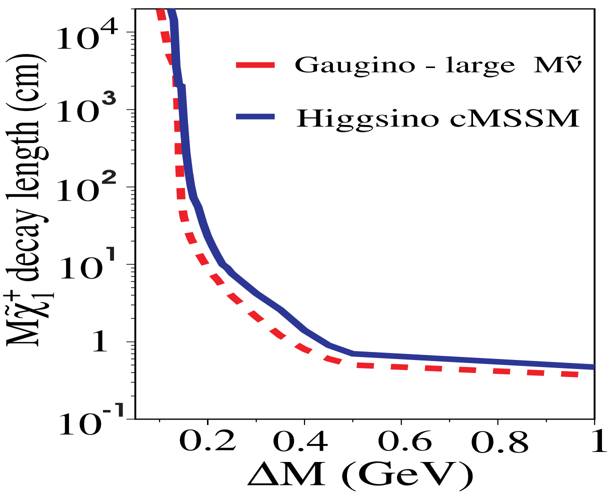
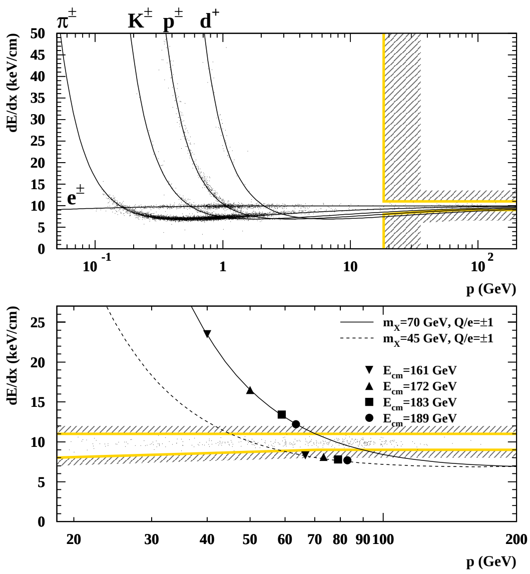


Figure 3: Typical chargino lifetimes as a function of the mass difference with the lightest neutralino, Δm.



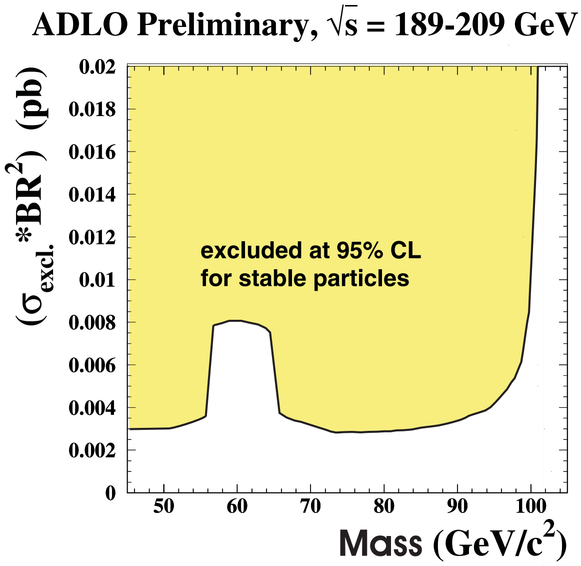


Figure 4: Example of the use of ionization energy loss to search for heavy stable charged particle production (left). Also shown (right) is the excluded cross-section for heavy stable charged particle production from a combination of the data from the 4 LEP experiments.

Many other chargino searches have been performed by the LEP experiments, including charginos in models with RPV or GMSB. No evidence for chargino production has been observed. For most values of Δm, cross-sections larger than 0.1 pb are excluded for $M_{\tilde{\chi}^\pm} < 100$ GeV. For Δm of a few 100 MeV, or very near the kinematic limit of

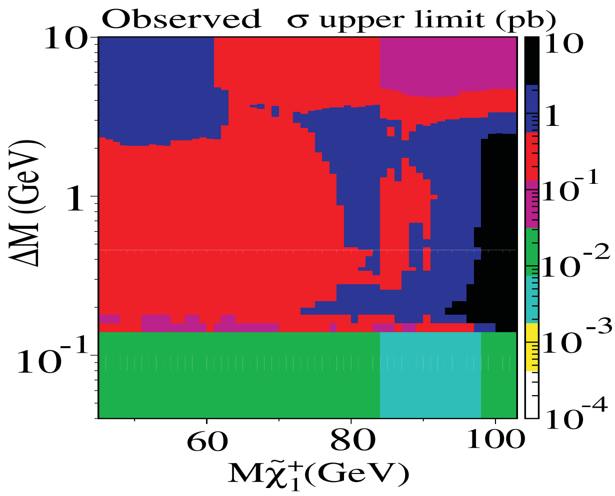


Figure 5: Limits at the 95% C.L. on the cross-section for the process $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ for small mass differences, Δm.

$M_{\tilde{\chi}^\pm} \approx 104$ GeV, cross-sections larger than 1 pb are excluded. Taken together, these results essentially exclude the presence of a chargino within the kinematic reach of LEP.

2.2 Searches for Scalar Leptons

The other good candidate for SUSY discovery is the search for scalar lepton ($\tilde{\ell}$) production, $e^+e^- \to \tilde{\ell}\tilde{\ell}$. The $\tilde{\ell}$ is often assumed to decay via $\tilde{\ell} \to \ell\tilde{\chi}_1^0$, leading to the signature of a lepton pair with significant missing energy. The cross-section for the process $e^+e^- \to \tilde{\ell}\tilde{\ell}$ is usually lower than that for chargino production, and is typically around 0.1 pb as shown in Figure 6. Also shown in Figure 6 is the excluded cross-section from the combined data of the four LEP experiments for the process $e^+e^- \to \tilde{\tau}\tilde{\tau}$, assuming the decays $\tilde{\tau} \to \tau\tilde{\chi}_1^0$, which is the most difficult process to detect. Cross-sections near 0.1 pb can be excluded for most of the (M,Δm) plane.

Searches have also been performed for slepton pair production in models with RPV. Sample excluded cross-sections are shown in Figure 7 for both the case where the slepton decays directly via RPV [8], or when it decays via $\tilde{\ell} \to \ell\tilde{\chi}_1^0$ followed by the RPV decay of the $\tilde{\chi}_1^0$ [9].

In GMSB models, the sleptons can decay via the process $\tilde{\ell} \to \ell\tilde{G}$. This decay has an effectively arbitrary lifetime, leading to interesting signatures such as heavy stable charged particles, tracks with kinks or large impact parameters, as well as and the previously considered signature of lepton pairs with missing energy. Figure 8 shows the confidence level of a background-only hypothesis for the search $e^+e^- \to \tilde{\tau}\tilde{\tau}$ followed by the decay $\tilde{\tau} \to \tau\tilde{G}$ for different $\tilde{\tau}$ masses and lifetimes. With no evidence for a signal present, Figure 8 also shows the excluded cross-section for this process. Cross-sections larger than 0.1 pb are excluded for most of the kinematically accessible region [6].

A large number of more specialized searches for slepton production have also been performed, and in all cases the results are consistent with the background-only hypothesis.

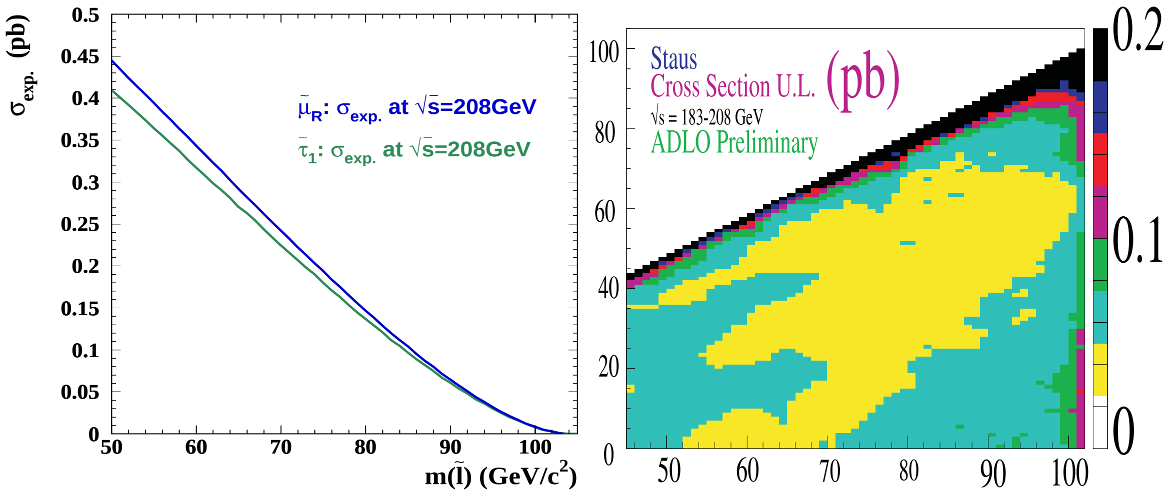


Figure 6: Cross-sections for $e^+e^- \longrightarrow \tilde{\mu}_R\tilde{\mu}_R$ and $e^+e^- \longrightarrow \tilde{\tau}_1\tilde{\tau}_1$ (left). The $\tilde{\mu}_R$ is the SUSY partner of the right handed muon, while $\tilde{\tau}_1$ indicates the lightest stau, a mixture of $\tilde{\tau}_R$ and $\tilde{\tau}_L$. The mixing angle is chosen to minimize the production cross-section. Also shown (right) is the 95% C.L. excluded cross-section for the process $e^+e^- \longrightarrow \tilde{\tau}\tilde{\tau}$ followed by $\tilde{\tau} \longrightarrow \tau\tilde{\chi}_1^0$ using the combined data of the four LEP experiments.

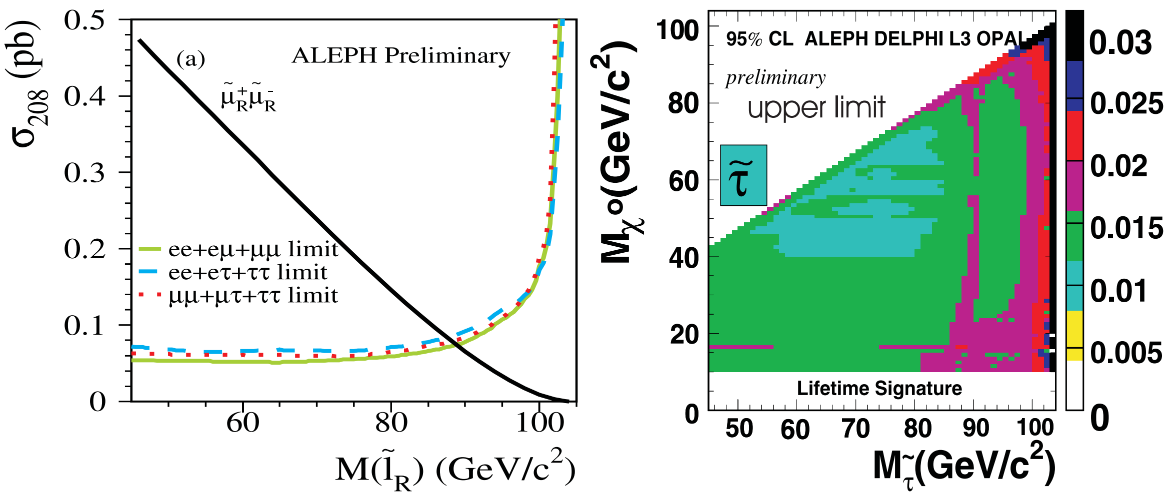


Figure 7: Cross-sections excluded at the 95% C.L. for the process $e^+e^- \longrightarrow \tilde{\mu}\tilde{\mu}$ followed by the direct RPV decays of the smuons (left), and also for $e^+e^- \longrightarrow \tilde{\tau}\tilde{\tau}$ followed by the decays $\tilde{\tau} \longrightarrow \tau\tilde{\chi}_1^0$ with RPV $\tilde{\chi}_1^0$ decays (right).

Slepton pair production cross-sections larger than about 0.1 pb are excluded in most searches, and for much of the kinematic range the exclusions are even more restrictive.

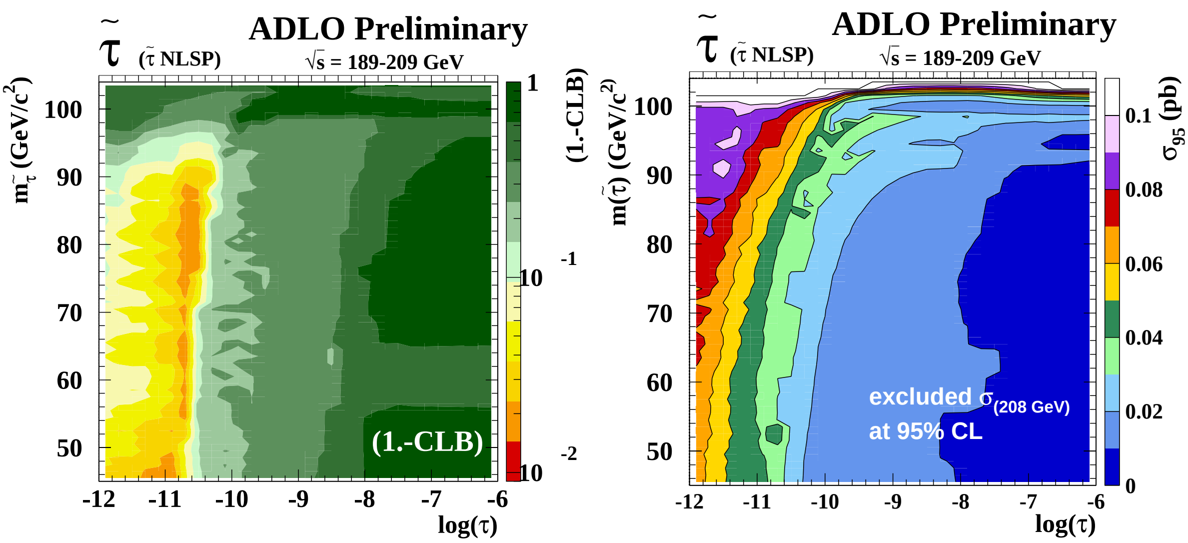


Figure 8: The background-only hypothesis confidence level for the search for $e^+e^- \to \tilde{\tau}\tilde{\tau}$ followed by the decays $\tilde{\tau} \to \tau\tilde{G}$ for different $\tilde{\tau}$ masses and lifetimes is shown on the left. The excluded cross-section at the 95% C.L. for this process is shown on the right.

3 Constraints on Parameters of SUSY Models

Many models simpler than the full MSSM may be constructed to reduce the number of free parameters and to avoid its serious problems. The most popular are "top-down" models which assume a simple particle spectrum at the highest energy scales ($M_{\rm GUT}$ or $M_{\rm Planck}$) determined by a few parameters; the electroweak-scale particle masses and couplings can then be determined from renormalization group evolution. One of the most popular models remains minimal supergravity (mSUGRA). An example mSUGRA particle spectrum for different energy scales is shown in Figure 9 (taken from [10]). In mSUGRA, the LSP is typically the weakly interacting lightest neutralino ($\tilde{\chi}^0_1$).

Another popular model is GMSB in which SUSY breaking is communicated via SM gauge interactions, which contrasts to the mSUGRA case where SUSY breaking is mediated by gravity. The chief phenomenological difference between mSUGRA and GMSB is the LSP, which in GMSB is almost always a light (< 1 GeV) gravitino, $\tilde{G}$. More exotic models, including the possibility of SUSY breaking being mediated by the super-conformal anomaly [11] (AMSB), are not considered here.

It is difficult to find examples of truly model-independent constraints on SUSY parameters. If one assumes that all SUSY particles are heavy except for the $\tilde{G}$, it is possible to place direct constraints on the mass of the $\tilde{G}$ from the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$ using events consisting of a single photon with missing energy. The spectrum of the mass recoiling off single photons from the combined data set of the four LEP experiments is shown in Figure 10 [12]. Differences between data and the background expectation are consistent with the errors on the background Monte Carlo event generators used. Using such searches, DELPHI has excluded at the 95% C.L. a $\tilde{G}$ with mass smaller than 1.12×10^{-5} eV, corresponding to a SUSY breaking scale $\sqrt{F} > 217$ GeV [13].

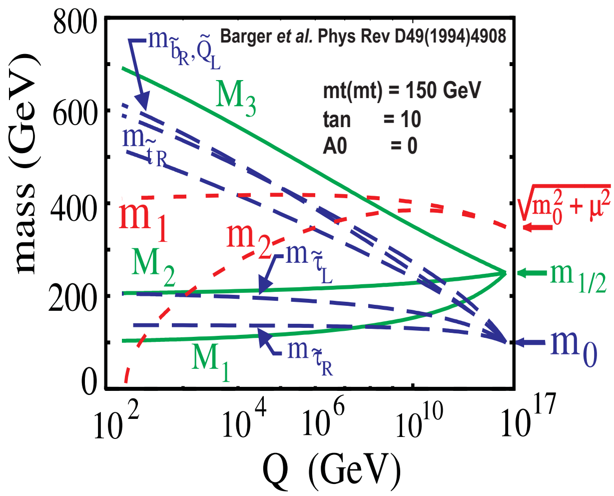


Figure 9: Example evolution of SUSY particle masses in mSUGRA from [10]. The parameter m_0 is the unified scalar particle mass at the GUT or Planck scale, $m_{1/2}$ is the gaugino mass at the GUT scale and μ is the higgsino mass parameter. The additional parameters, the ratio of the higgs vevs ($\tan\beta$) and the trilinear mixing parameter (A_0) are fixed for this plot as indicated.

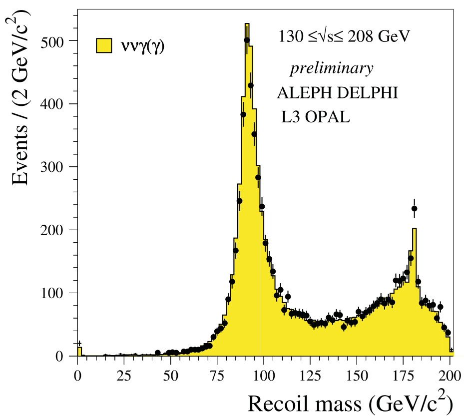


Figure 10: The mass recoiling off single photons from the combined data set of the four LEP experiments. The points are the data, and the shaded region is the expectation from Standard Model processes.

3.1 Gauge Mediated SUSY

In GMSB models, all SUSY particles decay (sometimes cascading via other SUSY particles) to the next-to-lightest SUSY particle (NLSP), which then decays to the $\tilde{\mathrm{G}}$ and the NLSP's partner SM particle. The NLSP is almost always either the $\tilde{\chi}^0_1$ or the lightest slepton ($\tilde{\ell}_1$), leading to the decays[1] $\tilde{\chi}^0_1 \to \tilde{\mathrm{G}}\gamma$ or $\tilde{\ell}_1 \to \tilde{\mathrm{G}}\ell$. The coupling of the NLSP

[1]The lightest neutralino essentially always has a non-negligible $\tilde{\gamma}$ component in GMSB, and the kinematically preferred γ decay normally dominates over $\tilde{\chi}^0_1 \to \tilde{\mathrm{G}}\mathrm{Z}$ and $\tilde{\chi}^0_1 \to \tilde{\mathrm{G}}\mathrm{h}$ (where h is the lightest

to the $\tilde{\mathrm{G}}$ is suppressed, and the lifetime of the NLSP is effectively arbitrary. This leads to potentially interesting experimental signatures such as non-pointing photons from $\tilde{\chi}_1^0$ decays or kinked tracks (even heavy long lived charged particles) from the $\tilde{\ell}_1$.

A further complication in the $\tilde{\ell}_1$ NLSP case is that mixing in the third generation will preferentially make the NLSP the lightest scalar tau lepton ($\tilde{\tau}_1$), particularly for large $\tan\beta$. Example limits on the $\tilde{\tau}_1$ mass from searches at LEP [6] are shown in Figure 11. The limits for scalar muons are somewhat more restrictive, while the constraints on scalar electrons are rather model dependent due to the presence of t-channel $\tilde{\chi}^0$ exchange diagrams in the production process.

The many different particle searches are combined to constrain the parameter space allowed in a minimal GMSB model [14]. The most important parameters are $\tan\beta$ and the SUSY particle mass scale parameter, Λ. Examples of constraints from LEP are also shown in Figure 11. The LEP constraints are comparable to those expected from Run IIa at the Tevatron, but the Tevatron should develop discovery sensitivity beyond LEP in the Run IIb era [15].

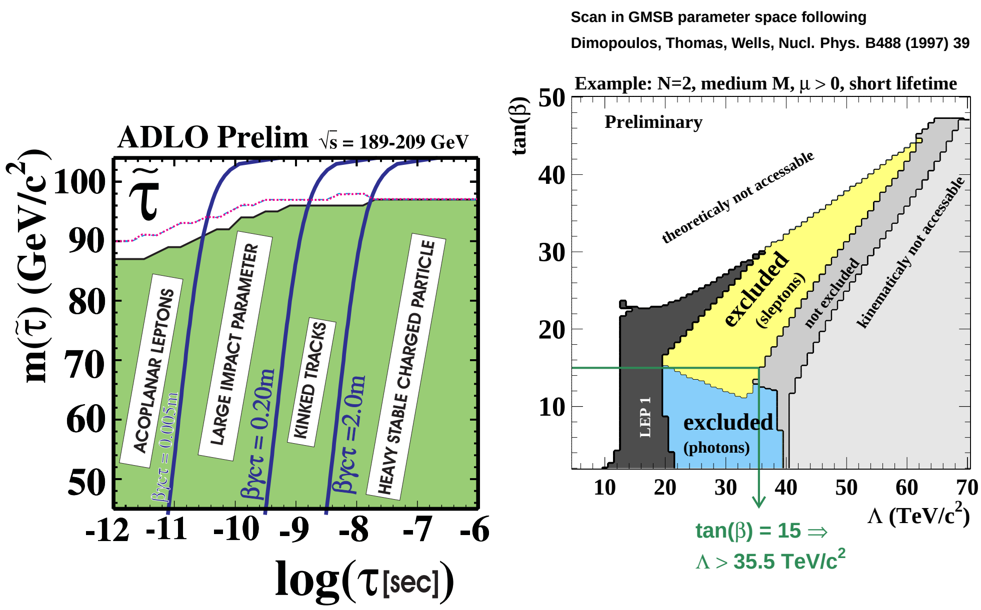


Figure 11: GMSB scalar tau exclusion region (shaded) for different lifetimes (left), assuming $\mathrm{BR}(\tilde{\tau} \to \tau\tilde{\mathrm{G}}) = 1$. The median expected exclusion for a background-only hypothesis is indicated with the dashed line. The solid lines are contours of different $\tilde{\tau}$ lifetimes (detector frame), which determine the most sensitive analysis channel. Also shown is a sample excluded region for GMSB (right) in the $\tan\beta$ *vs.* Λ (the SUSY particle mass scale parameter) plane from the combination of the data of the four LEP experiments.

SUSY Higgs boson).

3.2 Minimal SUGRA and related models

Minimal SUGRA (mSUGRA) is the most common example of a model in which SUSY is mediated by gravity. With a $\tilde{\chi}_1^0$ LSP, the phenomenology is driven by the NLSP, which could in general be the next lightest neutralino ($\tilde{\chi}_2^0$), the lightest chargino, the lightest slepton, or even in unusual configurations the lightest scalar squark ($\tilde{\mathrm{q}}$). The large top quark ($\tilde{\mathrm{t}}$) mass can cause the scalar top squark to be very light, and even be the NLSP. The parameter set of mSUGRA and a closely related constrained CMSSM is shown in Table 2.

Parameter	Description
$m_{1/2}$	GUT scale gaugino mass
m_0	Common GUT-scale scalar mass
	(EW-scale masses from RGE's)
$\tan\beta$	v_2/v_1, Ratio of vevs of two Higgs doublets
A_0	Common trilinear coupling
sign(μ)	Sign of Higgs mixing parameter
$\lvert\mu\rvert$	Magnitude of Higgs mixing parameter
m_{A}	Pseudo-scalar Higgs mass

Table 2: Parameters in mSUGRA and related models. The first four parameters represent the true set of mSUGRA parameters. Many LEP results also permit the magnitude of the Higgs mixing parameter and one Higgs mass parameter to take any value, which is denoted the CMSSM in this note.

Constraints on the masses of scalar quarks, assuming that all except for the $\tilde{\mathrm{t}}$ are degenerate in mass, from the Tevatron [16] and LEP [17] are shown in Figure 12. The limits assume GUT unification of the gluino and $\tilde{\chi}_1^0$ masses. Corresponding limits in the case of a $\tilde{\mathrm{t}}$ NLSP are shown in Figure 12 [17]. The results from CDF and D0 dominate the scalar quark sensitivity, except for small mass differences between the $\tilde{\mathrm{q}}$ and the $\tilde{\chi}_1^0$ where the LEP sensitivity is higher.

Exclusions from the searches for scalar leptons either assuming the RPC decays $\tilde{\ell} \to \ell\tilde{\chi}_1^0$ or assuming RPV decays are shown in Figure 13, both in the context of the CMSSM. In the RPC case, results from all slepton flavours are shown [6], while in the RPV case only scalar tau exclusions are shown [9].

Excluded values of chargino mass in the CMSSM are shown in Figure 14 from the combined data of the four LEP experiments. In the worst case of small Δm in the deep Higgsino region, the 95% C.L. mass exclusion is 92 GeV. In all other cases, the lower mass limit is higher, often near the kinematic limit of 104 GeV.

Combining the results of the chargino, slepton, squark searches with those of the direct search for Higgs bosons [18], constraints can be placed on the mSUGRA or CMSSM parameter space. Of particular interest is the limit on the $\tilde{\chi}_1^0$ LSP in a general CMSSM, shown in Figure 15 [19]. In this very general model, but neglecting mixing in the scalar tau sector, $\tilde{\chi}_1^0$ less than 45 GeV are excluded at the 95% C.L.

Constraints on parameters in the mSUGRA model [20] are shown in Figure 16 as projections in the $m_{1/2}$ *vs.* m_0 plane. Figure 16 shows the case $\tan\beta = 50$ and $A_0 = 0$,

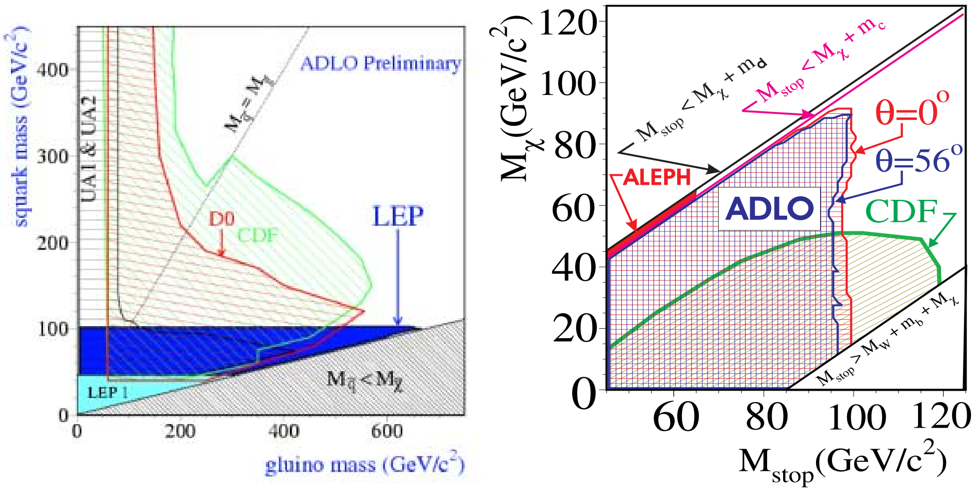


Figure 12: Excluded scalar quark and gluino mass regions (left) in models with a $\tilde{\chi}_1^0$ LSP assuming GUT relations between the gluino and $\tilde{\chi}_1^0$ masses and 5 mass-degenerate quarks. Also shown (right) are excluded scalar top and $\tilde{\chi}_1^0$ masses from combinations of the four LEP experiments (ADLO) and from CDF.

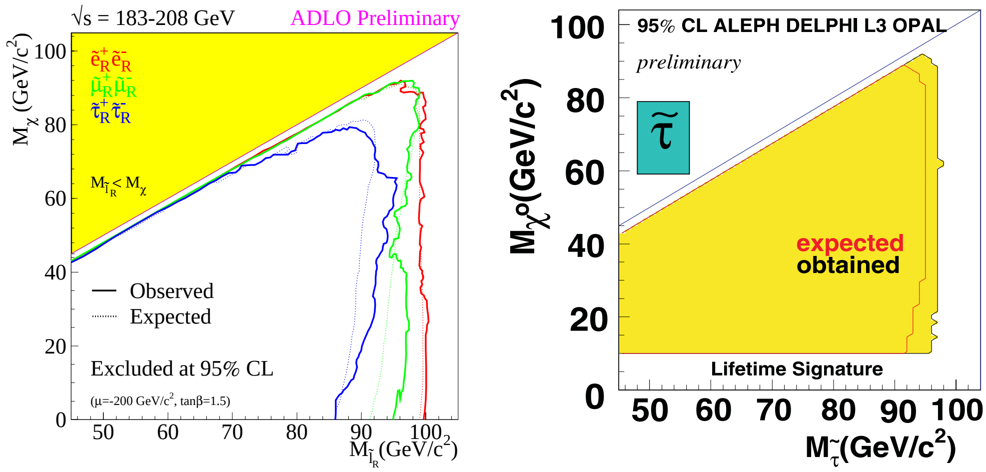


Figure 13: Excluded regions in slepton-neutralino mass plane for RPC (left) and RPV (right) cases in the CMSSM. In the RPV plot, only scalar taus are shown.

and also includes projected sensitivities for direct searches from Run IIb and the contour corresponding to $BR(B_S \rightarrow \mu\mu) = 10^{-7}$, which could be achievable even in Run IIa. Figure 16 shows the case $\tan\beta = 30$, but allowing the A_0 parameter to have any value (which considerably decreases the region excluded by LEP). Finally, Figure 17 shows excluded $\tilde{\chi}_1^0$ masses in the mSUGRA model as a function of $\tan\beta$. Masses less than 50 GeV are excluded at the 95% confidence level for any value of the mSUGRA parameters.

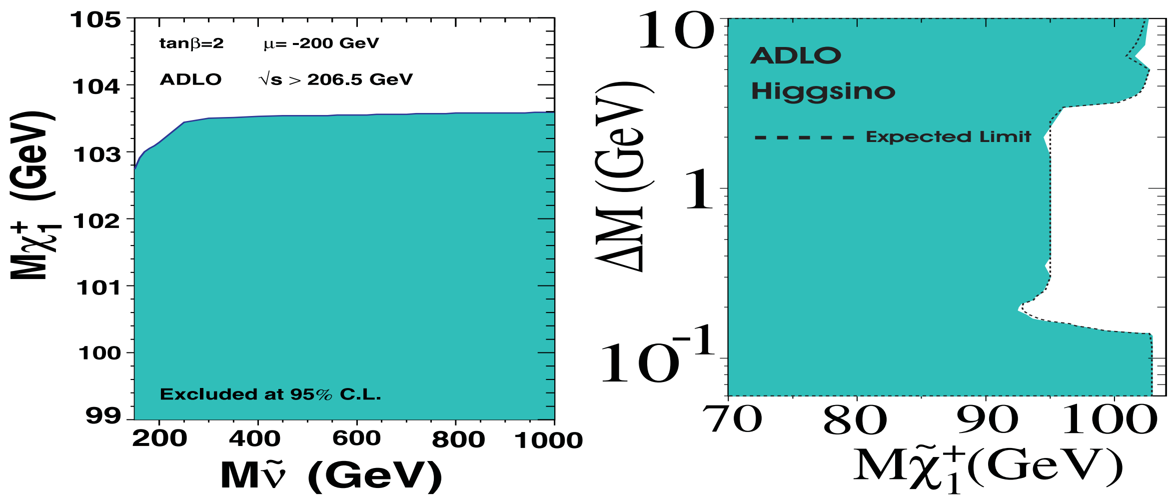


Figure 14: Chargino masses excluded at the 95% C.L. On the left is the specific example of $\tan\beta = 2$ and $\mu = -200$ GeV, while on the right is the case of a small Δm with a Higgsino-like chargino.

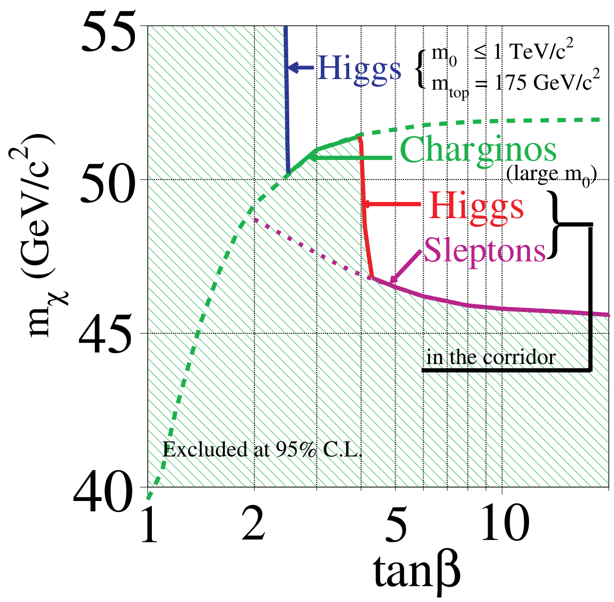


Figure 15: Constraints from different processes on the mass of the neutralino LSP in the CMSSM using the combined data from the four LEP experiments.

4 Conclusions

The LEP experiments finished taking data in 2000, and are currently finalizing their results in searches for signs of SUSY particle production. No evidence for physics beyond the Standard Model is observed. Many constraints from LEP on the parameters of different SUSY models are the most stringent, and will remain so for many years. If SUSY

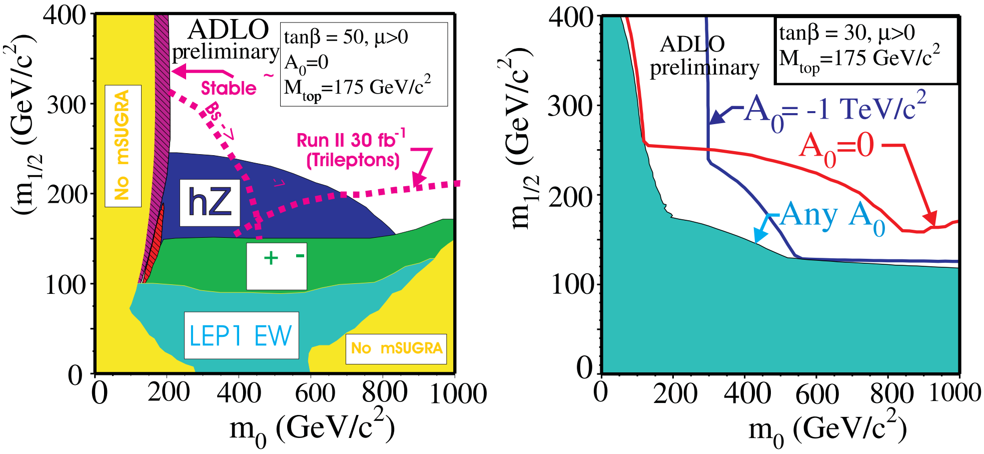


Figure 16: Regions excluded at the 95% confidence level from the LEP experiments from different search processes in the mSUGRA model. Also indicated is the contour corresponding to $BR(B_S \to \mu\mu) = 10^{-7}$ which may be measurable at Run IIa at the Tevatron, and also the reach from direct searches at the Tevatron with the full Run IIb data set in the trilepton channel. The Tevatron prospects are taken from [21]. The plot on the right shows the effect of scanning on the A_0 parameter, which considerably decreases the excluded region from LEP.

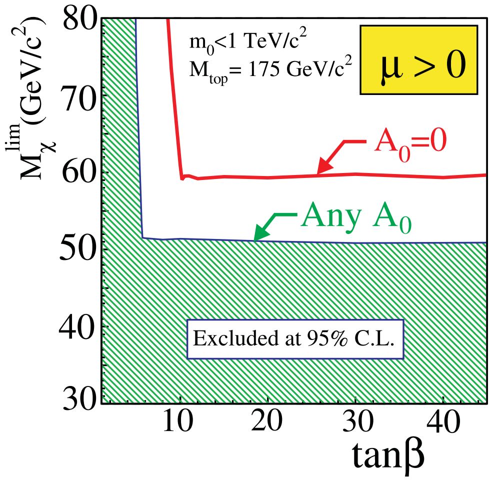


Figure 17: Masses of the LSP $\tilde{\chi}_1^0$ excluded at the 95% confidence level by the LEP experiments in the mSUGRA model.

is discovered and studied at the LHC and a future linear collider, it will appear beyond the LEP kinematic limit.

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