Supersymmetric Particle Searches

SUPERSYMMETRY

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A. Introduction: Supersymmetry is a generalization of the space-time symmetries of quantum field theory that transforms fermions into bosons and vice versa. It also provides a framework for the unification of particle physics and gravity, which takes place at an energy of order the Planck scale ($\approx 10^{19}$ GeV) [1–3]. However, supersymmetry is clearly not an exact symmetry of nature, and therefore must be broken. In theories of "low-energy" supersymmetry, the effective scale of supersymmetry breaking is tied to the electroweak scale [4–6]. In this way, it is hoped that supersymmetry will ultimately explain the origin of the large hierarchy between the W and Z masses and the Planck scale. At present, there are no unambiguous experimental results that require the existence of low-energy supersymmetry. However, if experimentation at future colliders uncovers evidence for supersymmetry, this would have a profound effect on the study of TeV-scale physics and the development of a more fundamental theory of mass and symmetry-breaking phenomena in particle physics.

B. Structure of the MSSM: The minimal supersymmetric extension of the Standard Model (MSSM) consists of taking the Standard Model and adding the corresponding supersymmetric partners [7]. In addition, the MSSM contains two hypercharge $Y = \pm 1$ Higgs doublets, which is the minimal structure for the Higgs sector of an anomaly-free supersymmetric extension of the Standard Model. The supersymmetric structure of the theory also requires (at least) two Higgs doublets to generate mass for both "up"-type and "down"-type quarks (and charged leptons) [8,9]. All renormalizable supersymmetric interactions consistent with (global) B–L conservation (B =baryon number and L =lepton number) are included. Finally, the most general soft-supersymmetry-breaking terms are added [10].

If supersymmetry is relevant for explaining the scale of electroweak interactions, then the mass parameters that occur in the soft-supersymmetry-breaking terms must be of order 1 TeV or below [11]. Some bounds on these parameters exist due to the absence of supersymmetric-particle production at current accelerators (see the Particle Listings following this note). Additional constraints arise from limits on the contributions of virtual supersymmetric particle exchange to a variety of Standard Model processes [12]. The impact of precision electroweak measurements at LEP and SLC on the MSSM parameter space is discussed briefly at the end of this note.

As a consequence of B–L invariance, the MSSM possesses a discrete R-parity invariance, where $R = (-1)^{3(B-L)+2S}$ for a particle of spin S [13]. Note that this formula implies that all the ordinary Standard Model particles have even R-parity, whereas the corresponding supersymmetric partners have odd R-parity. The conservation of R-parity in scattering and decay processes has a crucial impact on supersymmetric phenomenology. For example, starting from an initial state involving ordinary (R-even) particles, it follows that supersymmetric particles must be produced in pairs. In general, these particles are highly unstable and decay quickly into lighter states. However, R-parity invariance also implies that the lightest supersymmetric particle (LSP) is absolutely stable, and must eventually be produced at the end of a decay chain initiated by the decay of a heavy unstable supersymmetric particle.

In order to be consistent with cosmological constraints, the LSP is almost certainly electrically and color neutral [14].

Consequently, the LSP is weakly-interacting in ordinary matter, *i.e.* it behaves like a stable heavy neutrino and will escape detectors without being directly observed. Thus, the canonical signature for (R-parity conserving) supersymmetric theories is missing (transverse) energy, due to the escape of the LSP.

Some model builders attempt to relax the assumption of R-parity conservation. Models of this type must break B–L and are therefore strongly constrained by experiment [15]. Nevertheless, it is still important to allow for the possibility of R-parity violating processes in the search for supersymmetry. In such models, the LSP is unstable and supersymmetric particles can be singly produced and destroyed in association with B or L violation. These features lead to a phenomenology of broken-R-parity models that is very different from that of the MSSM.

In the MSSM, supersymmetry breaking is accomplished by including the soft-supersymmetry breaking terms mentioned earlier. These terms parametrize our ignorance of the fundamental mechanism of supersymmetry breaking. If this breaking occurs spontaneously, then (in the absence of supergravity) a massless Goldstone fermion called the *goldstino* ($\widetilde{G}$) must exist. The goldstino would then be the LSP and could play an important role in supersymmetric phenomenology [16]. In models that incorporate supergravity, this picture changes. If supergravity is spontaneously broken, the goldstino is absorbed ("eaten") by the *gravitino* ($g_{3/2}$), the spin-3/2 partner of the graviton [17]. By this super-Higgs mechanism, the gravitino acquires a mass ($m_{3/2}$). In many models, the gravitino mass is of order the electroweak-symmetry-breaking scale, while its couplings are gravitational in strength [1,18]. Such a gravitino would play no role in supersymmetric phenomenology at colliders.

The parameters of the MSSM are conveniently described by considering separately the supersymmetry-conserving sector and the supersymmetry-breaking sector. A careful discussion of the conventions used in defining the MSSM parameters can be found in Ref. 19. Among the parameters of the supersymmetry conserving sector are: (i) gauge couplings: g_s, g, and g', corresponding to the Standard Model gauge group SU(3)×SU(2)×U(1) respectively; (ii) Higgs-Yukawa couplings: λ_e, λ_u, and λ_d (which are 3×3 matrices in flavor space); and (iii) a supersymmetry-conserving Higgs mass parameter μ.

The supersymmetry-breaking sector contains the following set of parameters: (i) gaugino Majorana masses M_3, M_2 and M_1 associated with the SU(3), SU(2), and U(1) subgroups of the Standard Model; (ii) scalar mass matrices for the squarks and sleptons; (iii) Higgs-squark-squark trilinear interaction terms (the so-called "A-parameters") and corresponding terms involving the sleptons; and (iv) three scalar Higgs mass parameters—two diagonal and one off-diagonal mass terms for the two Higgs doublets. These three mass parameters can be re-expressed in terms of the two Higgs vacuum expectation values, v_1 and v_2, and one physical Higgs mass. Here, v_1 (v_2) is the vacuum expectation value of the Higgs field which couples exclusively to down-type (up-type) quarks and leptons. Note that $v_1^2 + v_2^2 = (246 \text{ GeV})^2$ is fixed by the W mass (or equivalently by the Fermi constant G_F), while the ratio

$$\tan\beta = v_2/v_1 \tag{1}$$

is a free parameter of the model.

The supersymmetric constraints imply that the MSSM Higgs sector is automatically CP-conserving (at tree-level). Thus, $\tan\beta$ is a real parameter (conventionally chosen to be positive), and the physical neutral Higgs scalars are CP-eigenstates. Nevertheless, the MSSM does contain a number of possible new sources of CP violation. For example, gaugino-mass parameters, the A-parameters, and μ may be complex. Some combination of these complex phases must be less than of order 10^{-2}–10^{-3} (for a supersymmetry-breaking scale of 100 GeV) to avoid generating electric dipole moments for the neutron, electron, and atoms in conflict with observed data [20]. However, these complex phases have little impact on the direct searches for supersymmetric particles, and are usually ignored in experimental analyses.

C. The Higgs sector of the MSSM: Before describing the supersymmetric-particle sector, let us consider the Higgs sector of the MSSM [21]. There are five physical Higgs particles in this model: a charged Higgs pair ($H^{\pm}$), two CP-even neutral Higgs bosons (denoted by H_1^0 and H_2^0 where $m_{H_1^0} \leq m_{H_2^0}$) and one CP-odd neutral Higgs boson (A^0). The properties of the Higgs sector are determined by the Higgs potential which is made up of quadratic terms [whose squared-mass coefficients were mentioned above Eq. (1)] and quartic interaction terms. The strengths of the interaction terms are directly related to the gauge couplings by supersymmetry (and are not affected at tree-level by supersymmetry-breaking). As a result, $\tan\beta$ [defined in Eq. (1)] and one Higgs mass determine: the Higgs spectrum, an angle α [which indicates the amount of mixing of the original $Y = \pm 1$ Higgs doublet states in the physical CP-even scalars], and the Higgs boson couplings.

When one-loop radiative corrections are incorporated, additional parameters of the supersymmetric model enter via virtual loops. The impact of these corrections can be significant [22,23]. For example, at tree-level, the MSSM predicts

$m_{H_1^0} \leq m_Z$ [8,9]. If true, this would imply that experiments to be performed at LEP-2 operating at its maximum energy and luminosity would rule out the MSSM if H_1^0 were not found. However, this Higgs mass bound can be violated when the radiative corrections are incorporated. For example, in Ref. 22, the following approximate upper bound was obtained for $m_{H_1^0}$ (assuming $m_{A^0} > m_Z$) in the limit of $m_Z \ll m_t \ll M_{\widetilde{t}}$ [where top-squark ($\widetilde{t}_L$–$\widetilde{t}_R$) mixing is neglected]

$$m_{H_1^0}^2 \lesssim m_Z^2 + \frac{3g^2 m_Z^4}{16\pi^2 m_W^2} \times \left\{ \ln\left(\frac{M_{\widetilde{t}}^2}{m_t^2}\right) \left[\frac{2m_t^4 - m_t^2 m_Z^2}{m_Z^4}\right] + \frac{m_t^2}{3m_Z^2} \right\}. \tag{2}$$

More refined computations (which include the effects of top-squark mixing, renormalization group improvement, and the leading two-loop contributions) yield $m_{H_1^0} \lesssim 125$ GeV for $m_t =$ 175 GeV and a top-squark mass of $M_{\widetilde{t}} = 1$ TeV [24]. Clearly, the radiative corrections to the Higgs masses have a significant impact on the search for the Higgs bosons of the MSSM at LEP [25].

D. Supersymmetric-particle spectrum: Consider next the supersymmetric-particle sector of the MSSM. The supersymmetric partners of the gauge and Higgs bosons are fermions, whose names are obtained by appending "ino" at the end of the corresponding Standard Model particle name. The *gluino* is the color octet Majorana fermion partner of the gluon with mass $M_{\widetilde{g}} = |M_3|$. The supersymmetric partners of the electroweak gauge and Higgs bosons (the *gauginos* and *Higgsinos*) can mix. As a result, the physical mass eigenstates are model-dependent linear combinations of these states, called *charginos* and *neutralinos*, which are obtained by diagonalizing the corresponding mass matrices. The chargino-mass matrix depends on M_2, μ, $\tan\beta$ and m_W [26].

The corresponding chargino-mass eigenstates are denoted by $\widetilde{\chi}_1^+$ and $\widetilde{\chi}_2^+$, with masses

$$M^2_{\widetilde{\chi}_1^+,\widetilde{\chi}_2^+} = \tfrac{1}{2}\Big\{ |\mu|^2 + |M_2|^2 + 2m_W^2 \mp \Big[\big(|\mu|^2 + |M_2|^2 + 2m_W^2\big)^2 - 4|\mu|^2|M_2|^2 - 4m_W^4 \sin^2 2\beta + 8m_W^2 \sin 2\beta\, \mathrm{Re}(\mu M_2) \Big]^{1/2} \Big\}, \quad (3)$$

where the states are ordered such that $M_{\widetilde{\chi}_1^+} \le M_{\widetilde{\chi}_2^+}$. If CP-violating effects are ignored (in which case, M_2 and μ are real parameters), then one can choose a convention where $\tan\beta$ and M_2 are positive. (Note that the relative sign of M_2 and μ is meaningful. The sign of μ is convention-dependent; the reader is warned that both sign conventions appear in the literature.) The sign convention for μ implicit in Eq. (3) is used by the LEP collaborations [27] in their plots of exclusion contours in the M_2 *vs.* μ plane derived from the non-observation of $Z \to \widetilde{\chi}_1^+\widetilde{\chi}_1^-$. The neutralino mass matrix depends on M_1, M_2, μ, $\tan\beta$, m_Z, and the weak mixing angle θ_W [26]. The corresponding neutralino eigenstates are usually denoted by $\widetilde{\chi}_i^0$ $(i = 1, \ldots 4)$, according to the convention that $M_{\widetilde{\chi}_1^0} \le M_{\widetilde{\chi}_2^0} \le M_{\widetilde{\chi}_3^0} \le M_{\widetilde{\chi}_4^0}$. If a chargino or neutralino eigenstate approximates a particular gaugino or Higgsino state, it may be convenient to use the corresponding nomenclature. For example, if M_1 and M_2 are small compared to m_Z (and μ), then the lightest neutralino $\widetilde{\chi}_1^0$ will be nearly a pure photino, $\widetilde{\gamma}$ (the supersymmetric partner of the photon).

It is common practice in the literature to reduce the supersymmetric parameter freedom by requiring that all three gaugino-mass parameters are equal at some grand unification scale. Then, at the electroweak scale, the gaugino-mass parameters can be expressed in terms of one of them (say, M_2). The other two gaugino-mass parameters are given by

$$M_3 = (g_s^2/g^2)M_2 \ , \qquad M_1 = (5g'^2/3g^2)M_2 \ . \tag{4}$$

Having made this assumption, the chargino and neutralino masses and mixing angles depend only on three unknown parameters: the gluino mass, μ, and $\tan\beta$. However, the assumption of gaugino-mass unification could prove false and must eventually be tested experimentally.

The supersymmetric partners of the quarks and leptons are spin-zero bosons: the *squarks*, charged *sleptons*, and *sneutrinos*. For a given fermion f, there are two supersymmetric partners $\widetilde{f}_L$ and $\widetilde{f}_R$ which are scalar partners of the corresponding left and right-handed fermion. (There is no $\widetilde{\nu}_R$.) However, in general, $\widetilde{f}_L$ and $\widetilde{f}_R$ are not mass-eigenstates since there is $\widetilde{f}_L$-$\widetilde{f}_R$ mixing which is proportional in strength to the corresponding element of the scalar mass-squared matrix [28]:

$$M_{LR}^2 = \begin{cases} m_d(A_d - \mu\tan\beta), & \text{for “down”-type } f \\ m_u(A_u - \mu\cot\beta), & \text{for “up”-type } f, \end{cases} \tag{5}$$

where m_d (m_u) is the mass of the appropriate “down” (“up”) type quark or lepton. Here, A_d and A_u are (unknown) soft-supersymmetry-breaking A–parameters and μ and $\tan\beta$ have been defined earlier. The signs of the A parameters are also convention-dependent; see Ref. 19. Due to the appearance of the *fermion* mass in Eq. (5), one expects M_{LR} to be small compared to the diagonal squark and slepton masses, with the possible exception of the top-squark, since m_t is large, and the bottom-squark and tau-slepton if $\tan\beta \gg 1$.

The (diagonal) L- and R-type squark and slepton masses are given by [2]

$$M^2_{\widetilde{u}_L} = M^2_{\widetilde{Q}} + m_u^2 + m_Z^2 \cos 2\beta (\tfrac{1}{2} - \tfrac{2}{3}\sin^2\theta_W) \tag{6}$$

$$M^2_{\widetilde{u}_R} = M^2_{\widetilde{U}} + m_u^2 + \tfrac{2}{3} m_Z^2 \cos 2\beta \sin^2\theta_W \tag{7}$$

$$M^2_{\widetilde{d}_L} = M^2_{\widetilde{Q}} + m_d^2 - m_Z^2 \cos 2\beta (\tfrac{1}{2} - \tfrac{1}{3}\sin^2\theta_W) \tag{8}$$

$$M^2_{\widetilde{d}_R} = M^2_{\widetilde{D}} + m_d^2 - \tfrac{1}{3} m_Z^2 \cos 2\beta \sin^2\theta_W \tag{9}$$

$$M^2_{\widetilde{\nu}} = M^2_{\widetilde{L}} + \tfrac{1}{2} m_Z^2 \cos 2\beta \tag{10}$$

$$M^2_{\widetilde{e}_L} = M^2_{\widetilde{L}} + m_e^2 - m_Z^2 \cos 2\beta (\tfrac{1}{2} - \sin^2\theta_W) \tag{11}$$

$$M^2_{\widetilde{e}_R} = M^2_{\widetilde{E}} + m_e^2 - m_Z^2 \cos 2\beta \sin^2\theta_W\ . \tag{12}$$

The soft-supersymmetry-breaking parameters: $M_{\widetilde{Q}}$, $M_{\widetilde{U}}$, $M_{\widetilde{D}}$, $M_{\widetilde{L}}$, and $M_{\widetilde{E}}$ are unknown parameters. In the equations above, the notation of first generation fermions has been used and generational indices have been suppressed. Further complications such as intergenerational mixing are possible, although there are some constraints from the nonobservation of flavor-changing neutral currents (FCNC) [29].

E. Reducing the MSSM parameter freedom: One way to guarantee the absence of significant FCNC's mediated by virtual supersymmetric-particle exchange is to posit that the diagonal soft-supersymmetry-breaking scalar squared-masses are universal in flavor space at some energy scale (normally taken to be at or near the Planck scale) [5,30,31]. Renormalization group evolution is used to determine the low-energy values for the scalar mass parameters listed above. This assumption substantially reduces the MSSM parameter freedom. For example, supersymmetric grand unified models with universal scalar masses at the Planck scale typically give [32] $M_{\widetilde{L}} \approx M_{\widetilde{E}} < M_{\widetilde{Q}} \approx M_{\widetilde{U}} \approx M_{\widetilde{D}}$ with the squark masses somewhere between a factor of 1–3 larger than the slepton masses (neglecting generational distinctions). More specifically, the first two generations are thought to be nearly degenerate in mass, while $M_{\widetilde{Q}_3}$ and $M_{\widetilde{U}_3}$ are typically reduced by a factor of 1–3 from the other soft-supersymmetry-breaking masses because of renormalization effects due to the heavy top quark mass.

As a result, four flavors of squarks (with two squark eigenstates per flavor) and $\widetilde{b}_R$ will be nearly mass-degenerate and somewhat heavier than six flavors of nearly mass-degenerate sleptons (with two per flavor for the charged sleptons and one per flavor for the sneutrinos). On the other hand, the $\widetilde{b}_L$ mass and the diagonal $\widetilde{t}_L$ and $\widetilde{t}_R$ masses are reduced compared to the common squark mass of the first two generations. In addition, third generation squark masses and tau-slepton masses are sensitive to the strength of the respective $\widetilde{f}_L$–$\widetilde{f}_R$ mixing as discussed below Eq. (5).

Two additional theoretical frameworks are often introduced to reduce further the MSSM parameter freedom [1,2,33]. The first involves grand unified theories (GUTs) and the desert hypothesis (*i.e* no new physics between the TeV-scale and the GUT-scale). Perhaps one of the most compelling hints for low-energy supersymmetry is the unification of SU(3)×SU(2)×U(1) gauge couplings predicted by supersymmetric GUT models [5,34] (with the supersymmetry breaking scale of order 1 TeV or below). The unification, which takes place at an energy scale of order 10^{16} GeV, is quite robust (and depends weakly on the details of the GUT-scale theory). For example, a recent analysis [35] finds that supersymmetric GUT unification implies that $\alpha_s(m_Z) = 0.129 \pm 0.010$, not including threshold corrections due to GUT-scale particles (which could diminish the value of $\alpha_s(m_Z)$). This result is compatible with the world average of $\alpha_s(m_Z) = 0.118 \pm 0.003$ as quoted by the Particle Data Group. In contrast, gauge coupling unification in the simplest nonsupersymmetric GUT models fails by many standard deviations [36].

Grand unification can impose additional constraints through the unification of Higgs-fermion Yukawa couplings (λ_f). There is some evidence that $\lambda_b = \lambda_\tau$ leads to good low-energy phenomenology [37], and an intriguing possibility that in the MSSM (in the parameter regime where $\tan\beta \simeq m_t/m_b$) $\lambda_b = \lambda_\tau = \lambda_t$ may be phenomenologically viable [38]. However, such unification constraints are GUT-model dependent, and do not address the origin of the first and second generation fermion masses and the CKM mixing matrix. Finally, grand unification imposes constraints on the soft-supersymmetry-breaking parameters. For example, gaugino-mass unification leads to the relations given in Eq. (4). Diagonal squark and slepton soft-supersymmetry-breaking scalar masses may also be unified at the GUT scale (analogous to the unification of Higgs-fermion Yukawa couplings).

In order to further reduce the number of independent soft-supersymmetry-breaking parameters (with or without grand unification), an additional simplifying assumption is required. In the minimal supergravity theory, the soft-supersymmetry-breaking parameters are often taken to have the following simple form. Referring to the parameter list given above Eq. (1), the Planck-scale values of the soft-supersymmetry-breaking terms depend on the following minimal set of parameters: (i) a universal gaugino mass $m_{1/2}$; (ii) a universal diagonal scalar-mass parameter m_0 [whose consequences were described at the beginning of this section]; (iii) a universal A-parameter, A_0; and (iv) three scalar Higgs mass parameters—two common diagonal-squared masses given by $|\mu_0|^2 + m_0^2$ and an off-diagonal-squared mass given by $B_0\mu_0$ (which defines the Planck-scale supersymmetry-breaking parameter B_0), where μ_0 is the Planck-scale value of the μ-parameter.

As before, renormalization group evolution is used to compute the low-energy values of the supersymmetry-breaking parameters and determines the supersymmetric-particle spectrum. Moreover, in this approach, electroweak symmetry breaking is induced radiatively if one of the Higgs diagonal-squared masses is forced negative by the evolution. This occurs in models with a large Higgs-top quark Yukawa coupling (*i.e.* large m_t). As a result, the two Higgs vacuum expectation values (or equivalently, m_Z and $\tan\beta$) can be expressed as a function of the Planck-scale supergravity parameters. The simplest procedure [32] is to remove μ_0 and B_0 in favor of m_Z and $\tan\beta$ (the sign of μ_0 is not fixed in this process). In this case, the MSSM spectrum and its interactions are determined by m_0, A_0, $m_{1/2}$, $\tan\beta$, and the sign of μ_0 (in addition to the parameters of the Standard Model). However, the minimal approach above is probably too restrictive. Theoretical considerations suggest that the universality of Planck-scale soft-supersymmetry breaking parameters is not generic [39]. In the absence of a fundamental theory of supersymmetry breaking, further progress will require a detailed knowledge of the supersymmetric-particle spectrum in order to determine the nature of the Planck-scale parameters. Of course, any of the theoretical assumptions described in this section could be wrong and must eventually be tested experimentally.

F. The MSSM and precision of electroweak data: The MSSM (with or without constraints imposed from the theory near the Planck scale) provides a framework that can be tested by precision electroweak data. The level of accuracy of the measured Z decay observables at LEP and SLC is sufficient to test the structure of the one-loop radiative corrections of the electroweak model [40], and is thus potentially sensitive to the virtual effects of undiscovered particles. Combining the most recent LEP and SLC electroweak results [41] with the recent top-quark mass measurement at the Tevatron [42], a weak preference is found [41,43] for a light Higgs boson mass of order m_Z, which is consistent with the MSSM Higgs mass upper bound previously noted. Moreover, for Z decay observables, the effects of virtual supersymmetric-particle exchange are suppressed by a factor of $m_Z^2/M_{\rm SUSY}^2$, and therefore decouple in the limit of large supersymmetric-particle masses. It follows that for $M_{\rm SUSY}^2 \gg m_Z$ (in practice, it is sufficient to have all supersymmetric-particle masses above 200 GeV) the MSSM yields an equally good fit to the precision electroweak data as compared to the Standard Model fit.

On the other hand, there are a few tantalizing hints in the data for deviations from Standard Model predictions. Indeed, if $R_b \equiv \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$ is confirmed to lie above its Standard Model prediction due to the presence of new physics, then a plausible candidate for the new physics would be the MSSM with some light supersymmetric particles (*e.g.* a light chargino and top-squark and/or a light CP-odd scalar, A^0) close in mass to their present LEP bounds [44,45]. Such a scenario would be tested by the search for supersymmetric particles at LEP-2 and the Tevatron.

G. Beyond the MSSM: Nonminimal versions of low-energy supersymmetry can also be constructed. These models add additional matter and/or gauge super-multiplets to the MSSM (at the TeV scale or below). Experimental and theoretical constraints place some restrictions on these approaches, although no comprehensive treatment has yet appeared in the literature.

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MINIMAL SUPERSYMMETRIC STANDARD MODEL ASSUMPTIONS

All results shown below (except where stated otherwise) are based on the Minimal Supersymmetric Standard Model (MSSM) as described in the Note on Supersymmetry. This includes the assumption that R-parity is conserved. In addition the following assumptions are made in most cases:

1) The $\widetilde{\chi}_1^0$ (or $\widetilde{\gamma}$) is the lightest supersymmetric particle (LSP).
2) $m_{\widetilde{f}_L} = m_{\widetilde{f}_R}$ where $\widetilde{f}_L$ and $\widetilde{f}_R$ refer to the scalar partners of left-and right-handed fermions.

Limits involving different assumptions either are identified with comments or are in the miscellaneous section.

When needed, specific assumptions of the eigenstate content of neutralinos and charginos are indicated (use of the notation $\widetilde{\gamma}$ (photino), $\widetilde{H}$ (Higgsino), $\widetilde{W}$ (w-ino), and $\widetilde{Z}$ (z-ino) indicates the approximation of a pure state was made).

$\widetilde{\chi}_1^0$ (Lightest Neutralino) MASS LIMIT

$\widetilde{\chi}_1^0$ is likely to be the lightest supersymmetric particle (LSP). See also the $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$ section below.

We have divided the $\widetilde{\chi}_1^0$ listings below into three sections: 1) Accelerator limits for $\widetilde{\chi}_1^0$, 2) Bounds on $\widetilde{\chi}_1^0$ from dark matter searches, and 3) Other bounds on $\widetilde{\chi}_1^0$ from astrophysics and cosmology.

Accelerator limits for $\widetilde{\chi}_1^0$

These papers generally exclude regions in the $M_2-\mu$ parameter plane based on accelerator experiments. Unless otherwise stated, these papers assume minimal supersymmetry and GUT relations (gaugino-mass unification condition).

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>23	95	[1] ACCIARRI	95E	L3	$\tan\beta > 3$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
≥ 0		[2] FRANKE	94	RVUE	$\widetilde{\chi}_1^0$ mixed with a singlet
>20	95	[3] DECAMP	92	ALEP	$\tan\beta > 3$
>18.8		[4] BAER	91	RVUE	$\tan\beta > 1.6$
>18.4	90	[5] HIDAKA	91	RVUE	
> (10–13)	90	[6] ROSZKOWSKI	90	RVUE	$\tan\beta \geq 1$
>5	90	[7] HEARTY	89	ASP	$\widetilde{\gamma}$; for $m_{\widetilde{e}} < 55$ GeV

[1] ACCIARRI 95E limit for $\tan\beta > 2$ is 20 GeV, and the bound disappears if $\tan\beta \sim 1$.
[2] FRANKE 94 reanalyzed the LEP constraints on the neutralinos in the MSSM with an additional singlet.
[3] DECAMP 92 limit for $\tan\beta > 2$ is $m > 13$ GeV.
[4] BAER 91 limit obtained from LEP and preliminary CDF results assuming $\tan\beta > 1.6$.
[5] HIDAKA 91 limit obtained from LEP and preliminary CDF limits on the gluino mass (as analyzed in BAER 91).
[6] ROSZKOWSKI 90 limit obtained from ALEPH and CDF/UA2 results assuming $\tan\beta \geq 1$.
[7] HEARTY 89 assumed pure $\widetilde{\gamma}$ eigenstate and $m_{\widetilde{e}_L} = m_{\widetilde{e}_R}$. There is no limit for $m_{\widetilde{e}} > 58$ GeV. Uses $e^+ e^- \rightarrow \gamma\widetilde{\gamma}\widetilde{\gamma}$. No GUT relation assumptions are made.

Bounds on $\widetilde{\chi}_1^0$ from dark matter searches

These papers generally exclude regions in the $M_2-\mu$ parameter plane assuming that $\widetilde{\chi}_1^0$ is the dominant form of dark matter in the galactic halo. These limits are based on the lack of detection in laboratory experiments or by the absence of a signal in underground neturino detectors. The latter signal is expected if $\widetilde{\chi}_1^0$ accumlates in the Sun or the Earth and annihilates into high-energy ν's.

VALUE	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[8] MORI	93	KAMI
	[9] BOTTINO	92	COSM
	[10] BOTTINO	91	RVUE
	[11] GELMINI	91	COSM
	[12] KAMIONKOW...	91	RVUE
	[13] MORI	91B	KAMI
none 4–15 GeV	[14] OLIVE	88	COSM

[8] MORI 93 excludes some region in M_2–μ parameter space depending on tanβ and lightest scalar Higgs mass for neutralino dark matter $m_{\widetilde{\chi}^0} > m_W$, using limits on upgoing muons produced by energetic neutrinos from neutralino annihilation in the Sun and the Earth.

[9] BOTTINO 92 excludes some region M_2-μ parameter space assuming that the lightest neutralino is the dark matter, using upgoing muons at Kamiokande, direct searches by Ge detectors, and by LEP experiments. The analysis includes top radiative corrections on Higgs parameters and employs two different hypotheses for nucleon-Higgs coupling. Effects of rescaling in the local neutralino density according to the neutralino relic abundance are taken into account.

[10] BOTTINO 91 excluded a region in $M_2-\mu$ plane using upgoing muon data from Kamioka experiment, assuming that the dark matter surrounding us is composed of neutralinos and that the Higgs boson is not too heavy.

[11] GELMINI 91 exclude a region in $M_2-\mu$ plane using dark matter searches.

[12] KAMIONKOWSKI 91 excludes a region in the M_2–μ plane using IMB limit on upgoing muons originated by energetic neutrinos from neutralino annihilation in the sun, assuming that the dark matter is composed of neutralinos and that $m_{H_1^0} \lesssim$ 50 GeV. See Fig. 8 in the paper.

[13] MORI 91B exclude a part of the region in the M_2–μ plane with $m_{\widetilde{\chi}_1^0} \lesssim$ 80 GeV using a limit on upgoing muons originated by energetic neutrinos from neutralino annihilation in the earth, assuming that the dark matter surrounding us is composed of neutralinos and that $m_{H_1^0} \lesssim$ 80 GeV.

[14] OLIVE 88 result assumes that photinos make up the dark matter in the galactic halo. Limit is based on annihilations in the sun and is due to an absence of high energy neutrinos detected in underground experiments. The limit is model dependent.

Other bounds on $\widetilde{\chi}_1^0$ from astrophysics and cosmology

Most of these papers generally exclude regions in the $M_2-\mu$ parameter plane by requiring that the $\widetilde{\chi}_1^0$ contribution to the overall cosmological density is less than some maximal value to avoid overclosure of the Universe. Those not based on the cosmological density are indicated. Many of these papers also include LEP and/or other bounds.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
none 100 eV – 15 GeV	SREDNICKI	88	COSM	$\widetilde{\gamma}$; $m_{\widetilde{f}}$=100 GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

	[15] FALK	95	COSM	*CP*-violating phases
	DREES	93	COSM	Minimal supergravity
	FALK	93	COSM	Sfermion mixing
	KELLEY	93	COSM	Minimal supergravity
	MIZUTA	93	COSM	Co-annihilation
	ELLIS	92F	COSM	Minimal supergravity
	KAWASAKI	92	COSM	Minimal supergravity, m_0=A=0
	LOPEZ	92	COSM	Minimal supergravity, m_0=A=0
	MCDONALD	92	COSM	
	NOJIRI	91	COSM	Minimal supergravity
	[16] OLIVE	91	COSM	
	ROSZKOWSKI	91	COSM	
	ELLIS	90	COSM	
	[17] GRIEST	90	COSM	
	[18] GRIFOLS	90	ASTR	$\widetilde{\gamma}$; SN 1987A
	KRAUSS	90	COSM	
	[16] OLIVE	89	COSM	
> 100 eV	[19] ELLIS	88B	ASTR	$\widetilde{\gamma}$; SN 1987A
none 100 eV – (5–7) GeV	SREDNICKI	88	COSM	$\widetilde{\gamma}$; $m_{\widetilde{f}}$=60 GeV
none 100 eV–5 GeV	ELLIS	84	COSM	$\widetilde{\gamma}$; for $m_{\widetilde{f}}$=100 GeV
	GOLDBERG	83	COSM	$\widetilde{\gamma}$
	[20] KRAUSS	83	COSM	$\widetilde{\gamma}$
	VYSOTSKII	83	COSM	$\widetilde{\gamma}$

[15] Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim$ 350 GeV for m_t = 174 GeV.

[16] Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim$ 350 GeV for $m_t \leq$ 200 GeV. Mass of the higgsino (=LSP) is limited to $m_{\widetilde{H}} \lesssim$ 1 TeV for $m_t \leq$ 200 GeV.

[17] Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim$ 550 GeV. Mass of the higgsino (=LSP) is limited to $m_{\widetilde{H}} \lesssim$ 3.2 TeV.

[18] GRIFOLS 90 argues that SN1987A data exclude a light photino ($\lesssim$ 1 MeV) if $m_{\widetilde{q}} <$ 1.1 TeV, $m_{\widetilde{e}} <$ 0.83 TeV.

[19] ELLIS 88B argues that the observed neutrino flux from SN 1987A is inconsistent with a light photino if 60 GeV $\lesssim m_{\widetilde{q}} \lesssim$ 2.5 TeV. If m(higgsino) is O(100 eV) the same argument leads to limits on the ratio of the two Higgs v.e.v.'s. LAU 93 discusses possible relations of ELLIS 88B bounds.

[20] KRAUSS 83 finds $m_{\widetilde{\gamma}}$ not 30 eV to 2.5 GeV. KRAUSS 83 takes into account the gravitino decay. Find that limits depend strongly on reheated temperature. For example a new allowed region $m_{\widetilde{\gamma}}$ = 4–20 MeV exists if $m_{\text{gravitino}}$ <40 TeV. See figure 2.

$\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_3$, $\widetilde{\chi}^0_4$ (Neutralinos) MASS LIMITS

Neutralinos are unknown mixtures of photinos, z-inos, and neutral higgsinos (the supersymmetric partners of photons and of Z and Higgs bosons). The limits here apply only to $\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_3$, and $\widetilde{\chi}^0_4$. $\widetilde{\chi}^0_1$ is the lightest supersymmetric particle (LSP); see $\widetilde{\chi}^0_1$ Mass Limits. It is not possible to quote rigorous mass limits because they are extremely model dependent; i.e. they depend on branching ratios of various $\widetilde{\chi}^0$ decay modes, on the masses of decay products ($\widetilde{e}$, $\widetilde{\gamma}$, $\widetilde{q}$, $\widetilde{g}$), and on the $\widetilde{e}$ mass exchanged in $e^+e^- \rightarrow \widetilde{\chi}^0_i\widetilde{\chi}^0_j$. Often limits are given as contour plots in the $m_{\widetilde{\chi}^0} - m_{\widetilde{e}}$ plane vs other parameters. When specific assumptions are made, e.g, the neutralino is a pure photino ($\widetilde{\gamma}$), pure z-ino ($\widetilde{Z}$), or pure neutral higgsino ($\widetilde{H}^0$), the neutralinos will be labelled as such.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
> 52	95	[21] ACCIARRI	95E	L3	$\widetilde{\chi}^0_2$, tanβ >3
> 84	95	[21] ACCIARRI	95E	L3	$\widetilde{\chi}^0_3$, tanβ >3
>127	95	[21] ACCIARRI	95E	L3	$\widetilde{\chi}^0_4$, tanβ >3
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[22] ABACHI	96	D0	$p\overline{p} \rightarrow \widetilde{\chi}^{\pm}_1\widetilde{\chi}^0_2$
> 45	95	[23] DECAMP	92	ALEP	$\widetilde{\chi}^0_2$, tanβ >3
> 45	95	[24] HIDAKA	91	RVUE	$\widetilde{\chi}^0_2$
> 70	95	[24] HIDAKA	91	RVUE	$\widetilde{\chi}^0_3$
>108	95	[24] HIDAKA	91	RVUE	$\widetilde{\chi}^0_4$
		[25] ABREU	90G	DLPH	$Z \rightarrow \widetilde{\chi}^0\widetilde{\chi}^0$
		[26] AKRAWY	90N	OPAL	$Z \rightarrow \widetilde{\chi}^0\widetilde{\chi}^0$
> 57	90	[27] BAER	90	RVUE	$\widetilde{\chi}^0_3$; $\Gamma(Z)$; tanβ > 1
		[28] BARKLOW	90	MRK2	$Z \rightarrow \widetilde{\chi}^0_1\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_2\widetilde{\chi}^0_2$
		[29] DECAMP	90K	ALEP	$Z \rightarrow \widetilde{\chi}^0\widetilde{\chi}^0$
> 41	95	[30] SAKAI	90	AMY	$e^+e^- \rightarrow \widetilde{H}^0_1\widetilde{H}^0_2$ ($\widetilde{H}^0_2 \rightarrow f\overline{f}\widetilde{H}^0_1$)
> 31	95	[31] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{Z}$ ($\widetilde{Z} \rightarrow q\overline{q}\widetilde{\gamma}$), $m_{\widetilde{e}}$ < 70 GeV
> 30	95	[32] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{Z}$ ($\widetilde{Z} \rightarrow q\overline{q}\widetilde{g}$)
> 31.3	95	[33] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{H}^0_1\widetilde{H}^0_2$ ($\widetilde{H}^0_2 \rightarrow f\overline{f}\widetilde{H}^0_1$)
> 22	95	[34] BEHREND	87B	CELL	$e^+e^- \rightarrow \gamma\widetilde{\gamma}\widetilde{Z}$ ($\widetilde{Z} \rightarrow \widetilde{\nu}\nu$)
		[35] AKERLOF	85	HRS	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\chi}^0$ ($\widetilde{\chi}^0 \rightarrow q\overline{q}\widetilde{\gamma}$)
none 1–21	95	[36] BARTEL	85L	JADE	$e^+e^- \rightarrow \widetilde{H}^0_1\widetilde{H}^0_2$, $\widetilde{H}^0_2 \rightarrow f\overline{f}\widetilde{H}^0_1$
		[37] BEHREND	85	CELL	$e^+e^- \rightarrow$ monojet X
> 35	95	[38] ADEVA	84B	MRKJ	$e^+e^- \rightarrow \gamma\widetilde{Z}$ ($\widetilde{Z} \rightarrow \ell\overline{\ell}\widetilde{\gamma}$)
> 28	95	[39] BARTEL	84C	JADE	$e^+e^- \rightarrow \gamma\widetilde{Z}$ ($\widetilde{Z} \rightarrow f\overline{f}\widetilde{\gamma}$)
		[40] ELLIS	84	COSM	

[21] ACCIARRI 95E limits go down to 0 GeV ($\widetilde{\chi}^0_2$), 60 GeV ($\widetilde{\chi}^0_3$), and 90 GeV ($\widetilde{\chi}^0_4$) for tanβ=1.

[22] ABACHI 96 searches for 3-lepton final states. Efficiencies are calculated using mass relations and branching ratios in the Minimal Supergravity scenario. Results are presented as lower bounds on $\sigma(\widetilde{\chi}^{\pm}_1\widetilde{\chi}^0_2) \times$ B($\widetilde{\chi}^{\pm}_1 \rightarrow \ell\nu_\ell\widetilde{\chi}^0_1$) $\times$ B($\widetilde{\chi}^0_2 \rightarrow \ell^+\ell^-\widetilde{\chi}^0_1$) as a function of $m_{\widetilde{\chi}^0_1}$. Limits range from 3.1 pb ($m_{\widetilde{\chi}^0_1}$ = 45 GeV) to 0.6 pb ($m_{\widetilde{\chi}^0_1}$ = 100 GeV).

[23] For $\tan\beta > 2$ the limit is >40 GeV; and it disappears for $\tan\beta < 1.6$.

[24] HIDAKA 91 limit obtained from LEP and preliminary CDF limits on the gluino mass (as analyzed in BAER 91).

[25] ABREU 90G exclude $B(Z \rightarrow \widetilde{\chi}^0_1 \widetilde{\chi}^0_2) \geq 10^{-3}$ and $B(Z \rightarrow \widetilde{\chi}^0_2 \widetilde{\chi}^0_2) \geq 2 \times 10^{-3}$ assuming $\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1 f \overline{f}$ via virtual Z. These exclude certain regions in model parameter space, see their Fig. 5.

[26] AKRAWY 90N exclude $B(Z \rightarrow \widetilde{\chi}^0_1 \widetilde{\chi}^0_2) \gtrsim$ 3–5 $\times 10^{-4}$ assuming $\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1 f \overline{f}$ or $\widetilde{\chi}^0_1 \gamma$ for most accessible masses. These exclude certain regions in model parameter space, see their Fig. 7.

[27] BAER 90 is independent of decay modes. Limit from analysis of supersymmetric parameter space restrictions implied by $\Delta\Gamma(Z) < 120$ MeV. These result from decays of Z to all combinations of $\widetilde{\chi}^{\pm}_i$ and $\widetilde{\chi}^0_i$. Minimal supersymmetry with $\tan\beta > 1$ is assumed.

[28] See Figs. 4, 5 in BARKLOW 90 for the excluded regions.

[29] DECAMP 90K exclude certain regions in model parameter space, see their figures.

[30] SAKAI 90 assume $m_{\widetilde{H}^0_1} = 0$. The limit is for $m_{\widetilde{H}^0_2}$.

[31] Pure $\widetilde{\gamma}$ and pure $\widetilde{Z}$ eigenstates. $B(\widetilde{Z} \rightarrow q \overline{q} \widetilde{\gamma}) = 0.60$ and $B(\widetilde{Z} \rightarrow e^+ e^- \widetilde{\gamma}) = 0.13$. $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} < 70$ GeV. $m_{\widetilde{\gamma}} < 10$ GeV.

[32] Pure $\widetilde{\gamma}$ and pure $\widetilde{Z}$ eigenstates. $B(\widetilde{Z} \rightarrow q \overline{q} \widetilde{g}) = 1$. $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} < 70$ GeV. $m_{\widetilde{\gamma}} = 0$.

[33] Pure higgsino. The LSP is the other higgsino and is taken massless. Limit degraded if $\widetilde{\chi}^0$ not pure higgsino or if LSP not massless.

[34] Pure $\widetilde{\gamma}$ and pure $\widetilde{Z}$ eigenstates. $B(\widetilde{Z} \rightarrow \widetilde{\nu} \nu) = 1$. $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} = 26$ GeV. $m_{\widetilde{\gamma}} = 10$ GeV. No excluded region remains for $m_{\widetilde{e}} > 30$ GeV.

[35] AKERLOF 85 is $e^+ e^-$ monojet search motivated by UA1 monojet events. Observed only one event consistent with $e^+ e^- \rightarrow \widetilde{\gamma} + \widetilde{\chi}^0$ where $\widetilde{\chi}^0 \rightarrow$ monojet. Assuming that missing-p_T is due to $\widetilde{\gamma}$, and monojet due to $\widetilde{\chi}^0$, limits dependent on the mixing and $m_{\widetilde{e}}$ are given, see their figure 4.

[36] BARTEL 85L assume $m_{\widetilde{H}^0_1} = 0$, $\Gamma(Z \rightarrow \widetilde{H}^0_1 \widetilde{H}^0_2) \gtrsim \frac{1}{2} \Gamma(Z \rightarrow \nu_e \overline{\nu}_e)$. The limit is for $m_{\widetilde{H}^0_2}$.

[37] BEHREND 85 find no monojet at $E_{\rm cm} = 40$–46 GeV. Consider $\widetilde{\chi}^0$ pair production via Z^0. One is assumed as massless and escapes detector. Limit is for the heavier one, decaying into a jet and massless $\widetilde{\chi}^0$. Both $\widetilde{\chi}^0$'s are assumed to be pure higgsino. For these very model-dependent results, BEHREND 85 excludes $m = 1.5$–19.5 GeV.

[38] ADEVA 84B observed no events with signature of acoplanar lepton pair with missing energy. Above example limit is for $m_{\widetilde{\gamma}} < 2$ GeV and $m_{\widetilde{e}} < 40$ GeV, and assumes $B(\widetilde{Z} \rightarrow \mu^+ \mu^- \widetilde{\gamma}) = B(\widetilde{Z} \rightarrow e^+ e^- \widetilde{\gamma}) = 0.10$. BR = 0.05 gives 33.5 GeV limit.

[39] BARTEL 84C search for $e^+ e^- \rightarrow \widetilde{Z} + \widetilde{\gamma}$ with $\widetilde{Z} \rightarrow \widetilde{\gamma} + e^+ e^-$, $\mu^+ \mu^-$, $q \overline{q}$, etc. They see no acoplanar events with missing-p_T due to two $\widetilde{\gamma}$'s. Above example limit is for $m_{\widetilde{e}} = 40$ GeV and for light stable $\widetilde{\gamma}$ with $B(\widetilde{Z} \rightarrow e^+ e^- \widetilde{\gamma}) = 0.1$.

[40] ELLIS 84 find if lightest neutralino is stable, then $m_{\widetilde{\chi}^0}$ not 100 eV – 2 GeV (for $m_{\widetilde{q}} = 40$ GeV). The upper limit depends on $m_{\widetilde{q}}$ (similar to the $\widetilde{\gamma}$ limit) and on nature of $\widetilde{\chi}^0$. For pure higgsino the higher limit is 5 GeV.

$\widetilde{\chi}^{\pm}_1$, $\widetilde{\chi}^{\pm}_2$ (Charginos) MASS LIMITS

Charginos ($\widetilde{\chi}^{\pm}$'s) are unknown mixtures of w-inos and charged higgsinos (the supersymmetric partners of W and Higgs bosons). Mass limits are relatively model dependent, so assumptions concerning branching ratios need to be specified. When specific assumptions are made, e.g. the chargino is a pure w-ino ($\widetilde{W}$) or pure charged higgsino ($\widetilde{H}^{\pm}$), the charginos will be labelled as such.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>44.0	95	[41] ADRIANI	93M	L3	$Z \to \widetilde{\chi}^+\widetilde{\chi}^-$, $\Gamma(Z)$
>45.2	95	[42] DECAMP	92	ALEP	$Z \to \widetilde{\chi}^+\widetilde{\chi}^-$, all $m_{\widetilde{\chi}^0_1}$
>47	95	[42] DECAMP	92	ALEP	$Z \to \widetilde{\chi}^+\widetilde{\chi}^-$, $m_{\widetilde{\chi}^0_1}$ <41 GeV
>99	95	[43] HIDAKA	91	RVUE	$\widetilde{\chi}^{\pm}_2$
>44.5	95	[44] ABREU	90G	DLPH	$Z \to \widetilde{\chi}^+\widetilde{\chi}^-$, $m_{\widetilde{\gamma}}$ < 20 GeV
>45	95	[45] AKRAWY	90D	OPAL	$e^+e^- \to \widetilde{\chi}^+\widetilde{\chi}^-$; $m_{\widetilde{\gamma}}$ < 20 GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

		[46] ABACHI	96	D0	$p\overline{p} \to \widetilde{\chi}^{\pm}_1\widetilde{\chi}^0_2$
		[47] DATTA	92	RVUE	$Z \to \widetilde{\chi}^+\widetilde{\chi}^-$, $\widetilde{\chi}^0\widetilde{\chi}^0$
>43	90	[48] DREES	91	RVUE	$\widetilde{\chi}^{\pm}_1$
>45	95	ABREU	90G	DLPH	Stable $\widetilde{\chi}^{\pm}$, $\widetilde{\chi}^+\widetilde{\chi}^-$
>28.2	95	ADACHI	90C	TOPZ	Stable $\widetilde{\chi}^{\pm}$, $\widetilde{\chi}^+\widetilde{\chi}^-$
>45	95	[49] AKESSON	90B	UA2	$p\overline{p} \to ZX$ $(Z \to \widetilde{W}^+\widetilde{W}^-)$
>37	90	[50] BAER	90	RVUE	$\Gamma(Z)$; $\tan\beta$ > 1
>45	95	[51] BARKLOW	90	MRK2	$Z \to \widetilde{W}^+\widetilde{W}^-$
>42	95	[52] BARKLOW	90	MRK2	$Z \to \widetilde{H}^+\widetilde{H}^-$
>44.5	95	[53] DECAMP	90C	ALEP	$e^+e^- \to \widetilde{\chi}^+\widetilde{\chi}^-$; $m_{\widetilde{\gamma}}$ < 28 GeV
>25.5	95	[54] ADACHI	89	TOPZ	$e^+e^- \to \widetilde{\chi}^+\widetilde{\chi}^-$
>44	95	[55] ADEVA	89B	L3	$e^+e^- \to \widetilde{W}^+\widetilde{W}^-$, $\widetilde{W} \to \ell\widetilde{\nu}$ or $\ell\nu\widetilde{\gamma}$
>45	90	[56] ANSARI	87D	UA2	$p\overline{p} \to ZX$ $(Z \to \widetilde{W}^+\widetilde{W}^-$, $\widetilde{W}^{\pm} \to e^{\pm}\widetilde{\nu})$
>40		[57] BAER	87B	RVUE	$p\overline{p} \to W/ZX$ $(W/Z \to \widetilde{W}, \widetilde{Z}, \widetilde{\gamma})$

[41] ADRIANI 93M limit from $\Delta\Gamma(Z)$< 35.1 MeV. For pure wino, the limit is 45.5 GeV.

[42] DECAMP 92 limit is for a general $\widetilde{\chi}^{\pm}$ (all contents).

[43] HIDAKA 91 limit obtained from LEP and preliminary CDF limits on the gluino mass (as analyzed in BAER 91).

[44] ABREU 90G limit is for a general $\widetilde{\chi}^{\pm}$. They assume charginos have a three-body decay such as $\ell^+\nu\widetilde{\gamma}$.

[45] AKRAWY 90D assume charginos have three-body decay such as $\ell^+\nu\widetilde{\gamma}$ (i.e. $m_{\widetilde{\nu}} > m_{\widetilde{\chi}^+}$). A two-body decay, $\widetilde{\chi}^+ \to \ell\widetilde{\nu}$ would have been seen by their search for acoplanar leptons. The result is independent of the hadronic branching ratio. They search for acoplanar electromagnetic clusters and quark jets.

[46] ABACHI 96 searches for 3-lepton final states. Efficiencies are calculated using mass relations and branching ratios in the Minimal Supergravity scenario. Results are presented as lower bounds on $\sigma(\widetilde{\chi}^{\pm}_1\widetilde{\chi}^0_2) \times B(\widetilde{\chi}^{\pm}_1 \to \ell\nu_\ell\widetilde{\chi}^0_1) \times B(\widetilde{\chi}^0_2 \to \ell^+\ell^-\widetilde{\chi}^0_1)$ as a function

of $m_{\widetilde{\chi}^0_1}$. Limits range from 3.1 pb ($m_{\widetilde{\chi}^0_1}$ = 45 GeV) to 0.6 pb ($m_{\widetilde{\chi}^0_1}$ = 100 GeV). See Fig. 3 for some explicit mass limits as a function of parameters.

[47] DATTA 92 exclude some regions in chargino-gluino mass plane from LEP experiments.

[48] DREES 91 limit obtained from LEP results within minimal supersymmetry with gaugino-mass unification condition. They make use of DECAMP 90C analysis plus additional constraint from total Z width. The bound can only be evaded if the chargino mixes with other charged singlets or with gauginos of a right-handed gauge group.

[49] AKESSON 90B assume $\widetilde{W} \rightarrow e\widetilde{\nu}$ with B $> 20\%$ and $m_{\widetilde{\nu}} = 0$. The limit disappears if $m_{\widetilde{\nu}} > 30$ GeV.

[50] BAER 90 is independent of decay modes. Limit from analysis of supersymmetric parameter space restrictions implied by $\Delta\Gamma(Z) < 120$ MeV. These result from decays of Z to all combinations of $\widetilde{\chi}^{\pm}_i$ and $\widetilde{\chi}^0_i$. Minimal supersymmetry with $\tan\beta > 1$ is assumed.

[51] BARKLOW 90 assume 100% $\widetilde{W} \rightarrow W^* \widetilde{\chi}^0_1$. Valid up to $m_{\widetilde{\chi}^0_1} \lesssim [m_{\widetilde{W}} - 5\text{ GeV}]$.

[52] BARKLOW 90 assume 100% $\widetilde{H} \rightarrow H^* \widetilde{\chi}^0_1$. Valid up to $m_{\widetilde{\chi}^0_1} \lesssim [m_{\widetilde{H}} - 8\text{ GeV}]$.

[53] DECAMP 90C assume charginos have three-body decay such as $\ell^+ \nu \widetilde{\gamma}$ (i.e. $m_{\widetilde{\nu}} > m_{\widetilde{\chi}+}$), and branching ratio to each lepton is 11%. They search for acoplanar dimuons, dielectrons, and μe events. Limit valid for $m_{\widetilde{\gamma}} < 28$ GeV.

[54] ADACHI 89 assume only single photon annihilation in the production. The limit applies for arbitrary decay branching ratios with B($\widetilde{\chi} \rightarrow e\nu\widetilde{\gamma}$) + B($\widetilde{\chi} \rightarrow \mu\nu\widetilde{\gamma}$) + B($\widetilde{\chi} \rightarrow \tau\nu\widetilde{\gamma}$) + B($\widetilde{\chi} \rightarrow q\overline{q}\widetilde{\gamma}$) = 1 (lepton universality is *not* assumed). The limit is for $m_{\widetilde{\gamma}} = 0$ but a very similar limit is obtained for $m_{\widetilde{\gamma}} = 10$ GeV. For B($\widetilde{\chi} \rightarrow q\overline{q}\widetilde{\gamma}$) = 1, the limit increases to 27.8 GeV.

[55] ADEVA 89B assume for $\ell\nu\widetilde{\gamma}$ ($\ell\widetilde{\nu}$) mode that B(e) = B(μ) = B(τ) = 11% (33%) and search for acoplanar dimuons, dielectrons, and μe events. Also assume $m_{\widetilde{\gamma}} < 20$ GeV and for $\ell\widetilde{\nu}$ mode that $m_{\widetilde{\nu}} = 10$ GeV.

[56] ANSARI 87D looks for high p_T e^+e^- pair with large missing p_T at the CERN $p\overline{p}$ collider at E_{cm} = 546–630 GeV. The limit is valid when $m_{\widetilde{\nu}} \lesssim 20$ GeV, B($\widetilde{W} \rightarrow e\widetilde{\nu}_e$) = 1/3, and B($Z \rightarrow \widetilde{W}^+ \widetilde{W}^-$) is calculated by assuming pure gaugino eigenstate. See their Fig. 3(b) for excluded region in the $m_{\widetilde{W}} - m_{\widetilde{\nu}}$ plane.

[57] BAER 87B argue that the charged heavy lepton mass limit of 41 GeV obtained by UA1 collaboration (ALBAJAR 87B) corresponds to the mass limit of 40 GeV under the assumptions that the LSP (photino) has a mass smaller than 8 GeV and that the gaugino-higgsino mixing is parametrized by the three minimal supergravity model parameters. In grand unified theories $m_{\widetilde{\gamma}} < 8$ implies $m_{\widetilde{g}} < 50$ GeV. For larger gluino masses, this limit can be evaded as discussed in BAER 88.

$\widetilde{\nu}$ (Sneutrino) MASS LIMIT

The limit depends on the number, $N(\widetilde{\nu})$, of sneutrinos assumed to be degenerate in mass. Only $\widetilde{\nu}_L$ (not $\widetilde{\nu}_R$) exist. It is possible that $\widetilde{\nu}$ could be the lightest supersymmetric particle (LSP).

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
> 41.8	95	[58] ADRIANI	93M	L3	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=3
> 37.1	95	[58] ADRIANI	93M	L3	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1
> 41	95	[59] DECAMP	92	ALEP	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=3
> 36	95	ABREU	91F	DLPH	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1
> 32	95	[60] ABREU	91F	DLPH	$\Gamma(Z)$; $N(\widetilde{\nu})$=1
> 31.2	95	[61] ALEXANDER	91F	OPAL	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1

• • • We do not use the following data for averages, fits, limits, etc. • • •

$>$ 46.0	95	[62] BUSKULIC	95E	ALEP	$N(\widetilde{\nu})$=1, $\widetilde{\nu} \rightarrow \nu\nu\ell\overline{\ell}'$
none 20–25000		[63] BECK	94	COSM	Stable $\widetilde{\nu}$, dark matter
$<$600		[64] FALK	94	COSM	$\widetilde{\nu}$ LSP, cosmic abundance
$>$ 38.4	90	[65] DREES	91	RVUE	$\Gamma(Z)$; $N(\widetilde{\nu})$=3
$>$ 28.9	90	[65] DREES	91	RVUE	$\Gamma(Z)$; $N(\widetilde{\nu})$=1
none 3–90	90	[66] SATO	91	KAMI	Stable $\widetilde{\nu}_e$ or $\widetilde{\nu}_\mu$, dark matter
none 4–90	90	[66] SATO	91	KAMI	Stable $\widetilde{\nu}_\tau$, dark matter
$>$ 31.4	95	[67] ADEVA	90I	L3	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1
$>$ 39.4	95	[67] ADEVA	90I	L3	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=3
$>$ 36.5	90	[68] BAER	90	RVUE	$\Gamma(Z)$; $N(\widetilde{\nu})$=3

[58] ADRIANI 93M limit from $\Delta\Gamma(Z)$(invisible)$<$ 16.2 MeV.

[59] DECAMP 92 limit is from Γ(invisible)/$\Gamma(\ell\ell)$ = 5.91 $\pm$ 0.15 (N_ν = 2.97 $\pm$ 0.07).

[60] ABREU 91F limit ($>$32 GeV) is independent of sneutrino decay mode.

[61] ALEXANDER 91F limit is for one species of $\widetilde{\nu}$ and is derived from Γ(invisible, new)/$\Gamma(\ell\ell)$ $<$ 0.38.

[62] BUSKULIC 95E looked for $Z \rightarrow \widetilde{\nu}\overline{\widetilde{\nu}}$, where $\widetilde{\nu} \rightarrow \nu\chi^0_1$ and χ^0_1 decays via R-parity violating interactions into two leptons and a neutrino.

[63] BECK 94 limit can be inferred from limit on Dirac neutrino using $\sigma(\widetilde{\nu}) = 4\sigma(\nu)$. Also private communication with H.V. Klapdor-Kleingrothaus.

[64] FALK 94 puts an upper bound on $m_{\widetilde{\nu}}$ when $\widetilde{\nu}$ is LSP by requiring its relic density does not overclose the Universe.

[65] DREES 91 limits from $\Delta\Gamma(Z)$ (nonhadronic) $<$ 38.3 MeV. Independent of decay modes. Minimal supersymmetry assumed.

[66] SATO 91 search for high-energy neutrinos from the sun produced by annihilation of sneutrinos in the sun. Sneutrinos are assumed to be stable and to constitute dark matter in our galaxy. SATO 91 follow the analysis of NG 87, OLIVE 88, and GAISSER 86.

[67] ADEVA 90I limit is from ΔN_ν $<$ 0.19.

[68] BAER 90 limit from $\Delta\Gamma(Z)$ (nonhadronic) $<$ 53 MeV. Independent of decay modes. Mininal supersymmetry assumed. The 95%CL bound is 35.6 GeV.

$\widetilde{e}$ (Selectron) MASS LIMIT

Limits assume $m_{\widetilde{e}_L} = m_{\widetilde{e}_R}$ unless otherwise stated.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
> 45	95	[69] ADRIANI	93M	L3	$m_{\widetilde{\chi}^0_1}$ <40 GeV, $\widetilde{e}^+\widetilde{e}^-$
> 45	95	[70] DECAMP	92	ALEP	$m_{\widetilde{\chi}^0_1}$ <41 GeV, $\widetilde{e}^+\widetilde{e}^-$
> 50	95	HEARTY	89	ASP	$m_{\widetilde{\gamma}}$ <5 GeV; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>$ 45.6	95	[71] BUSKULIC	95E	ALEP	$\widetilde{e} \rightarrow e\nu\ell\overline{\ell}'$
$>$ 51.9	90	HOSODA	94	VNS	$m_{\widetilde{\gamma}}$=0; $\gamma\widetilde{\gamma}\widetilde{\gamma}$

>72.6	90	[72] HOSODA	94	RVUE	$m_{\widetilde{\gamma}}$=0; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>42	95	ABREU	90G	DLPH	$m_{\widetilde{\gamma}}$ < 40 GeV; $\widetilde{e}^+\widetilde{e}^-$
>38	95	[73] AKESSON	90B	UA2	$m_{\widetilde{\gamma}}=0$; $p\overline{p}\rightarrow ZX$ $(Z\rightarrow \widetilde{e}^+\widetilde{e}^-)$
>43.4	95	[74] AKRAWY	90D	OPAL	$m_{\widetilde{\gamma}}$ < 30 GeV; $\widetilde{e}^+\widetilde{e}^-$
>38.1	90	[75] BAER	90	RVUE	$\widetilde{e}_L$; $\Gamma(Z)$; $\tan\beta>1$
>43.5	95	[76] DECAMP	90C	ALEP	$m_{\widetilde{\gamma}}$ < 36 GeV; $\widetilde{e}^+\widetilde{e}^-$
>830		GRIFOLS	90	ASTR	$m_{\widetilde{\gamma}}$ < 1 MeV
>29.9	95	SAKAI	90	AMY	$m_{\widetilde{\gamma}}$ < 20 GeV; $\widetilde{e}^+\widetilde{e}^-$
>29	95	TAKETANI	90	VNS	$m_{\widetilde{\gamma}}$ < 25 GeV; $\widetilde{e}^+\widetilde{e}^-$
>60		[77] ZHUKOVSKII	90	ASTR	$m_{\widetilde{\gamma}}=0$
>28	95	[78] ADACHI	89	TOPZ	$m_{\widetilde{\gamma}}\lesssim 0.85 m_{\widetilde{e}}$; $\widetilde{e}^+\widetilde{e}^-$
>41	95	[79] ADEVA	89B	L3	$m_{\widetilde{\gamma}}$ < 20 GeV; $\widetilde{e}^+\widetilde{e}^-$
>32	90	[80] ALBAJAR	89	UA1	$p\overline{p}\rightarrow W^{\pm}X$ $(W^{\pm}\rightarrow \widetilde{e}_L\widetilde{\nu})$ $(\widetilde{e}_L\rightarrow e\widetilde{\gamma})$
>14	90	[81] ALBAJAR	89	UA1	$Z\rightarrow \widetilde{e}^+\widetilde{e}^-$
>53	95	[82,83] HEARTY	89	ASP	$m_{\widetilde{\gamma}}$=0; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>65	95	[82,84] HEARTY	89	RVUE	$m_{\widetilde{\gamma}}$=0; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>35	95	HEARTY	89	ASP	$m_{\widetilde{\gamma}}$ <10 GeV; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>51.5	90	[85,86] BEHREND	88B	CELL	$m_{\widetilde{\gamma}}=0$ GeV; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>64	95	[85,87] BEHREND	88B	RVUE	$m_{\widetilde{\gamma}}=0$ GeV; $\gamma\widetilde{\gamma}\widetilde{\gamma}$
>48	90	BEHREND	88B	CELL	$m_{\widetilde{\gamma}}$ < 5 GeV; $\gamma\widetilde{\gamma}\widetilde{\gamma}$

[69] ADRIANI 93M limit is for $m_{\widetilde{e}_L}\gg m_{\widetilde{e}_R}$ using acolinear di-lepton events.

[70] DECAMP 92 limit is for $m_{\widetilde{e}_L}\gg m_{\widetilde{e}_R}$; for equal masses the limit would improve. They looked for acoplanar electrons.

[71] BUSKULIC 95E looked for $Z\rightarrow \widetilde{e}^+_R\widetilde{e}^-_R$ where $\widetilde{e}_R\rightarrow e\chi^0_1$ and χ^0_1 decays via R-parity violating interactions into two leptons and a neutrino.

[72] HOSODA 94 combines the results of HOSODA 94, HEARTY 89, BEHREND 88B, and FORD 86.

[73] AKESSON 90B assume $m_{\widetilde{\gamma}}=0$. Very similar limits hold for $m_{\widetilde{\gamma}}\lesssim 20$ GeV.

[74] AKRAWY 90D look for acoplanar electrons. For $m_{\widetilde{e}_L}\gg m_{\widetilde{e}_R}$, limit is 41.5 GeV, for $m_{\widetilde{\gamma}}<30$ GeV.

[75] BAER 90 limit from $\Delta\Gamma(Z)$ (nonhadronic) < 53 MeV. Independent of decay modes. Mininal supersymmetry and $\tan\beta>1$ assumed.

[76] DECAMP 90C look for acoplanar electrons. For $m_{\widetilde{e}_L}\gg m_{\widetilde{e}_R}$ limit is 42 GeV, for $m_{\widetilde{\gamma}}<33$ GeV.

[77] ZHUKOVSKII 90 set limit by saying the luminosity of a magnetized neutron star due to massless photino emission by electrons be small compared with its neutrino luminosity.

[78] ADACHI 89 assume only photon and photino exchange and $m_{\widetilde{e}_L}=m_{\widetilde{e}_R}$. The limit for the nondegenerate case is 26 GeV.

[79] ADEVA 89B look for acoplanar electrons.

[80] ALBAJAR 89 limit applies for $\widetilde{e}_L$ when $m_{\widetilde{e}_L}=m_{\widetilde{\nu}_L}$ and $m_{\widetilde{\gamma}}=0$. See their Fig. 55 for the 90% CL excluded region in the $m_{\widetilde{e}_L}-m_{\widetilde{\nu}_L}$ plane. For $m_{\widetilde{\nu}}=m_{\widetilde{\gamma}}=0$, limit is 50 GeV.

[81] ALBAJAR 89 assume $m_{\widetilde{\gamma}} = 0$.

[82] HEARTY 89 assume $m_{\widetilde{\gamma}} = 0$. The limit is very sensitive to $m_{\widetilde{\gamma}}$; no limit can be placed for $m_{\widetilde{\gamma}} \gtrsim$ 13 GeV.

[83] The limit is reduced to 43 GeV if only one $\widetilde{e}$ state is produced ($\widetilde{e}_L$ or $\widetilde{e}_R$ very heavy).

[84] Results of HEARTY 89, BEHREND 88B, ADEVA 87, and FORD 86 are combined. The limit is reduced to 53 GeV if only one $\widetilde{e}$ state is exchanged ($\widetilde{e}_L$ or $\widetilde{e}_R$ very heavy).

[85] BEHREND 88B limits assume pure photino eigenstate and $m_{\widetilde{e}_L} = m_{\widetilde{e}_R}$.

[86] The 95% CL limit for BEHREND 88B is 47.5 GeV for $m_{\widetilde{\gamma}} = 0$. The limit for $m_{\widetilde{e}_L} \gg m_{\widetilde{e}_R}$ is 40 GeV at 90% CL.

[87] BEHREND 88B combined their data with those from ASP (HEARTY 87), MAC (FORD 86), and MARK-J (H. Wu, Ph. D. Thesis, University of Hamburg, 1986).

$\widetilde{\mu}$ (Smuon) MASS LIMIT

Limits assume $m_{\widetilde{\mu}_L} = m_{\widetilde{\mu}_R}$ unless otherwise stated.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>45	95	[88] ADRIANI	93M	L3	$m_{\widetilde{\chi}^0_1}$ <40 GeV, $\widetilde{\mu}^+\widetilde{\mu}^-$
>45	95	[89] DECAMP	92	ALEP	$m_{\widetilde{\chi}^0_1}$ <41 GeV, $\widetilde{\mu}^+\widetilde{\mu}^-$
>43	95	[90] AKRAWY	90D	OPAL	$m_{\widetilde{\gamma}} < 30$ GeV; $\widetilde{\mu}^+\widetilde{\mu}^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>45.6	95	[91] BUSKULIC	95E	ALEP	$\widetilde{\mu} \rightarrow \mu\nu\ell\overline{\ell}'$
>36	95	ABREU	90G	DLPH	$m_{\widetilde{\gamma}} < 33$ GeV; $\widetilde{\mu}^+\widetilde{\mu}^-$
>38.1	90	[92] BAER	90	RVUE	$\widetilde{\mu}_L$; $\Gamma(Z)$; $\tan\beta > 1$
>42.6	95	[93] DECAMP	90C	ALEP	$m_{\widetilde{\gamma}} < 34$ GeV; $\widetilde{\mu}^+\widetilde{\mu}^-$
>27	95	SAKAI	90	AMY	$m_{\widetilde{\gamma}} < 18$ GeV; $\widetilde{\mu}^+\widetilde{\mu}^-$
>24.5	95	TAKETANI	90	VNS	$m_{\widetilde{\gamma}} < 15$ GeV; $\widetilde{\mu}^+\widetilde{\mu}^-$
>24.5	95	[94] ADACHI	89	TOPZ	$m_{\widetilde{\gamma}} \lesssim 0.8 m_{\widetilde{\mu}}$; $\widetilde{\mu}^+\widetilde{\mu}^-$
>41	95	[95] ADEVA	89B	L3	$m_{\widetilde{\gamma}} < 20$ GeV; $\widetilde{\mu}^+\widetilde{\mu}^-$

[88] ADRIANI 93M limit is for $m_{\widetilde{\mu}_L} \gg m_{\widetilde{\mu}_R}$ using acolinear di-lepton events.

[89] DECAMP 92 limit is for $m_{\widetilde{\mu}_L} \gg m_{\widetilde{\mu}_R}$; for equal masses the limit would improve. They looked for acoplanar muons.

[90] AKRAWY 90D look for acoplanar muons. For $m_{\widetilde{\mu}_L} \gg m_{\widetilde{\mu}_R}$, limit is 41.0 GeV, for $m_{\widetilde{\gamma}} < 30$ GeV.

[91] BUSKULIC 95E looked for $Z \rightarrow \widetilde{\mu}^+_R \widetilde{\mu}^-_R$, where $\widetilde{\mu}_R \rightarrow \mu \chi^0_1$ and χ^0_1 decays via *R*-parity violating interactions into two leptons and a neutrino.

[92] BAER 90 limit from $\Delta\Gamma(Z)$ (nonhadronic) < 53 MeV. Independent of decay modes. Mininal supersymmetry and $\tan\beta > 1$ assumed.

[93] DECAMP 90C look for acoplanar muons. For $m_{\widetilde{\mu}_L} \gg m_{\widetilde{\mu}_R}$ limit is 40 GeV, for $m_{\widetilde{\gamma}} <$ 30 GeV.

[94] ADACHI 89 assume only photon exchange, which gives a conservative limit. $m_{\widetilde{\mu}_L} = m_{\widetilde{\mu}_R}$ assumed. The limit for nondegenerate case is 22 GeV.

[95] ADEVA 89B look for acoplanar muons.

$\widetilde{\tau}$ (Stau) MASS LIMIT

Limits assume $m_{\widetilde{\tau}_L} = m_{\widetilde{\tau}_R}$ unless otherwise stated.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>44	95	[96] ADRIANI	93M	L3	$m_{\widetilde{\chi}_1^0}$ <38 GeV, $\widetilde{\tau}^+\widetilde{\tau}^-$
>45	95	[97] DECAMP	92	ALEP	$m_{\widetilde{\chi}_1^0}$ <38 GeV, $\widetilde{\tau}^+\widetilde{\tau}^-$
>43.0	95	[98] AKRAWY	90D	OPAL	$m_{\widetilde{\gamma}} < 23$ GeV; $\widetilde{\tau}^+\widetilde{\tau}^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>45.6	95	[99] BUSKULIC	95E	ALEP	$\widetilde{\tau} \rightarrow \tau\nu\ell\overline{\ell}'$
>35	95	ABREU	90G	DLPH	$m_{\widetilde{\gamma}} < 25$ GeV; $\widetilde{\tau}^+\widetilde{\tau}^-$
>38.1	90	[100] BAER	90	RVUE	$\widetilde{\tau}_L$; $\Gamma(Z)$; tan$\beta > 1$
>40.4	95	[101] DECAMP	90C	ALEP	$m_{\widetilde{\gamma}} < 15$ GeV; $\widetilde{\tau}^+\widetilde{\tau}^-$
>25	95	SAKAI	90	AMY	$m_{\widetilde{\gamma}} < 10$ GeV; $\widetilde{\tau}^+\widetilde{\tau}^-$
>25.5	95	TAKETANI	90	VNS	$m_{\widetilde{\gamma}} < 15$ GeV; $\widetilde{\tau}^+\widetilde{\tau}^-$
>21.7	95	[102] ADACHI	89	TOPZ	$m_{\widetilde{\gamma}}$=0; $\widetilde{\tau}^+\widetilde{\tau}^-$

[96] ADRIANI 93M limit is for $m_{\widetilde{\tau}_L} \gg m_{\widetilde{\tau}_R}$.

[97] DECAMP 92 limit is for $m_{\widetilde{\tau}_L} \gg m_{\widetilde{\tau}_R}$; for equal masses the limit would improve. They looked for acoplanar particles.

[98] AKRAWY 90D look for acoplanar particles. For $m_{\widetilde{\tau}_L} \gg m_{\widetilde{\tau}_R}$, limit is 41.0 GeV, for $m_{\widetilde{\gamma}} < 23$ GeV.

[99] BUSKULIC 95E looked for $Z \rightarrow \widetilde{\tau}_R^+\widetilde{\tau}_R^-$, where $\widetilde{\tau}_R \rightarrow \tau\chi_1^0$ and χ_1^0 decays via *R*-parity violating interactions into two leptons and a neutrino.

[100] BAER 90 limit from $\Delta\Gamma(Z)$ (nonhadronic) < 53 MeV. Independent of decay modes. Mininal supersymmetry and tan$\beta > 1$ assumed.

[101] DECAMP 90C look for acoplanar charged particle pairs. Limit is for $m_{\widetilde{\tau}_L} = m_{\widetilde{\tau}_R}$. For $m_{\widetilde{\gamma}} \leq 24$ GeV, the limit is 37 GeV. For $m_{\widetilde{\tau}_L} \gg m_{\widetilde{\tau}_R}$ and $m_{\widetilde{\gamma}} < 15$ GeV, the limit is 33 GeV.

[102] ADACHI 89 assume only photon exchange, which gives a conservative limit. $m_{\widetilde{\tau}_L} = m_{\widetilde{\tau}_R}$ assumed.

Stable $\widetilde{\ell}$ (Slepton) MASS LIMIT

Limits on scalar leptons which leave detector before decaying. Limits from Z decays are independent of lepton flavor. Limits from continuum e^+e^- annihilation are also independent of flavor for smuons and staus. However, selectron limits from continuum e^+e^- annihilation depend on flavor because there is an additional contribution from neutralino exchange that in general yields stronger limits. All limits assume $m_{\widetilde{\ell}_L} = m_{\widetilde{\ell}_R}$ unless otherwise stated.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>40	95	ABREU	90G	DLPH	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>26.3	95	ADACHI	90C	TOPZ	$\widetilde{\mu}$, $\widetilde{\tau}$
>38.8	95	AKRAWY	90O	OPAL	$\widetilde{\ell}_R$
>27.1	95	[103] SAKAI	90	AMY	
>32.6	95	SODERSTROM	90	MRK2	
>24.5	95	[104] ADACHI	89	TOPZ	

[103] SAKAI 90 limit improves to 30.1 GeV for $\widetilde{e}$ if $m_{\widetilde{\gamma}} \approx m_{\widetilde{e}}$.

[104] ADACHI 89 assume only photon (and photino for $\widetilde{e}$) exchange. The limit for $\widetilde{e}$ improves to 26 GeV for $m_{\widetilde{\gamma}} \approx m_{\widetilde{e}}$.

$\widetilde{q}$ (Squark) MASS LIMIT

For $m_{\widetilde{q}} > 60$–70 GeV, it is expected that squarks would undergo a cascade decay via a number of neutralinos and/or charginos rather than undergo a direct decay to photinos as assumed by some papers. Limits obtained when direct decay is assumed are usually higher than limits when cascade decays are included. The limits from Z decay do not assume GUT relations and are more model independent.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
> 224	95	[105] ABE	96D	CDF	$m_{\widetilde{g}} \leq m_{\widetilde{q}}$; with cascade decays
> 176	95	[106] ABACHI	95C	D0	Any $m_{\widetilde{g}} <300$ GeV; with cascade decays
> 212	95	[106] ABACHI	95C	D0	$m_{\widetilde{g}} \leq m_{\widetilde{q}}$; with cascade decays
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[107] ABE	95T	CDF	$\widetilde{q} \to \widetilde{\chi}^0_2 \to \widetilde{\chi}^0_1 \gamma$
> 45.3	95	[108] BUSKULIC	95E	ALEP	$\widetilde{q} \to q \nu \ell \overline{\ell}'$
> 239	95	[109] AHMED	94B	H1	$e p \to \widetilde{q}$; R-parity violation, λ=0.30
> 135	95	[109] AHMED	94B	H1	$e p \to \widetilde{q}$; R-parity violation, λ=0.1
> 35.3	95	[110] ADRIANI	93M	L3	$Z \to \widetilde{u}\overline{\widetilde{u}}$, $\Gamma(Z)$
> 36.8	95	[110] ADRIANI	93M	L3	$Z \to \widetilde{d}\overline{\widetilde{d}}$, $\Gamma(Z)$
> 90	90	[111] ABE	92L	CDF	Any $m_{\widetilde{g}} <410$ GeV; with cascade decay
> 218	90	[112] ABE	92L	CDF	$m_{\widetilde{g}} = m_{\widetilde{q}}$; with cascade decay
> 180	90	[111] ABE	92L	CDF	$m_{\widetilde{g}} < m_{\widetilde{q}}$; with cascade decay
> 100		[113] ROY	92	RVUE	$p \overline{p} \to \widetilde{q}\widetilde{q}$; R-parity violating
		[114] NOJIRI	91	COSM	
> 45	95	[115] ABREU	90F	DLPH	$Z \to \widetilde{q}\overline{\widetilde{q}}$, $m_{\widetilde{\gamma}} < 20$ GeV
> 43	95	[116] ABREU	90F	DLPH	$Z \to \widetilde{d}\overline{\widetilde{d}}$, $m_{\widetilde{\gamma}} < 20$ GeV
> 42	95	[117] ABREU	90F	DLPH	$Z \to \widetilde{u}\overline{\widetilde{u}}$, $m_{\widetilde{\gamma}} < 20$ GeV
> 27.0	95	ADACHI	90C	TOPZ	Stable $\widetilde{u}$, $\widetilde{u}\overline{\widetilde{u}}$
> 74	90	[118] ALITTI	90	UA2	Any $m_{\widetilde{q}}$; B($\widetilde{q} \to q\widetilde{g}$ or $q\widetilde{\gamma}$) = 1

>106	90	[118] ALITTI	90	UA2	$m_{\widetilde{q}} = m_{\widetilde{g}}$; $B(\widetilde{q} \to q\widetilde{\gamma}) = 1$
>39.2	90	[119] BAER	90	RVUE	$\widetilde{d}_L$; $\Gamma(Z)$
>45	95	[120,121] BARKLOW	90	MRK2	$Z \to \widetilde{q}\overline{\widetilde{q}}$
>40	95	[120,122] BARKLOW	90	MRK2	$Z \to \widetilde{d}\overline{\widetilde{d}}$
>39	95	[120,123] BARKLOW	90	MRK2	$Z \to \widetilde{u}\overline{\widetilde{u}}$
>1100		GRIFOLS	90	ASTR	$m_{\widetilde{\gamma}} < 1$ MeV
>24	95	SAKAI	90	AMY	$e^+e^- \to \widetilde{d}\overline{\widetilde{d}} \to d\overline{d}\widetilde{\gamma}\widetilde{\gamma}$; $m_{\widetilde{\gamma}} < 10$ GeV
>26	95	SAKAI	90	AMY	$e^+e^- \to \widetilde{u}\overline{\widetilde{u}} \to u\overline{u}\widetilde{\gamma}\widetilde{\gamma}$; $m_{\widetilde{\gamma}} < 10$ GeV
>26.3	95	[124] ADACHI	89	TOPZ	$e^+e^- \to \widetilde{q}\overline{\widetilde{q}} \to q\overline{q}\widetilde{\gamma}\widetilde{\gamma}$
		[125] NATH	88	THEO	$\tau(p \to \nu K)$ in supergravity GUT
>45	90	[126] ALBAJAR	87D	UA1	Any $m_{\widetilde{g}} > m_{\widetilde{q}}$
>75	90	[126] ALBAJAR	87D	UA1	$m_{\widetilde{g}} = m_{\widetilde{q}}$

[105] ABE 96D searched for production of gluinos and five degenerate squarks in final states containing a pair of leptons, two jets, and missing E_T. The two leptons arise from the semileptonic decays of charginos produced in the cascade decays. The limit is derived for fixed $\tan\beta = 4.0$, $\mu = -400$ GeV, and $m_{H^+} = 500$ GeV, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity scenario.

[106] ABACHI 95C assume five degenerate squark flavors with $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$. Sleptons are assumed to be heavier than squarks. The limits are derived for fixed $\tan\beta = 2.0$ $\mu = -250$ GeV, and m_{H^+}=500 GeV, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity scenario. The bounds are weakly sensitive to the three fixed parameters for a large fraction of parameter space. No limit is given for $m_{\text{gluino}} >$547 GeV.

[107] ABE 95T looked for a cascade decay of five degenerate squarks into $\widetilde{\chi}^0_2$ which further decays into $\widetilde{\chi}^0_1$ and a photon. No signal is observed. Limits vary widely depending on the choice of parameters. For $\mu = -40$ GeV, $\tan\beta = 1.5$, and heavy gluinos, the range $50< m_{\widetilde{q}}$ (GeV)<110 is excluded at 90% CL. See the paper for details.

[108] BUSKULIC 95E looked for $Z \to \widetilde{q}\overline{\widetilde{q}}$, where $\widetilde{q} \to q\chi^0_1$ and χ^0_1 decays via R-parity violating interactions into two leptons and a neutrino.

[109] AHMED 94B looked for squarks as s-channel resonance in ep collision via R-parity violating coupling in the superpotential $W = \lambda L_1 Q_1 d_1$. The degeneracy of all squarks Q_1 and d_1 is assumed. The squarks decay dominantly via the same R-violating coupling into eq or νq if $\lambda \gtrsim 0.2$. For smaller λ, decay into photino is assumed which subsequently decays into $eq\overline{q}$, and the bound depends on $m_{\widetilde{\gamma}}$. See paper for excluded region on $(m_{\widetilde{q}},\lambda)$ plane.

[110] ADRIANI 93M limit from $\Delta\Gamma(Z)< 35.1$ MeV and assumes $m_{\widetilde{q}_L} \gg m_{\widetilde{q}_R}$.

[111] ABE 92L assume five degenerate squark flavors and $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$. ABE 92L includes the effect of cascade decay, for a particular choice of parameters, $\mu = -250$ GeV, $\tan\beta = 2$. Results are weakly sensitive to these parameters over much of parameter space. No limit for $m_{\widetilde{q}} \leq 50$ GeV (but other experiments rule out that region). Limits are 10–20 GeV higher if $B(\widetilde{q} \to q\widetilde{\gamma}) = 1$. Limit assumes GUT relations between gaugino masses and the gauge coupling; in particular that for $|\mu|$ not small, $m_{\widetilde{\chi}^0_1} \approx m_{\widetilde{g}}/6$. This last relation implies that as $m_{\widetilde{g}}$ increases, the mass of $\widetilde{\chi}^0_1$ will eventually exceed $m_{\widetilde{q}}$ so that

no decay is possible. Even before that occurs, the signal will disappear; in particular no bounds can be obtained for $m_{\widetilde{g}}$ >410 GeV. m_{H^+}=500 GeV.

112 ABE 92L bounds are based on similar assumptions as ABACHI 95C. No limits for m_{gluino} >410 GeV.

113 ROY 92 reanalyzed CDF limits on di-lepton events to obtain limits on squark production in R-parity violating models. The 100% decay $\widetilde{q} \rightarrow q\widetilde{\chi}$ where $\widetilde{\chi}$ is the LSP, and the LSP decays either into $\ell q \overline{d}$ or $\ell \ell \overline{e}$ is assumed.

114 NOJIRI 91 argues that a heavy squark should be nearly degenerate with the gluino in minimal supergravity not to overclose the universe.

115 ABREU 90F assume six degenerate squarks and $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$. $m_{\widetilde{q}} < 41$ GeV is excluded at 95% CL for $m_{\text{LSP}} < m_{\widetilde{q}} - 2$ GeV.

116 ABREU 90F exclude $m_{\widetilde{d}} < 38$ GeV at 95% for $m_{\text{LSP}} < m_{\widetilde{d}} - 2$ GeV.

117 ABREU 90F exclude $m_{\widetilde{u}} < 36$ GeV at 95% for $m_{\text{LSP}} < m_{\widetilde{u}} - 2$ GeV.

118 ALITTI 90 searched for events having $\geq$ 2 jets with $E_T^1 > 25$ GeV, $E_T^2 > 15$ GeV, $|\eta| < 0.85$, and $\Delta\phi < 160°$, with a missing momentum > 40 GeV and no electrons. They assume $\widetilde{q} \rightarrow q\widetilde{\gamma}$ (if $m_{\widetilde{q}} < m_{\widetilde{g}}$) or $\widetilde{q} \rightarrow q\widetilde{g}$ (if $m_{\widetilde{q}} > m_{\widetilde{g}}$) decay and $m_{\widetilde{\gamma}} \lesssim$ 20 GeV. Five degenerate squark flavors and $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$ are assumed. Masses below 50 GeV are not excluded by the analysis.

119 BAER 90 limit from $\Delta\Gamma(Z) <$ 120 MeV, assuming $m_{\widetilde{d}_L} = m_{\widetilde{u}_L} = m_{\widetilde{e}_L} = m_{\widetilde{\nu}}$. Independent of decay modes. Minimal supergravity assumed.

120 BARKLOW 90 assume 100% $\widetilde{q} \rightarrow q\widetilde{\gamma}$.

121 BARKLOW 90 assume five degenerate squarks (left- and right-handed). Valid up to $m_{\widetilde{\chi}_1^0} \lesssim [m_{\widetilde{q}} - 4 \text{ GeV}]$.

122 BARKLOW 90 result valid up to $m_{\widetilde{\chi}_1^0} \lesssim [m_{\widetilde{d}} - 5 \text{ GeV}]$.

123 BARKLOW 90 result valid up to $m_{\widetilde{\chi}_1^0} \lesssim [m_{\widetilde{u}} - 6 \text{ GeV}]$.

124 ADACHI 89 assume only photon exchange, which gives a a conservative limit. The limit is only for one flavor of charge 2/3 $\widetilde{q}$. $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$ and $m_{\widetilde{\gamma}} = 0$ assumed. The limit decreases to 26.1 GeV for $m_{\widetilde{\gamma}} = 15$ GeV. The limit for nondegenerate case is 24.4 GeV.

125 NATH 88 uses Kamioka limit of $\tau(p \rightarrow \overline{\nu} K^+) > 7 \times 10^{31}$ yrs to constrain squark mass $m_{\widetilde{q}} > 1000$ GeV by assuming that the proton decay proceeds via an exchange of a color-triplet Higgsino of mass $< 10^{16}$ GeV in the supersymmetric SU(5) GUT. The limit applies for $m_{\widetilde{\gamma}} \equiv (8/3)\sin^2\theta_W \widetilde{m}_2 > 10$ GeV ($\widetilde{m}_2$ is the SU(2) gaugino mass) and for a very conservative value of the three-quark proton wave function, barring cancellation between second and third generations. Lower squark mass is allowed if $m_{\widetilde{\gamma}}$ as defined above is smaller.

126 The limits of ALBAJAR 87D are from $p\overline{p} \rightarrow \widetilde{q}\overline{\widetilde{q}}X$ ($\widetilde{q} \rightarrow q\widetilde{\gamma}$) and assume 5 flavors of degenerate mass squarks each with $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$. They also assume $m_{\widetilde{g}} > m_{\widetilde{q}}$. These limits apply for $m_{\widetilde{\gamma}} \lesssim$ 20 GeV.

$\widetilde{t}$ (Stop) MASS LIMIT

Limit depends on decay mode. In e^+e^- collisions they also depend on the mixing angle of the mass eigenstate $\widetilde{t}_1 = \widetilde{t}_L\cos\theta_t + \widetilde{t}_R\sin\theta_t$. Coupling to Z vanishes when

θ_t = 0.98. In the Listings below, we use $\Delta m \equiv m_{\tilde{t}_1} - m_{\tilde{\chi}^0_1}$. See also bound in "$\tilde{q}$ (Squark) MASS LIMIT."

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
none 61–91	95	[127] ABACHI	96B	D0	$\tilde{t} \to c\tilde{\chi}^0_1$, $m_{\tilde{\chi}^0_1}$ <30 GeV
none 6.0–41.2	95	AKERS	94K	OPAL	$\tilde{t} \to c\tilde{\chi}^0_1$, θ_t=0, $\Delta(m)$ >2 GeV
none 5.0–46.0	95	AKERS	94K	OPAL	$\tilde{t} \to c\tilde{\chi}^0_1$, θ_t=0, $\Delta(m)$ >5 GeV
none 11.2–25.5	95	AKERS	94K	OPAL	$\tilde{t} \to c\tilde{\chi}^0_1$, θ_t=0.98, $\Delta(m)$ >2 GeV
none 7.9–41.2	95	AKERS	94K	OPAL	$\tilde{t} \to c\tilde{\chi}^0_1$, θ_t=0.98, $\Delta(m)$ >5 GeV
none 7.6–28.0	95	[128] SHIRAI	94	VNS	$\tilde{t} \to c\tilde{\chi}^0_1$, any θ_t, $\Delta(m)$ >10 GeV
none 10–20	95	[128] SHIRAI	94	VNS	$\tilde{t} \to c\tilde{\chi}^0_1$, any θ_t, $\Delta(m)$ > 2.5 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 11–41	95	[129] BUSKULIC	95E	ALEP	θ_t=0.98, $\tilde{t} \to c\nu\ell\overline{\ell}'$
		[130] BAER	91B	RVUE	$\tilde{t}$
		[131] DREES	90	RVUE	$\tilde{t}$

[127] ABACHI 96B searches for final states with 2 jets and missing E_T. Limits on $m_{\tilde{t}}$ are given as a function of $m_{\tilde{\chi}^0_1}$. See Fig. 4 for details.

[128] SHIRAI 94 bound assumes the cross section without the *s*-channel Z-exchange and the QCD correction, underestimating the cross section up to 20% and 30%, respectively. They assume m_c=1.5 GeV.

[129] BUSKULIC 95E looked for $Z \to \tilde{t}\overline{\tilde{t}}$, where $\tilde{t} \to c\chi^0_1$ and χ^0_1 decays via R-parity violating interactions into two leptons and a neutrino.

[130] BAER 91B argue that a top squark as light as 45 GeV may have escaped detection at the CDF detector at the Tevatron Collider (45 GeV is the limit from LEP experiments).

[131] DREES 90 argue that bounds from Z decay are not valid for $\tilde{t}$ for a certain range of $\tilde{t}_L$-$\tilde{t}_R$ mixing angle.

$\tilde{g}$ (Gluino) MASS LIMIT

For $m_{\tilde{g}}$ > 60–70 GeV, it is expected that gluinos would undergo a cascade decay via a number of neutralinos and/or charginos rather than undergo a direct decay to photinos as assumed by some papers. Limits obtained when direct decay is assumed are usually higher than limits when cascade decays are included.

There is an ongoing controversy (reflected in these Listings) about whether very light $\tilde{g}$'s ($1 \lesssim m_{\tilde{g}} \lesssim 4$ GeV) are ruled out. These papers sometimes make different assumptions and use different calculational techniques.

VALUE (GeV)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
>224	95		[132] ABE	96D	CDF	$m_{\tilde{q}} = m_{\tilde{g}}$; with cascade decays
>154	95		[132] ABE	96D	CDF	$m_{\tilde{g}} < m_{\tilde{q}}$; with cascade decays
>212	95		[133] ABACHI	95C	D0	$m_{\tilde{g}} \geq m_{\tilde{q}}$; with cascade decays
>144	95		[133] ABACHI	95C	D0	Any $m_{\tilde{q}}$; with cascade decays

• • • We do not use the following data for averages, fits, limits, etc. • • •

			[134] ABE	95T	CDF	$\tilde{g} \to \tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \gamma$
none 1.9–13.6	95		[135] AKERS	95R	OPAL	Z decay into a long-lived $(\tilde{g}\, q\, \overline{q})^{\pm}$
$<$ 0.7			[136] CLAVELLI	95	RVUE	quarkonia
			[137] HEBBEKER	93	RVUE	$e^+ e^-$ jet analyses
not 3–5			[138] LOPEZ	93C	RVUE	LEP
$>$218	90		[139] ABE	92L	CDF	$m_{\tilde{q}} \leq m_{\tilde{g}}$; with cascade decay
$>$100	90		[139] ABE	92L	CDF	Any $m_{\tilde{q}}$; with cascade decay
$\approx$ 4			[140] CLAVELLI	92	RVUE	α_s running
$>$100			[141] ROY	92	RVUE	$p\overline{p} \to \tilde{g}\tilde{g}$; R-parity violating
			[142] ANTONIADIS	91	RVUE	α_s running
$>$ 1			[143] ANTONIADIS	91	RVUE	$p N \to$ missing energy
$>$132	90		[144] HIDAKA	91	RVUE	
			[145] NOJIRI	91	COSM	
$>$ 79	90		[146] ALITTI	90	UA2	Any $m_{\tilde{g}}$; $B(\tilde{g} \to q\overline{q}\tilde{\gamma}) = 1$
$>$106	90		[146] ALITTI	90	UA2	$m_{\tilde{q}} = m_{\tilde{g}}$; $B(\tilde{g} \to q\overline{q}\tilde{\gamma}) = 1$
			[147] NAKAMURA	89	SPEC	R-Δ^{++}
none 4–53	90		[148] ALBAJAR	87D	UA1	Any $m_{\tilde{q}} > m_{\tilde{g}}$
none 4–75	90		[148] ALBAJAR	87D	UA1	$m_{\tilde{q}} = m_{\tilde{g}}$
none 16–58	90		[149] ANSARI	87D	UA2	$m_{\tilde{q}} \lesssim 100$ GeV
$>$ 3.8	90		[150] ARNOLD	87	EMUL	π^- (350 GeV). $\sigma \simeq A^1$
$>$ 3.2	90		[150] ARNOLD	87	EMUL	π^- (350 GeV). $\sigma \simeq A^{0.72}$
none 0.6–2.2	90		[151] TUTS	87	CUSB	$\Upsilon(1S) \to \gamma +$ gluinonium
none 1 –4.5	90	0	[152] ALBRECHT	86C	ARG	$1 \times 10^{-11} \lesssim \tau \lesssim 1 \times 10^{-9}$s
none 1–4	90	0	[153] BADIER	86	BDMP	$1 \times 10^{-10} < \tau < 1 \times 10^{-7}$s
none 3–5			[154] BARNETT	86	RVUE	$p\overline{p} \to$ gluino gluino gluon
none			[155] VOLOSHIN	86	RVUE	If (quasi) stable; $\tilde{g}\, u\, u\, d$
none 0.5–2			[156] COOPER-...	85B	BDMP	For $m_{\tilde{q}}$=300 GeV
none 0.5–4			[156] COOPER-...	85B	BDMP	For $m_{\tilde{q}}$ <65 GeV
none 0.5–3			[156] COOPER-...	85B	BDMP	For $m_{\tilde{q}}$=150 GeV
none 2–4			[157] DAWSON	85	RVUE	$\tau > 10^{-7}$ s
none 1–2.5			[157] DAWSON	85	RVUE	For $m_{\tilde{q}}$=100 GeV
none 0.5–4.1	90		[158] FARRAR	85	RVUE	FNAL beam dump
$>$ 1			[159] GOLDMAN	85	RVUE	Gluononium
$>$1–2			[160] HABER	85	RVUE	

	[161] BALL	84	CALO	
	[162] BRICK	84	RVUE	
	[163] FARRAR	84	RVUE	
> 2	[164] BERGSMA	83C	RVUE	For $m_{\widetilde{q}}$ <100 GeV
	[165] CHANOWITZ	83	RVUE	$\widetilde{g}u\overline{d}$, $\widetilde{g}uud$
>2–3	[166] KANE	82	RVUE	Beam dump
>1.5–2	FARRAR	78	RVUE	R-hadron

[132] ABE 96D searched for production of gluinos and five degenerate squarks in final states containing a pair of leptons, two jets, and missing E_T. The two leptons arise from the semileptonic decays of charginos produced in the cascade decays. The limits are derived for fixed $\tan\beta = 4.0$, $\mu = -400$ GeV, and $m_{H^+} = 500$ GeV, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity scenario. The bounds are weakly sensitive to the values of the three fixed parameters for a large fraction of parameter space. See Fig. 2 for the limits corresponding to different parameter choices.

[133] ABACHI 95C assume five degenerate squark flavors with with $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$. Sleptons are assumed to be heavier than squarks. The limits are derived for fixed $\tan\beta = 2.0$ $\mu = -250$ GeV, and m_{H^+}=500 GeV, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity scenario. The bounds are weakly sensitive to the three fixed parameters for a large fraction of parameter space.

[134] ABE 95T looked for a cascade decay of gluino into $\widetilde{\chi}^0_2$ which further decays into $\widetilde{\chi}^0_1$ and a photon. No signal is observed. Limits vary widely depending on the choice of parameters. For $\mu = -40$ GeV, $\tan\beta = 1.5$, and heavy squarks, the range $50<m_{\widetilde{g}}$ (GeV)<140 is excluded at 90% CL. See the paper for details.

[135] AKERS 95R looked for Z decay into $q\overline{q}\widetilde{g}\widetilde{g}$, by searching for charged particles with dE/dx consistent with $\widetilde{g}$ fragmentation into a state $(\widetilde{g}q\overline{q})^{\pm}$ with lifetime $\tau > 10^{-7}$ sec. The fragmentation probability into a charged state is assumed to be 25%.

[136] CLAVELLI 95 updates the analysis of CLAVELLI 93, based on a comparison of the hadronic widths of charmonium and bottomonium S-wave states. The analysis includes a parametrization of relativisitic corrections. Claims that the presence of a light gluino improves agreement with the data by slowing down the running of α_s.

[137] HEBBEKER 93 combined jet analyses at various e^+e^- colliders. The 4-jet analyses at TRISTAN/LEP and the measured α_s at PEP/PETRA/TRISTAN/LEP are used. A constraint on effective number of quarks N=6.3 ± 1.1 is obtained, which is compared to that with a light gluino, N=8.

[138] LOPEZ 93C uses combined restraint from the radiative symmetry breaking scenario within the minimal supergravity model, and the LEP bounds on the (M_2,μ) plane. Claims that the light gluino window is strongly disfavored.

[139] ABE 92L bounds are based on similar assumptions as ABACHI 95C. Not sensitive to m_{gluino} <40 GeV (but other experiments rule out that region).

[140] CLAVELLI 92 claims that a light gluino mass around 4 GeV should exist to explain the discrepancy between α_s at LEP and at quarkonia (Υ), since a light gluino slows the running of the QCD coupling.

[141] ROY 92 reanalyzed CDF limits on di-lepton events to obtain limits on gluino production in R-parity violating models. The 100% decay $\widetilde{g} \rightarrow q\overline{q}\widetilde{\chi}$ where $\widetilde{\chi}$ is the LSP, and the LSP decays either into $\ell q\overline{d}$ or $\ell\ell\overline{e}$ is assumed.

[142] ANTONIADIS 91 argue that possible light gluinos (< 5 GeV) contradict the observed running of α_s between 5 GeV and m_Z. The significance is less than 2 s.d.

[143] ANTONIADIS 91 intrepret the search for missing energy events in 450 GeV/c pN collisions, AKESSON 91, in terms of light gluinos.

[144] HIDAKA 91 limit obtained from LEP and preliminary CDF results within minimal supersymmetry with gaugino-mass unification condition. HIDAKA 91 limit extracted from BAER 91 analysis.

[145] NOJIRI 91 argues that a heavy gluino should be nearly degenerate with squarks in minimal supergravity not to overclose the universe.

[146] ALITTI 90 searched for events having $\geq$ 2 jets with $E_T^1 > 25$ GeV, $E_T^2 > 15$ GeV, $|\eta| < 0.85$, and $\Delta\phi < 160°$, with a missing momentum > 40 GeV and no electrons. They assume $\widetilde{g} \rightarrow q\overline{q}\widetilde{\gamma}$ decay and $m_{\widetilde{\gamma}} \lesssim 20$ GeV. Masses below 50 GeV are not excluded by the analysis.

[147] NAKAMURA 89 searched for a long-lived ($\tau \gtrsim 10^{-7}$ s) charge-(± 2) particle with mass $\lesssim 1.6$ GeV in proton-Pt interactions at 12 GeV and found that the yield is less than 10^{-8} times that of the pion. This excludes R-Δ^{++} (a $\widetilde{g}uuu$ state) lighter than 1.6 GeV.

[148] The limits of ALBAJAR 87D are from $p\overline{p} \rightarrow \widetilde{g}\widetilde{g}X$ ($\widetilde{g} \rightarrow q\overline{q}\widetilde{\gamma}$) and assume $m_{\widetilde{q}} > m_{\widetilde{g}}$. These limits apply for $m_{\widetilde{\gamma}} \lesssim 20$ GeV and $\tau(\widetilde{g}) < 10^{-10}$ s.

[149] The limit of ANSARI 87D assumes $m_{\widetilde{q}} > m_{\widetilde{g}}$ and $m_{\widetilde{\gamma}} \approx 0$.

[150] The limits assume $m_{\widetilde{q}} = 100$ GeV. See their figure 3 for limits vs. $m_{\widetilde{q}}$.

[151] The gluino mass is defined by half the bound $\widetilde{g}\widetilde{g}$ mass. If zero gluino mass gives a $\widetilde{g}\widetilde{g}$ of mass about 1 GeV as suggested by various glueball mass estimates, then the low-mass bound can be replaced by zero. The high-mass bound is obtained by comparing the data with nonrelativistic potential-model estimates.

[152] ALBRECHT 86C search for secondary decay vertices from $\chi_{b1}(1P) \rightarrow \widetilde{g}\widetilde{g}g$ where $\widetilde{g}$'s make long-lived hadrons. See their figure 4 for excluded region in the $m_{\widetilde{g}} - m_{\widetilde{g}}$ and $m_{\widetilde{g}} - m_{\widetilde{q}}$ plane. The lower $m_{\widetilde{g}}$ region below $\sim$ 2 GeV may be sensitive to fragmentation effects. Remark that the $\widetilde{g}$-hadron mass is expected to be $\sim$ 1 GeV (glueball mass) in the zero $\widetilde{g}$ mass limit.

[153] BADIER 86 looked for secondary decay vertices from long-lived $\widetilde{g}$-hadrons produced at 300 GeV π^- beam dump. The quoted bound assumes $\widetilde{g}$-hadron nucleon total cross section of 10μb. See their figure 7 for excluded region in the $m_{\widetilde{g}} - m_{\widetilde{q}}$ plane for several assumed total cross-section values.

[154] BARNETT 86 rule out light gluinos (m = 3–5 GeV) by calculating the monojet rate from gluino gluino gluon events (and from gluino gluino events) and by using UA1 data from $p\overline{p}$ collisions at CERN.

[155] VOLOSHIN 86 rules out stable gluino based on the cosmological argument that predicts too much hydrogen consisting of the charged stable hadron $\widetilde{g}uud$. Quasi-stable ($\tau > 1.\times 10^{-7}$s) light gluino of $m_{\widetilde{g}} <$3 GeV is also ruled out by nonobservation of the stable charged particles, $\widetilde{g}uud$, in high energy hadron collisions.

[156] COOPER-SARKAR 85B is BEBC beam-dump. Gluinos decaying in dump would yield $\widetilde{\gamma}$'s in the detector giving neutral-current-like interactions. For $m_{\widetilde{q}} >$330 GeV, no limit is set.

[157] DAWSON 85 first limit from neutral particle search. Second limit based on FNAL beam dump experiment.

[158] FARRAR 85 points out that BALL 84 analysis applies only if the $\widetilde{g}$'s decay before interacting, i.e. $m_{\widetilde{q}} < 80 m_{\widetilde{g}}^{1.5}$. FARRAR 85 finds $m_{\widetilde{g}} <$0.5 not excluded for $m_{\widetilde{q}}$ = 30–1000 GeV and $m_{\widetilde{g}} <$1.0 not excluded for $m_{\widetilde{q}}$ = 100–500 GeV by BALL 84 experiment.

[159] GOLDMAN 85 use nonobservation of a pseudoscalar $\widetilde{g}$-$\widetilde{g}$ bound state in radiative ψ decay.

[160] HABER 85 is based on survey of all previous searches sensitive to low mass $\widetilde{g}$'s. Limit makes assumptions regarding the lifetime and electric charge of the lightest supersymmetric particle.

[161] BALL 84 is FNAL beam dump experiment. Observed no interactions of $\widetilde{\gamma}$ in the calorimeter, where $\widetilde{\gamma}$'s are expected to come from pair-produced $\widetilde{g}$'s. Search for long-lived $\widetilde{\gamma}$ interacting in calorimeter 56m from target. Limit is for $m_{\widetilde{q}}$ = 40 GeV and production

cross section proportional to $A^{0.72}$. BALL 84 find no $\widetilde{g}$ allowed below 4.1 GeV at CL = 90%. Their figure 1 shows dependence on $m_{\widetilde{q}}$ and A. See also KANE 82.

[162] BRICK 84 reanalyzed FNAL 147 GeV HBC data for R-$\Delta(1232)^{++}$ with $\tau > 10^{-9}$ s and $p_{\mathrm{lab}} > 2$ GeV. Set CL = 90% upper limits 6.1, 4.4, and 29 microbarns in pp, $\pi^+ p$, $K^+ p$ collisions respectively. R-Δ^{++} is defined as being $\widetilde{g}$ and 3 up quarks. If mass = 1.2–1.5 GeV, then limits may be lower than theory predictions.

[163] FARRAR 84 argues that $m_{\widetilde{g}} < 100$ MeV is not ruled out if the lightest R-hadrons are long-lived. A long lifetime would occur if R-hadrons are lighter than $\widetilde{\gamma}$'s or if $m_{\widetilde{q}} > 100$ GeV.

[164] BERGSMA 83C is reanalysis of CERN-SPS beam-dump data. See their figure 1.

[165] CHANOWITZ 83 find in bag-model that charged *s*-hadron exists which is stable against strong decay if $m_{\widetilde{g}} < 1$ GeV. This is important since tracks from decay of neutral *s*-hadron cannot be reconstructed to primary vertex because of missed $\widetilde{\gamma}$. Charged *s*-hadron leaves track from vertex.

[166] KANE 82 inferred above $\widetilde{g}$ mass limit from retroactive analysis of hadronic collision and beam dump experiments. Limits valid if $\widetilde{g}$ decays inside detector.

Unstable $\widetilde{\gamma}$ (Photino) MASS LIMIT

Unless stated otherwise, the limits below assume that the $\widetilde{\gamma}$ decays either into $\gamma\widetilde{G}$ (goldstino) or into $\gamma\widetilde{H}^0$ (Higgsino).

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>40	95	[167] BUSKULIC	95E	ALEP	$e^+e^- \rightarrow \widetilde{\chi}^0_1\widetilde{\chi}^0_1$ $(\widetilde{\chi}^0_1 \rightarrow \nu\ell\overline{\ell}')$
		[168] BUSKULIC	95E	ALEP	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$ $(\widetilde{\gamma} \rightarrow \nu\ell\overline{\ell}')$
		[169] ACTON	93G	OPAL	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$ $(\widetilde{\gamma} \rightarrow \tau^{\pm}\ell^{\mp}\nu_{\ell'})$
		[170] ABE	89J	VNS	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$ $(\widetilde{\gamma} \rightarrow \gamma\widetilde{G}$ or $\gamma\widetilde{H}^0)$
>15	95	[171] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$ $(\widetilde{\gamma} \rightarrow \gamma\widetilde{G}$ or $\gamma\widetilde{H}^0)$
		[172] ADEVA	85	MRKJ	
		[173] BALL	84	CALO	Beam dump
		[174] BARTEL	84B	JADE	
		[174] BEHREND	83	CELL	
		[175] CABIBBO	81	COSM	

[167] BUSKULIC 95E looked for $e^+e^- \rightarrow \widetilde{\chi}^0_1\widetilde{\chi}^0_1$, where $\widetilde{\chi}^0_1$ decays via *R*-parity violating interaction into one neutrino and two opposite-charge leptons. The bound applies provided that $B(Z \rightarrow \widetilde{\chi}^0_1\widetilde{\chi}^0_1) > 3 \times 10^{-5}\beta^3$, β being the final state $\widetilde{\chi}^0_1$ velocity.

[168] BUSKULIC 95E looked for $e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$, where $\widetilde{\gamma}$ decays via *R*-parity violating interaction into one neutrino and two opposite-charge leptons. They extend the domain in the $(m_{\widetilde{e}}, m_{\widetilde{\gamma}})$ plane excluded by ACTON 93G to $m_{\widetilde{e}} > 220$ GeV/c^2 (for $m_{\widetilde{\gamma}}$=15 GeV/c^2) and to $m_{\widetilde{\gamma}} > 2$ GeV/c^2 (for $m_{\widetilde{e}} < 220$ GeV/c^2).

[169] ACTON 93G assume *R*-parity violation and decays $\widetilde{\gamma} \rightarrow \tau^{\pm}\ell^{\mp}\nu_{\ell}$ (ℓ= e or μ). They exclude $m_{\widetilde{\gamma}}$ = 4–43 GeV for $m_{\widetilde{e}_L} < 42$ GeV, and $m_{\widetilde{\gamma}}$ = 7–30 GeV for $m_{\widetilde{e}_L} < 100$ GeV (95% CL). Assumes $\widetilde{e}_R$ much heavier than $\widetilde{e}_L$, and lepton family number violation but L_e-L_{μ} conservation.

[170] ABE 89J exclude $m_{\widetilde{\gamma}} = 0.15$–25 GeV (95%CL) for $d = (100\ \text{GeV})^2$ and $m_{\widetilde{e}} = 40$ GeV in the case $\widetilde{\gamma} \rightarrow \gamma \widetilde{G}$, and $m_{\widetilde{\gamma}}$ up to 23 GeV for $m_{\widetilde{e}} = 40$ GeV in the case $\widetilde{\gamma} \rightarrow \gamma \widetilde{H}^0$.

[171] BEHREND 87B limit is for unstable photinos only. Assumes B($\widetilde{\gamma} \rightarrow \gamma(\widetilde{G}$or $\widetilde{H}^0$)) =1, $m_{\widetilde{G}\text{or}\widetilde{H}^0} \ll m_{\widetilde{\gamma}}$ and pure $\widetilde{\gamma}$ eigenstate. $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} < 100$ GeV.

[172] ADEVA 85 is sensitive to $\widetilde{\gamma}$ decay path <5 cm. With $m_{\widetilde{e}} = 50$ GeV, limit (CL = 90%) is $m_{\widetilde{\gamma}} > 20.5$ GeV. Assume $\widetilde{\gamma}$ decays to photon + goldstino and search for acoplanar photons with large missing p_T.

[173] BALL 84 is FNAL beam dump experiment. Observed no $\widetilde{\gamma}$ decay, where $\widetilde{\gamma}$'s are expected to come from $\widetilde{g}$'s produced at the target. Three possible $\widetilde{\gamma}$ lifetimes are considered. Gluino decay to goldstino + gluon is also considered.

[174] BEHREND 83 and BARTEL 84B look for 2γ events from $\widetilde{\gamma}$ pair production. With supersymmetric breaking parameter d = $(100\ \text{GeV})^2$ and $m_{\widetilde{e}} = 40$ GeV the excluded regions at CL = 95% would be $m_{\widetilde{\gamma}} = 100$ MeV – 13 GeV for BEHREND 83 $m_{\widetilde{\gamma}} =$ 80 MeV – 18 GeV for BARTEL 84B. Limit is also applicable if the $\widetilde{\gamma}$ decays radiatively within the detector.

[175] CABIBBO 81 consider $\widetilde{\gamma} \rightarrow \gamma +$ goldstino. Photino must be either light enough (<30 eV) to satisfy cosmology bound, or heavy enough (>0.3 MeV) to have disappeared at early universe.

Supersymmetry Miscellaneous Results

Results that do not appear under other headings or that make nonminimal assumptions.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[176] BARBER	84B	RVUE	
	[177] HOFFMAN	83	CNTR	$\pi p \rightarrow n(e^+ e^-)$

[176] BARBER 84B consider that $\widetilde{\mu}$ and $\widetilde{e}$ may mix leading to $\mu \rightarrow e\widetilde{\gamma}\widetilde{\gamma}$. They discuss mass-mixing limits from decay dist asym in LBL-TRIUMF data and e^+ polarization in SIN data.

[177] HOFFMAN 83 set CL = 90% limit $d\sigma/dt$ B($e^+ e^-$) < 3.5×10^{-32} cm^2/GeV^2 for spin-1 partner of Goldstone fermions with 140 <m <160 MeV decaying $\rightarrow e^+ e^-$ pair.

REFERENCES FOR Supersymmetric Particle Searches

ABACHI	96	PRL 76 2228	+Abbott, Abolins, Acharya+	(D0 Collab.)
ABACHI	96B	PRL 76 2222	+Abbott, Abolins, Acharya+	(D0 Collab.)
ABE	96D	PRL 76 2006	+Akimoto, Akopian, Albrow+	(CDF Collab.)
ABACHI	95C	PRL 75 618	+Abbott, Abolins, Acharya+	(D0 Collab.)
ABE	95T	PRL 75 613	+Albrow, Amidei, Anway-Wiese+	(CDF Collab.)
ACCIARRI	95E	PL B350 109	+Adam, Adraiani, Aguilar-Benitez+	(L3 Collab.)
AKERS	95R	ZPHY C67 203	+Alexander, Allison, Ametewee, Anderson+	(OPAL Collab.)
BUSKULIC	95E	PL B349 238	+Casper, DeBonis, Decamp+	(ALEPH Collab.)
CLAVELLI	95	PR D51 1117	+Coulter	(ALAT)
FALK	95	PL B354 99	+Olive, Srednicki	(MINN, UCSB)
AHMED	94B	ZPHY C64 545	+Aid, Andreev, Andrieu, Appuhn, Arpagaus+	(H1 Collab.)
AKERS	94K	PL B337 207	+Alexander, Allison, Anderson+	(OPAL Collab.)
BECK	94	PL B336 141	+Bensch, Bockholt+	(MPIH, KIAE, SASSO)
FALK	94	PL B339 248	+Olive, Srednicki	(UCSB, MINN)
FRANKE	94	PL B336 415	+Fraas, Bartl	(WURZ, WIEN)
HOSODA	94	PL B331 211	+Abe, Amako, Arai+	(VENUS Collab.)
SHIRAI	94	PRL 72 3313	+Ohmoto, Abe, Amako+	(VENUS Collab.)
ACTON	93G	PL B313 333	+Akers, Alexander, Allison, Anderson+	(OPAL Collab.)
ADRIANI	93M	PRPL 236 1	+Aguilar-Benitez, Ahlen, Alcaraz, Aloisio+	(L3 Collab.)
CLAVELLI	93	PR D47 1973	+Coulter, Yuan	(ALAT)
DREES	93	PR D47 376	+Nojiri	(DESY, SLAC)
FALK	93	PL B318 354	+Madden, Olive, Srednicki	(UCB, UCSB, MINN)
HEBBEKER	93	ZPHY C60 63		(CERN)
KELLEY	93	PR D47 2461	+Lopez, Nanopoulos, Pois, Yuan	(TAMU, ALAH)

LAU	93	PR D47 1087		(HOUS)
LOPEZ	93C	PL B313 241	+Nanopoulos, Wang	(TAMU, HARC, CERN)
MIZUTA	93	PL B298 120	+Yamaguchi	(TOHO)
MORI	93	PR D48 5505	+(KEK, NIIG, TOKY, TOKA, KOBE, OSAK, TINT, GIFU)	
ABE	92L	PRL 69 3439	+Amidei, Anway-Wiese, Apollinari, Atac+	(CDF Collab.)
BOTTINO	92	MPL A7 733	+DeAlfaro, Fornengo, Morales, Puimedon+	(TORI, ZARA)
Also	91	PL B265 57	Bottino, de Alfaro, Fornengo, Mignola+	(TORI, INFN)
CLAVELLI	92	PR D46 2112		(ALAT)
DATTA	92	ZPHY C54 513	+Guchait, Raychaudhuri	(JADA, CALC)
DECAMP	92	PRPL 216 253	+Deschizeaux, Goy, Lees, Minard+	(ALEPH Collab.)
ELLIS	92F	PL B283 252	+Roszkowski	(CERN)
KAWASAKI	92	PR D46 1634	+Mizuta	(OSU, TOHO)
LOPEZ	92	NP B370 445	+Nanopoulos, Yuan	(TAMU)
MCDONALD	92	PL B283 80	+Olive, Srednicki	(LISB, MINN, UCSB)
ROY	92	PL B283 270		(CERN)
ABREU	91F	NP B367 511	+Adam, Adami, Adye, Akesson+	(DELPHI Collab.)
AKESSON	91	ZPHY C52 219	+Almehed, Angelis, Atherton, Aubry+	(HELIOS Collab.)
ALEXANDER	91F	ZPHY C52 175	+Allison, Allport, Anderson, Arcelli+	(OPAL Collab.)
ANTONIADIS	91	PL B262 109	+Ellis, Nanopoulos	(EPOL, CERN, TAMU, HARC)
BAER	91	PR D44 207	+Tata, Woodside	(FSU, HAWA, ISU)
BAER	91B	PR D44 725	+Drees, Godbole+	(FSU, DESY, BOMB, UCD, HAWA)
BOTTINO	91	PL B265 57	+de Alfaro, Fornengo, Mignola+	(TORI, INFN)
DREES	91	PR D43 2971	+Tata	(CERN, HAWA)
GELMINI	91	NP B351 623	+Gondolo, Roulet	(UCLA, TRST)
HIDAKA	91	PR D44 927		(TGAK)
KAMIONKOW...	91	PR D44 3021	Kamionkowski	(CHIC, FNAL)
MORI	91B	PL B270 89	+Nojiri, Oyama, Suzuki+	(Kamiokande Collab.)
NOJIRI	91	PL B261 76		(KEK)
OLIVE	91	NP B355 208	+Srednicki	(MINN, UCSB)
ROSZKOWSKI	91	PL B262 59		(CERN)
SATO	91	PR D44 2220	+Hirata, Kajita, Kifune, Kihara+	(Kamioka Collab.)
ABREU	90F	PL B247 148	+Adam, Adami, Adye, Alekseev+	(DELPHI Collab.)
ABREU	90G	PL B247 157	+Adam, Adami, Adye, Alekseev+	(DELPHI Collab.)
ADACHI	90C	PL B244 352	+Aihara, Doser, Enomoto+	(TOPAZ Collab.)
ADEVA	90I	PL B249 341	+Adriani, Aguilar-Benitez, Akbari, Alcarez+	(L3 Collab.)
AKESSON	90B	PL B238 442	+Alitti, Ansari, Ansorge+	(UA2 Collab.)
AKRAWY	90D	PL B240 261	+Alexander, Allison, Allport+	(OPAL Collab.)
AKRAWY	90N	PL B248 211	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
AKRAWY	90O	PL B252 290	+Alexander, Allison, Allport, Anderson+	(OPAL Collab.)
ALITTI	90	PL B235 363	+Ansari, Ansorge, Bagnaia, Bareyre+	(UA2 Collab.)
BAER	90	PR D41 3414	+Drees, Tata	(FSU, CERN, HAWA)
BARKLOW	90	PRL 64 2984	+Abrams, Adolphsen, Averill, Ballam+	(Mark II Collab.)
DECAMP	90C	PL B236 86	+Deschizeaux, Lees, Minard, Crespo+	(ALEPH Collab.)
DECAMP	90K	PL B244 541	+Deschizeaux, Goy, Lees+	(ALEPH Collab.)
DREES	90	PL B252 127	+Hikasa	(CERN, KEK)
ELLIS	90	PL B245 251	+Nanopoulos, Roszkowski, Schramm	(CERN, HARC, TAMU)
GRIEST	90	PR D41 3565	+Kamionkowski, Turner	(UCB, CHIC, FNAL)
GRIFOLS	90	NP B331 244	+Masso	(BARC)
KRAUSS	90	PRL 64 999		(YALE)
ROSZKOWSKI	90	PL B252 471		(TAMU, HARC)
SAKAI	90	PL B234 534	+Gu, Low, Abe, Fujii+	(AMY Collab.)
SODERSTROM	90	PRL 64 2980	+McKenna, Abrams, Adolphsen, Averill+	(Mark II Collab.)
TAKETANI	90	PL B234 202	+Odaka, Abe, Amako+	(VENUS Collab.)
ZHUKOVSKII	90	SJNP 52 931	+Eminov	(MOSU)
		Translated from YAF 52 1473.		
ABE	89J	ZPHY C45 175	+Amako, Arai, Fukawa+	(VENUS Collab.)
ADACHI	89	PL B218 105	+Aihara, Dijkstra, Enomoto, Fujii+	(TOPAZ Collab.)
ADEVA	89B	PL B233 530	+Adriani, Aguilar-Benitez, Akbari+	(L3 Collab.)
ALBAJAR	89	ZPHY C44 15	+Albrow, Allkofer, Arnison, Astbury+	(UA1 Collab.)
HEARTY	89	PR D39 3207	+Rothberg, Young, Johnson, Whitaker+	(ASP Collab.)
Also	87	PRL 58 1711	Hearty, Rothberg, Young, Johnson+	(ASP Collab.)
Also	86	PRL 56 685	Bartha, Burke, Extermann+	(ASP Collab.)
NAKAMURA	89	PR D39 1261	+Kobayashi, Konaka, Imai, Masaike+	(KYOT, TMTC)
OLIVE	89	PL B230 78	+Srednicki	(MINN, UCSB)
BAER	88	PR D38 1485	+Hagiwara, Tata	(FSU, KEK, WISC)
Also	89B	PR D39 989 erratum	Baer, Hagiwara, Tata	(FSU, KEK, WISC)
BEHREND	88B	PL B215 186	+Criegee, Dainton, Field+	(CELLO Collab.)
ELLIS	88B	PL B215 404	+Olive, Sarkar, Sciama	(CERN, MINN, RAL, CAMB)
NATH	88	PR D38 1479	+Arnowitt	(NEAS, TAMU)

OLIVE	88	PL B205 553	+Srednicki	(MINN, UCSB)
SREDNICKI	88	NP B310 693	+Watkins, Olive	(MINN, UCSB)
ADEVA	87	PL B194 167	+Anderhub, Ansari, Becker+	(Mark-J Collab.)
ALBAJAR	87B	PL B185 241	+Albrow, Allkofer, Arnison+	(UA1 Collab.)
ALBAJAR	87D	PL B198 261	+Albrow, Allkofer+	(UA1 Collab.)
ANSARI	87D	PL B195 613	+Bagnaia, Banner+	(UA2 Collab.)
ARNOLD	87	PL B186 435	+Barth+	(BRUX, DUUC, LOUC, BARI, AICH, CERN+)
BAER	87B	PR D35 1598	+Hagiwara, Tata	(KEK, ANL, WISC)
Also	86	PRL 57 294	Baer, Hagiwara, Tata	(ANL, DESY, WISC)
BEHREND	87B	ZPHY C35 181	+Buerger, Criegee, Dainton+	(CELLO Collab.)
HEARTY	87	PRL 58 1711	+Rothberg, Young, Johnson+	(ASP Collab.)
NG	87	PL B188 138	+Olive, Srednicki	(MINN, UCSB)
TUTS	87	PL B186 233	+Franzini, Youssef, Zhao+	(CUSB Collab.)
ALBRECHT	86C	PL 167B 360	+Binder, Harder+	(ARGUS Collab.)
BADIER	86	ZPHY C31 21	+Bemporad, Boucrot, Callot+	(NA3 Collab.)
BARNETT	86	NP B267 625	+Haber, Kane	(LBL, UCSC, MICH)
FORD	86	PR D33 3472	+Qi, Read+	(MAC Collab.)
GAISSER	86	PR D34 2206	+Steigman, Tilav	(BART, DELA)
VOLOSHIN	86	SJNP 43 495	+Okun	(ITEP)
		Translated from YAF 43 779.		
ADEVA	85	PL 152B 439	+Becker, Becker-Szendy+	(Mark-J Collab.)
Also	84C	PRPL 109 131	Adeva, Barber, Becker+	(Mark-J Collab.)
AKERLOF	85	PL 156B 271	+Bonvicini, Chapman, Errede+	(HRS Collab.)
BARTEL	85L	PL 155B 288	+Becker, Cords, Felst, Hagiwara+	(JADE Collab.)
BEHREND	85	PL 161B 182	+Burger, Criegee, Fenner+	(CELLO Collab.)
COOPER-...	85B	PL 160B 212	Cooper-Sarkar, Parker, Sarkar+	(WA66 Collab.)
DAWSON	85	PR D31 1581	+Eichten, Quigg	(LBL, FNAL)
FARRAR	85	PRL 55 895		(RUTG)
GOLDMAN	85	Physica 15D 181	+Haber	(LANL, UCSC)
HABER	85	PRPL 117 75	+Kane	(UCSC, MICH)
ADEVA	84B	PRL 53 1806	+Barber, Becker, Berdugo+	(Mark-J Collab.)
BALL	84	PRL 53 1314	+Coffin, Gustafson+	(MICH, FIRZ, OSU, FNAL, WISC)
BARBER	84B	PL 139B 427	+Shrock	(STON)
BARTEL	84B	PL 139B 327	+Becker, Bowdery, Cords+	(JADE Collab.)
BARTEL	84C	PL 146B 126	+Becker, Bowdery, Cords+	(JADE Collab.)
BRICK	84	PR D30 1134	+	(BROW, CAVE, IIT, IND, MIT, MONS, NIJM+)
ELLIS	84	NP B238 453	+Hagelin, Nanopoulos, Olive, Srednicki	(CERN)
FARRAR	84	PRL 53 1029		(RUTG)
BEHREND	83	PL 123B 127	+Chen, Fenner, Gumpel+	(CELLO Collab.)
BERGSMA	83C	PL 121B 429	+Dorenbosch, Jonker+	(CHARM Collab.)
CHANOWITZ	83	PL 126B 225	+Sharpe	(UCB, LBL)
GOLDBERG	83	PRL 50 1419		(NEAS)
HOFFMAN	83	PR D28 660	+Frank, Mischke, Moir, Schardt	(LANL, ARZS)
KRAUSS	83	NP B227 556		(HARV)
VYSOTSKII	83	SJNP 37 948		(ITEP)
		Translated from YAF 37 1597.		
KANE	82	PL 112B 227	+Leveille	(MICH)
CABIBBO	81	PL 105B 155	+Farrar, Maiani	(ROMA, RUTG)
FARRAR	78	PL 76B 575	+Fayet	(CIT)
Also	78B	PL 79B 442	Farrar, Fayet	(CIT)