Supersymmetric Particle Searches

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SUPERSYMMETRIC MODEL ASSUMPTIONS

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

$\widetilde{\chi}_1^0$ is often assumed 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 four sections:

1) Accelerator limits for stable $\widetilde{\chi}_1^0$,
2) Bounds on $\widetilde{\chi}_1^0$ from dark matter searches,
3) Other bounds on $\widetilde{\chi}_1^0$ from astrophysics and cosmology, and
4) Bounds on unstable $\widetilde{\chi}_1^0$.

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

Unless otherwise stated, results in this section assume spectra, production rates, decay modes, and branching ratios as evaluated in the MSSM, with gaugino and sfermion mass unification at the GUT scale. These papers generally study production of $\widetilde{\chi}_i^0 \widetilde{\chi}_j^0$ ($i \geq 1$, $j \geq 2$), $\widetilde{\chi}_1^+ \widetilde{\chi}_1^-$, and (in the case of hadronic collisions) $\widetilde{\chi}_1^+ \widetilde{\chi}_2^0$ pairs. The mass limits on $\widetilde{\chi}_1^0$ are either direct, or follow indirectly from the constraints set by the non-observation of $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ states on the gaugino and higgsino MSSM parameters M_2 and μ. In some cases, information is used from the nonobservation of slepton decays.

Obsolete limits obtained from $e^+ e^-$ collisions up to $\sqrt{s}$=184 GeV have been removed from this compilation and can be found in the 2000 Edition (The European Physical Journal **C15** 1 (2000)) of this Review. $\Delta m_0 = m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$.

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
>37	95	[1] BARATE 01	ALEP	all tanβ, all m_0
>31.6	95	[2] ABBIENDI 00H	OPAL	all tanβ, all $\Delta m_0 >5$ GeV, all m_0
>31.0	95	[3] ABREU 00J	DLPH	tan$\beta \geq 1$, $m_{\widetilde{\nu}} > 300$ GeV
>32.3	95	[4,5] ABREU 00W	DLPH	all tanβ, all Δm_0, all m_0
>32.5	95	[6] ACCIARRI 00D	L3	tan$\beta > 0.7$, $\Delta m_0 > 3$ GeV, all m_0
• • • We do not use the following data for averages, fits, limits, etc. • • •				
		[7] ABBOTT 98C	D0	$p\overline{p} \rightarrow \widetilde{\chi}_1^\pm \widetilde{\chi}_2^0$
>41	95	[8] ABE 98J	CDF	$p\overline{p} \rightarrow \widetilde{\chi}_1^\pm \widetilde{\chi}_2^0$

[1] BARATE 01 data collected at 189 to 202 GeV. Updates earlier analyses of sleptons and squarks from BARATE 99Q, and of charginos and neutralinos from BARATE 98X and BARATE 99P. The limit is based on the direct search for charginos and neutralinos and the constraints from the slepton search and Z^0 width measurements, as discussed in

BARATE 99P, assuming a negligible mixing in the stau sector. The limit improves to 48 GeV under the assumption of MSUGRA with unification of the Higgs and sfermion masses, when direct constraints on the Higgs mass from BARATE 01C are used and $m_{\widetilde{\tau}} - m_{\widetilde{\chi}_1^0} > 5$ GeV to avoid degeneracy at large tanβ. These limits include and update the results of BARATE 99P.

[2] ABBIENDI 00H data collected at $\sqrt{s}$=189 GeV. The results hold over the full parameter space defined by $0 \leq M_2 \leq 2$ TeV, $|\mu| \leq 500$ GeV, $m_0 \leq 500$ GeV, $A = \pm M_2$, $\pm m_0$, and 0. The minimum mass limit is reached for tanβ=1. The results of ABBIENDI 99F are used to constrain regions of parameter space dominated by radiative $\widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0 \gamma$ decays. The limit improves to 48.5 GeV for m_0=500 GeV and tanβ=35. See their Table and Figs 4–5 for the tanβ and m_0 dependence of the limits. Updates ABBIENDI 99G.

[3] ABREU 00J data collected at $\sqrt{s}$=189 GeV. The parameter space is scanned in the domain $0 < M_2 < 3000$ GeV, $|\mu| < 200$ GeV, $1 <$ tan$\beta < 35$. The analysis includes the effects of gaugino cascade decays. In the case of radiative neutralino decays, the limits from $Z \rightarrow \widetilde{\chi}_1^0 \widetilde{\chi}_2^0$ decays in ABREU 97J are assumed. Updates ABREU 99E.

[4] ABREU 00W combines data collected at $\sqrt{s}$=189 GeV with results from lower energies. The mass limit is obtained by constraining the MSSM parameter space with gaugino and sfermion mass universality at the GUT scale, using the results of negative direct searches for neutralinos (including cascade decays and $\widetilde{\tau}\tau$ final states) from ABREU 01, for charginos from ABREU 00J and ABREU 00T (for all Δm_+), and for charged sleptons from ABREU 01B. The results hold for the full parameter space defined by all values of M_2 and $|\mu| \leq 2$ TeV with the $\widetilde{\chi}_1^0$ as LSP.

[5] The limit is obtained for tanβ=4 and small m_0. If $m_{\widetilde{\nu}} > m_{\widetilde{\chi}_1^\pm}$, the limit improves to 32.4 GeV which is reached for tanβ=1. See their Figs. 3–4 for the dependence of the limit on tanβ, m_0, and M_2. No significant dependence of the limits on the mixing of the third generation nor on the mass of the lightest Higgs was observed.

[6] ACCIARRI 00D data collected at $\sqrt{s}$=189 GeV. The results hold over the full parameter space defined by $0.7 \leq$ tan$\beta \leq 60$, $0 \leq M_2 \leq 2$ TeV, $m_0 \leq 500$ GeV, $|\mu| \leq 2$ TeV The minimum mass limit is reached for tanβ=1 and large m_0. The results of slepton searches from ACCIARRI 99W are used to help set constraints in the region of small m_0. The limit improves to 48 GeV for $m_0 \gtrsim 200$ GeV and tan$\beta \gtrsim 10$. See their Figs. 6–8 for the tanβ and m_0 dependence of the limits. Updates ACCIARRI 98F.

[7] ABBOTT 98C searches for trilepton final states (ℓ=e,μ). See footnote to ABBOTT 98C in the Chargino Section for details on the assumptions. Assuming a negligible decay rate of $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ to quarks, they obtain $m_{\widetilde{\chi}_2^0} \gtrsim 51$ GeV.

[8] ABE 98J searches for trilepton final states (ℓ=e,μ). See footnote to ABE 98J in the Chargino Section for details on the assumptions. The quoted result corresponds to the best limit within the selected range of parameters, obtained for $m_{\widetilde{q}} > m_{\widetilde{g}}$, tan$\beta$=2, and $\mu = -600$ GeV.

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. • • •			
	[9] ABUSAIDI	00	CDMS
	[10] AMBROSIO	99	MCRO
	[11] BOTTINO	97	DAMA
	[12] LOSECCO	95	RVUE
	[13] MORI	93	KAMI
	[14] BOTTINO	92	COSM
	[15] BOTTINO	91	RVUE
	[16] GELMINI	91	COSM
	[17] KAMIONKOW.	91	RVUE
	[18] MORI	91B	KAMI
none 4–15 GeV	[19] OLIVE	88	COSM

[9] ABUSAIDI 00 set new limits on spin-independent WIMP-nuclei elastic-scattering cross sections. Claim to exclude (at 75% CL) entire $3\,\sigma$ allowed region reported by DAMA.

[10] AMBROSIO 99 set new neutrino flux limits which can be used to limit the parameter space in supersymmteric models based on neutralino annihilation in the Sun and the Earth.

[11] BOTTINO 97 points out that the current data from the dark-matter detection experiment DAMA are sensitive to neutralinos in domains of parameter space not excluded by terrestrial laboratory searches.

[12] LOSECCO 95 reanalyzed the IMB data and places lower limit on $m_{\widetilde{\chi}_1^0}$ of 18 GeV if the LSP is a photino and 10 GeV if the LSP is a higgsino based on LSP annihilation in the sun producing high-enery neutrinos and the limits on neutrino fluxes from the IMB detector.

[13] 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.

[14] 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.

[15] 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.

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

[17] 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.

[18] 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.

[19] 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 $\tilde{\chi}_1^0$ from astrophysics and cosmology

Most of these papers generally exclude regions in the $M_2-\mu$ parameter plane by requiring that the $\tilde{\chi}_1^0$ 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	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>46 GeV		[20] ELLIS	00	RVUE	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[21] FENG	00	COSM	
$>$ 42 GeV	95	[22] ELLIS	98	RVUE	Updated by ELLIS 98
$<$ 600 GeV		[23] ELLIS	98B	COSM	
		[24] EDSJO	97	COSM	Co-annihilation
		[25] FALK	95	COSM	*CP*-violating phases
		[26] DREES	93	COSM	Minimal supergravity
		[27] FALK	93	COSM	Sfermion mixing
		[26] KELLEY	93	COSM	Minimal supergravity
		[28] MIZUTA	93	COSM	Co-annihilation
		[29] LOPEZ	92	COSM	Minimal supergravity, m_0=A=0
		[30] MCDONALD	92	COSM	
		[31] GRIEST	91	COSM	
		[32] NOJIRI	91	COSM	Minimal supergravity
		[33] OLIVE	91	COSM	
		[34] ROSZKOWSKI	91	COSM	
		[35] GRIEST	90	COSM	
		[33] OLIVE	89	COSM	
none 100 eV – 15 GeV		SREDNICKI	88	COSM	$\tilde{\gamma}$; $m_{\tilde{f}}$=100 GeV
none 100 eV–5 GeV		ELLIS	84	COSM	$\tilde{\gamma}$; for $m_{\tilde{f}}$=100 GeV
		GOLDBERG	83	COSM	$\tilde{\gamma}$
		[36] KRAUSS	83	COSM	$\tilde{\gamma}$
		VYSOTSKII	83	COSM	$\tilde{\gamma}$

[20] ELLIS 00 updates ELLIS 98. Uses LEP e^+e^- data at $\sqrt{s}$=202 and 204 GeV to improve bound on neutralino mass to 51 GeV when scalar mass universality is assumed and 46 GeV when Higgs mass universality is relaxed. Limits on tanβ improve to $>$ 2.7 ($\mu > 0$), $>$ 2.2 ($\mu < 0$) when scalar mass universality is assumed and $>$ 1.9 (both signs of μ) when Higgs mass universality is relaxed.

[21] FENG 00 explores cosmologically allowed regions of MSSM parameter space with multi-TeV masses.

[22] ELLIS 98 updates ELLIS 97C and ELLIS 96B (see relative footnote). Use is made of one-loop mass and coupling relations, as well as of chargino limits from e^+e^- data at $\sqrt{s}$=183 GeV. The limits on tanβ from ELLIS 97C improve to: tan$\beta > 2$ ($\mu < 0$) and tan$\beta > 1.65$ ($\mu > 0$).

[23] ELLIS 98B assumes a universal scalar mass and radiative supersymmetry breaking with universal gaugino masses. The upper limit to the LSP mass is increaded due to the inclusion of $\chi - \widetilde{\tau}_R$ coannihilations.

[24] EDSJO 97 included all coannihilation processes between neutralinos and charginos for any neutralino mass and composition.

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

[26] DREES 93, KELLEY 93 compute the cosmic relic density of the LSP in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge symmetry.

[27] FALK 93 relax the upper limit to the LSP mass by considering sfermion mixing in the MSSM.

[28] MIZUTA 93 include coannihilations to compute the relic density of Higgsino dark matter.

[29] LOPEZ 92 calculate the relic LSP density in a minimal SUSY GUT model.

[30] MCDONALD 92 calculate the relic LSP density in the MSSM including exact tree-level annihilation cross sections for all two-body final states.

[31] GRIEST 91 improve relic density calcualtions to account for coannihilations, pole effects, and threshold effects.

[32] NOJIRI 91 uses minimal supergravity mass relations between squarks and sleptons to narrow cosmologically allowed parameter space.

[33] 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.

[34] ROSZKOWSKI 91 calculates LSP relic density in mixed gaugino/higgsino region.

[35] 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.

[36] 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.

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

Unless otherwise stated, results in this section assume spectra and production rates as evaluated in the MSSM. Unless otherwise stated, the goldstino or gravitino mass $m_{\widetilde{G}}$ is assumed to be negligible relative to all other masses. In the following, $\widetilde{G}$ is assumed to be undetected and to give rise to a missing energy ($\not{E}$) signature.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>85	95	[37] ABBIENDI	01	OPAL	$e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0$, GMSB, tan$\beta$=2
>76	95	[37] ABBIENDI	01	OPAL	$e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0$, GMSB, tan$\beta$=20
		[38] ABBIENDI	01B	OPAL	$e^+e^- \to \widetilde{G}\widetilde{\chi}_1^0$ ($\widetilde{\chi}_1^0 \to \gamma\widetilde{G}$)
none 45–88.3	95	[39] ABBIENDI	01B	OPAL	$e^+e^- \to \widetilde{B}\widetilde{B}$, ($\widetilde{B} \to \gamma\widetilde{G}$)
none 10–32	95	[40] ABREU	01D	DLPH	$\not{R}(\overline{UDD})$, all m_0, $0.5 \leq \tan\beta \leq 30$
>86	95	[41] ABREU	01G	DLPH	$e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0$ ($\widetilde{\chi}_1^0 \to \widetilde{\tau}\tau$, $\widetilde{\tau} \to \tau\widetilde{G}$)
>32.5	95	[42] ACCIARRI	01	L3	$\not{R}$, all m_0, $0.7 \leq \tan\beta \leq 40$
none 10–30	95	[43] ABREU	00U	DLPH	$\not{R}$ ($LL\overline{E}$), all m_0, $1 \leq \tan\beta \leq 30$
>82.5	95	[44] ABREU	00V	DLPH	$e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0$ ($\widetilde{\chi}_1^0 \to \widetilde{\tau}\tau$, $\widetilde{\tau} \to \tau\widetilde{G}$)
		[45] ABREU	00Z	DLPH	$e^+e^- \to \widetilde{G}\widetilde{\chi}_1^0$ ($\widetilde{\chi}_1^0 \to \widetilde{G}\gamma$)

>83.5	95	[46] ABREU	00Z	DLPH	$e^+e^- \to \tilde{B}\tilde{B}$ ($\tilde{B} \to \tilde{G}\gamma$)
>86	95	[47] BARATE	00G	ALEP	$e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1$ ($\tilde{\chi}^0_1 \to \gamma\tilde{G}$)
>29	95	[48] ABBIENDI	99T	OPAL	$e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1$, $\not{R}$, m_0=500 GeV, tan$\beta > 1.2$
>65	95	[49] ABE	99I	CDF	$p\overline{p} \to \tilde{\chi}\tilde{\chi}$, $\tilde{\chi}=\tilde{\chi}^0_{1,2},\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_1 \to \gamma\tilde{G}$
		[50] ACCIARRI	99R	L3	$e^+e^- \to \tilde{G}\tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to \tilde{G}\gamma$
>88.2	95	[51] ACCIARRI	99R	L3	$e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to \tilde{G}\gamma$
>29	95	[52] BARATE	99E	ALEP	$\not{R}$, $LQ\overline{D}$, tanβ=1.41, m_0=500 GeV
>77	95	[53] ABBOTT	98	D0	$p\overline{p} \to \tilde{\chi}\tilde{\chi}$, $\tilde{\chi}=\tilde{\chi}^0_{1,2},\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_1 \to \gamma\tilde{G}$
		[54] ABREU	98	DLPH	$e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1$ ($\tilde{\chi}^0_1 \to \gamma\tilde{G}$)
		[55] ACCIARRI	98V	L3	$e^+e^- \to \tilde{G}\tilde{\chi}^0_1$ ($\tilde{\chi}^0_1 \to \gamma\tilde{G}$)
>79	95	[56] ACCIARRI	98V	L3	$e^+e^- \to \tilde{B}\tilde{B}$ ($\tilde{B} \to \gamma\tilde{G}$)
		[57] BARATE	98H	ALEP	$e^+e^- \to \tilde{G}\tilde{\chi}^0_1$ ($\tilde{\chi}^0_1 \to \gamma\tilde{G}$)
>71	95	[58] BARATE	98H	ALEP	$e^+e^- \to \tilde{B}\tilde{B}$ ($\tilde{B} \to \gamma\tilde{G}$)
>23	95	[59] BARATE	98S	ALEP	$\not{R}$, $LL\overline{E}$
		[60] ELLIS	97	THEO	$e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1$, $\tilde{\chi}^0_1 \to \gamma\tilde{G}$
		[61] CABIBBO	81	COSM	

[37] ABBIENDI 01 looked for final states with $\gamma\gamma\not{E}$, $\ell\ell\not{E}$, with possibly additional activity and four leptons + $\not{E}$ to search for prompt decays of $\tilde{\chi}^0_1$ or $\tilde{\ell}_1$ in GMSB. They derive limits in the plane ($m_{\tilde{\chi}^0_1}$,$m_{\tilde{\tau}_1}$), see Fig. 6, allowing either the $\tilde{\chi}^0_1$ or a $\tilde{\ell}_1$ to be the NLSP. Two scenarios are considered: tanβ=2 with the 3 sleptons degenerate in mass and tanβ=20 where the $\tilde{\tau}_1$ is lighter than the other sleptons. Data taken at $\sqrt{s}$=189 GeV.

[38] ABBIENDI 01B obtained an upper limit on the cross section for the process $e^+e^- \to \tilde{G}\tilde{\chi}^0_1$ followed by the prompt decay $\tilde{\chi}^0_1 \to \gamma\tilde{G}$ shown in Fig. 11. Data taken at $\sqrt{s}$=189 GeV. These limits include and update the results of ABBIENDI 99F.

[39] ABBIENDI 01B looked for $\gamma\gamma\not{E}$ final states at $\sqrt{s}$=189 GeV. The limit is for pure bino $\tilde{B}$ NLSP and assumes $m_{\tilde{e}_R} = 1.35 m_{\tilde{\chi}^0_1}$ and $m_{\tilde{e}_L} = 2.7 m_{\tilde{\chi}^0_1}$. See Fig. 14 for the cross-section limits as function of $m_{\tilde{\chi}^0_1}$. These limits include and update the results of ABBIENDI 99F.

[40] ABREU 01D searches for multi-jet events, expected in the case of prompt decays from R-parity violating $\overline{UDD}$ couplings, using data from $\sqrt{s}$=189 GeV. Combined with the search for charginos, limits are obtained in the M_2 versus μ plane and a limit on the neutralino mass is derived from a scan over the parameters m_0 and tanβ. The weakest limit for $\tilde{\chi}^0_1$ is reached for high m_0 and tanβ=1.

[41] ABREU 01G use data from $\sqrt{s}$= 161–202 GeV. They look for 4-tau + $\not{E}$ final states, expected in GMSB when the $\tilde{\tau}_1$ is the NLSP and assuming a short-lived $\tilde{\chi}^0_1$ ($m_{\tilde{G}} \leq$ 1 eV). Limits are obtained in the plane ($m_{\tilde{\tau}}$,$m_{\tilde{\chi}^0_1}$) from a scan of the GMSB parameters space, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 and for the case of $\tilde{\chi}^0_1$ NLSP from ABREU 00Z. The limit above is reached for a single generation of messengers and when the $\tilde{\tau}_1$ is the NLSP. Stronger limits are obtained when more messenger generations are assumed or when the other sleptons are co-NLSP, see their Fig. 2. Supersedes the results of ABREU 00V.

[42] ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189 GeV. The search is performed for

direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00C in a scan of the parameter space assuing MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 99I.

[43] ABREU 00U searches for the production of charginos and neutralinos in the case of R-parity violation with $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons or jets plus leptons, assuming one coupling to be nonzero at the time and giving rise to direct or indirect decays. Limits are obtained in the M_2 versus μ plane and a limit on the neutralino mass is derived from a scan over the parameters m_0 and tanβ. The weakest limit for $\widetilde{\chi}^0_1$ is reached for high m_0 and tanβ=1. Supersedes the results of ABREU 00I.

[44] ABREU 00V use data from $\sqrt{s}$= 161–189 GeV. They look for 4-tau + $\not\!\!E$ final states, expected in GMSB when the $\widetilde{\tau}_1$ is the NLSP and assuming a short-lived $\widetilde{\chi}^0_1$ ($m_{\widetilde{G}}$ <1 eV). Limits are obtained in the plane ($m_{\widetilde{\tau}}$,$m_{\widetilde{\chi}^0_1}$) from a scan of the GMSB parameters space, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 and for the case of $\widetilde{\chi}^0_1$ NLSP from ABREU 00Z. The limit above is reached for a single generation of messengers and when the $\widetilde{\tau}_1$ is the NLSP. Stronger limits are obtained when more messenger generations are assumed or when the other sleptons are co-NLSP; see their Table 6. Supersedes the results of ABREU 99F.

[45] ABREU 00Z looks for $\gamma\not\!\!E$ final states using data from $\sqrt{s}$= 183–189 GeV. Assuming the decay $\widetilde{\chi}^0_1 \rightarrow \widetilde{G}\gamma$, limits on cross section are derived, see their Fig. 7.

[46] ABREU 00Z looks for diphoton +$\not\!\!E$ final states using data from $\sqrt{s}$= 130–189 GeV. The limit is derived for a pure bino $\widetilde{B}$ assuming the prompt decay $\widetilde{B} \rightarrow \widetilde{G}\gamma$ and $m_{\widetilde{e}_L} \gg m_{\widetilde{e}_R} = 2m_{\widetilde{B}}$. For long-lived neutralinos, cross-section limits are displayed in their Fig. 9. These results include and update limits from ABREU 99D.

[47] BARATE 00G search for diphoton + $\not\!\!E$ topologies using data collected at $\sqrt{s}$=189 GeV. Limits are obtained from a scan of GMSB parameters space, under the assumption of a short-lived $\widetilde{\chi}^0_1$ NLSP. The limit is reduced to 45 GeV for long-lived neutralinos.

[48] ABBIENDI 99T searches for the production of neutralinos in the case of R-parity violation with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings using data from $\sqrt{s}$=183 GeV. They investigate topologies with mulitiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. Mixed decays (where one particle has a direct, the other an indirect decay) are also considered for the $\overline{UDD}$ couplings. Upper limits on the cross section are derived which, combined with the constraint from the Z^0 width, allow to exclude regions in the M_2 versus μ plane for any coupling. Limits on the neutralino mass are obtained for non-zero $LL\overline{E}$ couplings $> 10^{-5}$. The limit disappears for tan$\beta < 1.2$ and it improves to 50 GeV for tan$\beta > 20$.

[49] ABE 99I looked for chargino and neutralino production, where the lightest neutralino in their decay products further decays into $\gamma\widetilde{G}$. The limit assumes the gaugino mass unification, and holds for 1 <tanβ < 25, M_2 < 200 GeV, and all μ. ABE 99I is an expanded version of ABE 98L.

[50] ACCIARRI 99R searches for $\gamma\not\!\!E$ final states using data from $\sqrt{s}$=189 GeV. From limits on cross section times branching ratio, mass limits are derived in a no-scale SUGRA model, see their Fig. 5. Supersedes the results of ACCIARRI 98V.

[51] ACCIARRI 99R searches for $\gamma\not\!\!E$ final states using data from $\sqrt{s}$=189 GeV. From a scan over the GMSB parameter space, a limit on the mass is derived under the assumption that the neutralino is the NLSP. Supersedes the results of ACCIARRI 98V.

[52] BARATE 99E looked for the decay of gauginos via R-violating couplings $LQ\overline{D}$. The bound is significantly reduced for smaller values of m_0. Data collected at $\sqrt{s}$=130–172 GeV.

[53] ABBOTT 98 studied the chargino and neutralino production, where the lightest neutralino in their decay products further decays into $\gamma \widetilde{G}$. The limit assumes the gaugino mass unification.

[54] ABREU 98 uses data at $\sqrt{s}$=161 and 172 GeV. Upper bounds on $\gamma\gamma\not{E}$ cross section are obtained. Similar limits on $\gamma\not{E}$ are also given, relevant for $e^+ e^- \rightarrow \widetilde{\chi}_1^0 \widetilde{G}$ production.

[55] ACCIARRI 98V obtained an upper bound on the cross section for the process $e^+ e^- \rightarrow \widetilde{G} \widetilde{\chi}_1^0$ followed by the prompt decay $\widetilde{\chi}_1^0 \rightarrow \widetilde{G} \gamma$ of 0.28–0.07 pb $m_{\widetilde{\chi}_1^0}$=0–183 GeV. See Fig. 4b for the detailed dependence on $m_{\widetilde{\chi}_1^0}$. Data taken at $\sqrt{s}$=183 GeV.

[56] ACCIARRI 98V looked for $\gamma\gamma\not{E}$ final states at $\sqrt{s}$=183 GeV. The limit is for pure bino $\widetilde{B}$ and assumes $m_{\widetilde{e}_{R,L}}$=150 GeV. The limit improves to 84 GeV for $m_{\widetilde{e}_{R,L}}$=100 GeV. See Fig. 7 for the cross-section limits as a function of $m_{\widetilde{\chi}_1^0}$, for different cases of neutralino composition.

[57] BARATE 98H obtained an upper bound on the cross section for the process $e^+ e^- \rightarrow \widetilde{G} \widetilde{\chi}_1^0$ followed by the prompt decay $\widetilde{\chi}_1^0 \rightarrow \widetilde{G} \gamma$ of 0.4–0.75 pb for $m_{\widetilde{\chi}_1^0}$ = 40–170 GeV. Data taken at $\sqrt{s}$ = 161,172 GeV.

[58] BARATE 98H looked for $\gamma\gamma \not{E}$ final states at $\sqrt{s}$ = 161,172 GeV. The limit is for pure bino $\widetilde{B}$ with $\tau(\widetilde{B}) <$ 3 ns and assumes $m_{\widetilde{e}_R} = 1.5 m_{\widetilde{B}}$. See Fig. 5 for the dependence of the limit on $m_{\widetilde{e}_R}$.

[59] BARATE 98S looked for the decay of gauginos via R-violating coupling $LL\overline{E}$. The bound improves to 25 GeV if the chargino decays into neutralino which further decays into lepton pairs. Data collected at $\sqrt{s}$=130–172 GeV.

[60] ELLIS 97 reanalyzed the LEP2 ($\sqrt{s}$=161 GeV) limits of $\sigma(\gamma\gamma+E_{\text{miss}}) <$ 0.2 pb to exclude $m_{\widetilde{\chi}_1^0} <$ 63 GeV if $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} <$ 150 GeV and $\widetilde{\chi}_1^0$ decays to $\gamma \widetilde{G}$ inside detector.

[61] 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.

$\widetilde{\chi}^0_2$, $\widetilde{\chi}^0_3$, $\widetilde{\chi}^0_4$ (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 $e^+e^- \rightarrow \widetilde{\chi}^0_i \widetilde{\chi}^0_j$. Limits arise either from direct searches, or from the MSSM constraints set on the gaugino and higgsino mass parameters M_2 and μ through searches for lighter charginos and neutralinos. 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.

Limits obtained from e^+e^- collisions at energies up to 136 GeV, as well as other limits from different techniques, are now superseded and have not been included in this compilation. They can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this Review.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$>$ 55.9	95	[62] ABBIENDI	00H	OPAL	$\widetilde{\chi}^0_2$, tanβ=1.5, Δm >10 GeV, all m_0
$>$106	95	[62] ABBIENDI	00H	OPAL	$\widetilde{\chi}^0_3$, tanβ=1.5, Δm >10 GeV, all m_0
> 62.4	95	[63] ABREU	00W	DLPH	$\widetilde{\chi}^0_2$, $1 \leq$ tan$\beta \leq 40$, all Δm_0, all m_0
> 99.9	95	[63] ABREU	00W	DLPH	$\widetilde{\chi}^0_3$, $1 \leq$ tan$\beta \leq 40$, all Δm_0, all m_0
>116.0	95	[63] ABREU	00W	DLPH	$\widetilde{\chi}^0_4$, $1 \leq$ tan$\beta \leq 40$, all Δm_0, all m_0
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[64] ABREU	01B	DLPH	$e^+e^- \rightarrow \widetilde{\chi}^0_i \widetilde{\chi}^0_j$
$>$ 68.0	95	[65] ACCIARRI	01	L3	$\widetilde{\chi}^0_2$, $\not{R}$, all m_0, $0.7 \leq$ tan$\beta \leq 40$
$>$ 99.0	95	[65] ACCIARRI	01	L3	$\widetilde{\chi}^0_3$, $\not{R}$, all m_0, $0.7 \leq$ tan$\beta \leq 40$
$>$ 50	95	[66] ABREU	00U	DLPH	$\widetilde{\chi}^0_2$, $\not{R}$ ($LL\overline{E}$), all Δm_0, $1 \leq$ tan$\beta \leq 30$
	95	[67] ABREU	00Z	DLPH	$e^+e^- \rightarrow \widetilde{\chi}^0_2 \widetilde{\chi}^0_2$ ($\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1 \gamma$)
		[68] ABBIENDI	99F	OPAL	$e^+e^- \rightarrow \widetilde{\chi}^0_2 \widetilde{\chi}^0_1$ ($\widetilde{\chi}^0_2 \rightarrow \gamma \widetilde{\chi}^0_1$)
		[69] ABBIENDI	99F	OPAL	$e^+e^- \rightarrow \widetilde{\chi}^0_2 \widetilde{\chi}^0_2$ ($\widetilde{\chi}^0_2 \rightarrow \gamma \widetilde{\chi}^0_1$)
		[70] ACCIARRI	99R	L3	$e^+e^- \rightarrow \widetilde{\chi}^0_2 \widetilde{\chi}^0_{2,1}$, $\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1 \gamma$
		[71] ABBOTT	98C	D0	$p\overline{p} \rightarrow \widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$
$>$ 82.2	95	[72] ABE	98J	CDF	$p\overline{p} \rightarrow \widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$
$>$ 92	95	[73] ACCIARRI	98F	L3	$\widetilde{H}^0_2$, tanβ=1.41, $M_2 < 500$ GeV
		[74] ACCIARRI	98V	L3	$e^+e^- \rightarrow \widetilde{\chi}^0_2 \widetilde{\chi}^0_{1,2}$ ($\widetilde{\chi}^0_2 \rightarrow \gamma \widetilde{\chi}^0_1$)
$>$ 53	95	[75] BARATE	98H	ALEP	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$ ($\widetilde{\gamma} \rightarrow \gamma \widetilde{H}^0$)
$>$ 74	95	[76] BARATE	98J	ALEP	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\gamma}$ ($\widetilde{\gamma} \rightarrow \gamma \widetilde{H}^0$)
		[77] ABACHI	96	D0	$p\overline{p} \rightarrow \widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$
		[78] ABE	96K	CDF	$p\overline{p} \rightarrow \widetilde{\chi}^\pm_1 \widetilde{\chi}^0_2$

[62] ABBIENDI 00H used the results of direct searches in the $e^+e^- \rightarrow \widetilde{\chi}^0_1 \widetilde{\chi}^0_{2,3}$ channels, as well as the indirect limits from $\widetilde{\chi}^0_1$ and $\widetilde{\chi}^\pm_1$ searches, in the framework of the MSSM with gaugino and sfermion mass unification at the GUT scale. See the footnote to ABBIENDI 00H in the chargino Section for further details on the assumptions. Data collected at $\sqrt{s}$=189 GeV. The limits improve to 86.2 GeV ($\widetilde{\chi}^0_2$) and 124 GeV ($\widetilde{\chi}^0_3$) for tanβ=35. See their Table 6 for more details on the tanβ and m_0 dependence of the limits. Quoted values consistent with erratum published in ABBIENDI 00Y. Updates ABBIENDI 99G.

[63] ABREU 00W combines data collected at $\sqrt{s}$=189 GeV with results from lower energies. The mass limit is obtained by constraining the MSSM parameter space with gaugino and sfermion mass universality at the GUT scale, using the results of negative direct searches for neutralinos (including cascade decays and $\widetilde{\tau}\tau$ final states) from ABREU 01, for charginos from ABREU 00J and ABREU 00T (for all Δm_+), and for charged sleptons from ABREU 01B. The results hold for the full parameter space defined by all values of M_2 and $|\mu| \leq 2$ TeV with the $\widetilde{\chi}^0_1$ as LSP.

[64] ABREU 01B used data from $\sqrt{s}$=189 GeV to search for the production of $\widetilde{\chi}^0_i \widetilde{\chi}^0_j$. They looked for di-jet and di-lepton pairs with $\not\!\!E$ for events from $\widetilde{\chi}^0_i \widetilde{\chi}^0_j$ with the decay $\widetilde{\chi}^0_j \rightarrow f\overline{f}\widetilde{\chi}^0_1$; multi-jet and multi-lepton pairs with or without additional photons to cover the cascade decays $\widetilde{\chi}^0_j \rightarrow f\overline{f}\widetilde{\chi}^0_2$, followed by $\widetilde{\chi}^0_j \rightarrow f\overline{f}\widetilde{\chi}^0_1$ or $\widetilde{\chi}^0_j \rightarrow \gamma\widetilde{\chi}^0_1$; multi-tau final states from $\widetilde{\chi}^0_2 \rightarrow \widetilde{\tau}\tau$ with $\widetilde{\tau} \rightarrow \tau\widetilde{\chi}^0_1$. Se Figs. 9 and 10 for limits on the (μ,M_2) plane for tanβ=1.0 and different values of m_0.

[65] ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from $\not\!R$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00C in a scan of the parameter space assuing MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 99I.

[66] ABREU 00U searches for the production of charginos and neutralinos in the case of R-parity violation with $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons or jets plus leptons, assuming one coupling to be nonzero at the time and giving rise to direct or indirect decays. LImits are obtained in the M_2 versus μ plane and a limit on the neutralino mass is derived from a scan over the parameters m_0 and tanβ.

[67] ABREU 00Z looks for diphoton $+\not\!\!E$ final states using data from $\sqrt{s}$= 130–189 GeV. They obtain an upper bound on the cross section, see their Fig. 10 for limits in the ($m_{\widetilde{\chi}^0_2}$,$m_{\widetilde{\chi}^0_1}$) plane. Updates ABREU 99D.

[68] ABBIENDI 99F looked for $\gamma\not\!\!E$ final states at $\sqrt{s}$=183 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \rightarrow \widetilde{\chi}^0_2\widetilde{\chi}^0_1$ followed by the prompt decay $\widetilde{\chi}^0_2 \rightarrow \gamma\widetilde{\chi}^0_1$ of 0.075–0.80 pb in the region $m_{\widetilde{\chi}^0_2}+m_{\widetilde{\chi}^0_1} > m_Z$, $m_{\widetilde{\chi}^0_2}$=91–183 GeV, and $\Delta m_0 > 5$ GeV. See Fig. 7 for explicit limits in the ($m_{\widetilde{\chi}^0_2}$,$m_{\widetilde{\chi}^0_1}$) plane.

[69] ABBIENDI 99F looked for $\gamma\gamma\not\!\!E$ final states at $\sqrt{s}$=183 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \rightarrow \widetilde{\chi}^0_2\widetilde{\chi}^0_2$ followed by the prompt decay $\widetilde{\chi}^0_2 \rightarrow \gamma\widetilde{\chi}^0_1$ of 0.08–0.37 pb for $m_{\widetilde{\chi}^0_2}$=45–81.5 GeV, and $\Delta m_0 > 5$ GeV. See Fig. 11 for explicit limits in the ($m_{\widetilde{\chi}^0_2}$,$m_{\widetilde{\chi}^0_1}$) plane.

[70] ACCIARRI 99R searches for $\gamma\not\!\!E$ and $\gamma\gamma\not\!\!E$ final states using data from $\sqrt{s}$=189 GeV. Limits on the cross section for the processes $e^+e^- \rightarrow \widetilde{\chi}^0_2\widetilde{\chi}^0_{2,1}$ with the decay $\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1\gamma$ are derived, as shown in their Figs. 4 and 7. Supersedes the results of ACCIARRI 98V.

[71] ABBOTT 98C searches for trilepton final states (ℓ=e,μ). See footnote to ABBOTT 98C in the Chargino Section for details on the assumptions. Assuming a negligible decay rate of $\widetilde{\chi}^\pm_1$ and $\widetilde{\chi}^0_2$ to quarks, they obtain $m_{\widetilde{\chi}^0_2} \gtrsim 103$ GeV.

[72] ABE 98J searches for trilepton final states (ℓ=e,μ). See footnote to ABE 98J in the Chargino Section for details on the assumptions. The quoted result for $m_{\widetilde{\chi}^0_2}$ corresponds to the best limit within the selected range of parameters, obtained for $m_{\widetilde{q}} > m_{\widetilde{g}}$, tan$\beta$=2, and μ=$-$600 GeV.

[73] ACCIARRI 98F is obtained from direct searches in the $e^+e^- \rightarrow \widetilde{\chi}^0_{1,2}\widetilde{\chi}^0_2$ production channels, and indirectly from $\widetilde{\chi}^\pm_1$ and $\widetilde{\chi}^0_1$ searches within the MSSM. See footone to ACCIARRI 98F in the chargino Section for futher details on the assumptions. Data taken at $\sqrt{s}$ = 130–172 GeV.

[74] ACCIARRI 98V looked for $\gamma(\gamma)\not\!\!E$ final states at $\sqrt{s}$=183 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \rightarrow \widetilde{\chi}^0_2\widetilde{\chi}^0_{1,2}$ followed by the prompt decay $\widetilde{\chi}^0_2 \rightarrow \gamma\widetilde{\chi}^0_1$. See Figs. 4a and 6a for explicit limits in the ($m_{\widetilde{\chi}^0_2}$,$m_{\widetilde{\chi}^0_1}$) plane.

[75] BARATE 98H looked for $\gamma\gamma\not\!\!E$ final states at $\sqrt{s}$ = 161,172 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \rightarrow \widetilde{\chi}^0_2\widetilde{\chi}^0_2$ followed by the prompt decay $\widetilde{\chi}^0_2 \rightarrow \gamma\widetilde{\chi}^0_1$ of 0.4–0.8 pb for $m_{\widetilde{\chi}^0_2}$ = 10–80 GeV. The bound above is for the specific case of $\widetilde{\chi}^0_1 = \widetilde{H}^0$ and $\widetilde{\chi}^0_2 = \widetilde{\gamma}$ and $m_{\widetilde{e}_R}$ = 100 GeV. See Fig. 6 and 7 for explicit limits in the ($\widetilde{\chi}^0_2$,$\widetilde{\chi}^0_1$) plane and in the ($\widetilde{\chi}^0_2$,$\widetilde{e}_R$) plane.

[76] BARATE 98J looked for $\gamma\gamma\not\!\!E$ final states at $\sqrt{s}$ = 161–183 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \rightarrow \widetilde{\chi}^0_2\widetilde{\chi}^0_2$ followed by the prompt decay $\widetilde{\chi}^0_2 \rightarrow \gamma\widetilde{\chi}^0_1$ of 0.08–0.24 pb for $m_{\widetilde{\chi}^0_2} < 91$ GeV. The bound above is for the specific case of $\widetilde{\chi}^0_1 = \widetilde{H}^0$ and $\widetilde{\chi}^0_2 = \widetilde{\gamma}$ and $m_{\widetilde{e}_R}$ = 100 GeV.

[77] 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).

[78] ABE 96K looked for tripleton events from chargino-neutralino production. They obtained lower bounds on $m_{\widetilde{\chi}^0_2}$ as a function of μ. The lower bounds are in the 45–50 GeV range for gaugino-dominant $\widetilde{\chi}^0_2$ with negative μ, if tanβ <10. See paper for more details of the assumptions.

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

Charginos are unknown mixtures of w-inos and charged higgsinos (the supersymmetric partners of W and Higgs bosons). A lower mass limit for the lightest chargino ($\widetilde{\chi}_1^{\pm}$) of approximately 45 GeV, independent of the field composition and of the decay mode, has been obtained by the LEP experiments from the analysis of the Z width and decays. These results, as well as other now superseded limits from e^+e^- collisions at energies below 136 GeV, and from hadronic collisions, can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this Review.

Unless otherwise stated, results in this section assume spectra, production rates, decay modes and branching ratios as evaluated in the MSSM, with gaugino and sfermion mass unification at the GUT scale. These papers generally study production of $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ and (in the case of hadronic collisions) $\widetilde{\chi}_1^+\widetilde{\chi}_2^0$ pairs, including the effects of cascade decays. The mass limits on $\widetilde{\chi}_1^{\pm}$ are either direct, or follow indirectly from the constraints set by the non-observation of $\widetilde{\chi}_2^0$ states on the gaugino and higgsino MSSM parameters M_2 and μ. For generic values of the MSSM parameters, limits from high-energy e^+e^- collisions coincide with the highest value of the mass allowed by phase-space, namely $m_{\widetilde{\chi}_1^{\pm}} \lesssim \sqrt{s}/2$. At the time of this writing, preliminary and unpublished results from the 1999 run of LEP2 at $\sqrt{s}$ up to 202 GeV give therefore a lower mass limit of approximately 101 GeV valid for general MSSM models. The limits become however weaker in special regions of the MSSM parameter space where the detection efficiencies or production cross sections are suppressed. For example, this may happen when: (i) the mass differences $\Delta m_+ = m_{\widetilde{\chi}_1^{\pm}} - m_{\widetilde{\chi}_1^0}$ or $\Delta m_\nu = m_{\widetilde{\chi}_1^{\pm}} - m_{\widetilde{\nu}}$ are very small, and the detection efficiency is reduced; (ii) the electron sneutrino mass is small, and the $\widetilde{\chi}_1^{\pm}$ production rate is suppressed due to a destructive interference between s and t channel exchange diagrams. The regions of MSSM parameter space where the following limits are valid are indicated in the comment lines or in the footnotes.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$>$ 71.7	95	[79] ABBIENDI	00H	OPAL	tanβ=35, Δm_+ >5 GeV, all m_0
$>$ 88.4	95	[80] ABREU	00J	DLPH	$\Delta m_+ \geq$ 3 GeV, $m_{\widetilde{\nu}} > m_{\widetilde{\chi}^{\pm}}$, tan$\beta \geq 1$
$>$ 59.8	95	[81] ABREU	00T	DLPH	$e^+e^- \rightarrow \widetilde{\chi}^{\pm}\widetilde{\chi}^{\mp}$, all Δm_+, $m_{\widetilde{\nu}}$ >500 GeV
$>$ 62.4	95	[82] ABREU	00W	DLPH	$1 \leq$ tan$\beta \leq 40$, all Δm_+, all m_0
> 67.7	95	[83] ACCIARRI	00D	L3	tan$\beta > 0.7$, all Δm_+, all m_0
$>$ 69.4	95	[84] ACCIARRI	00K	L3	$e^+e^- \rightarrow \widetilde{\chi}^{\pm}\widetilde{\chi}^{\mp}$, all Δm_+, heavy scalars
$>$ 68	95	[85] BARATE	98X	ALEP	tanβ=1.41, all m_0
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>$ 94.3	95	[86] ABREU	01C	DLPH	$\widetilde{\chi}^{\pm} \rightarrow \tau J$
$>$ 94	95	[87] ABREU	01D	DLPH	$\not{R}(\overline{UDD})$, all Δm_0, $0.5 \leq$ tan$\beta \leq$ 30
$>$ 95.2	95	[88] ABREU	01G	DLPH	$e^+e^- \rightarrow \widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^{\pm}$ ($\widetilde{\chi}_1^{\pm} \rightarrow \widetilde{\tau}_1\nu_\tau$, $\widetilde{\tau}_1 \rightarrow \tau\widetilde{G}$)
$>$ 93.8	95	[89] ACCIARRI	01	L3	$\not{R}$, all m_0, $0.7 \leq$ tan$\beta \leq 40$
$>$100	95	[90] BARATE	01B	ALEP	$\not{R}$ decays, $m_0 > 500$ GeV
$>$ 94.1	95	[91] ABREU	00J	DLPH	$e^+e^- \rightarrow \widetilde{\chi}^{\pm}\widetilde{\chi}^{\mp}$ ($\widetilde{\chi}^0 \rightarrow \gamma\widetilde{G}$), tan$\beta \geq 1$

> 94	95	[92] ABREU	00U	DLPH	$\not{R}$ ($LL\overline{E}$), all Δm_0, $1 \le \tan\beta \le 30$
> 91.8	95	[93] ABREU	00V	DLPH	$e^+ e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$ ($\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_1 \nu_\tau$, $\tilde{\tau}_1 \rightarrow \tau \tilde{G}$)
		[94] CHO	00B	THEO	EW analysis
> 76	95	[95] ABBIENDI	99T	OPAL	$\not{R}$, m_0=500 GeV
>120	95	[96] ABE	99I	CDF	$p\overline{p} \rightarrow \tilde{\chi}\tilde{\chi}$, $\tilde{\chi}=\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$
> 51	95	[97] MALTONI	99B	THEO	EW analysis, $\Delta m_+ \sim 1$ GeV
>150	95	[98] ABBOTT	98	D0	$p\overline{p} \rightarrow \tilde{\chi}\tilde{\chi}$, $\tilde{\chi}=\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$
		[99] ABBOTT	98C	D0	$p\overline{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0$
> 81.5	95	[100] ABE	98J	CDF	$p\overline{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0$
		[101] ACKERSTAFF	98K	OPAL	$\tilde{\chi}^+ \rightarrow \ell^+ \not{E}$
> 65.7	95	[102] ACKERSTAFF	98L	OPAL	$\Delta m_+ > 3$ GeV, $\Delta m_\nu > 2$ GeV
		[103] ACKERSTAFF	98V	OPAL	light gluino
		[104] CARENA	97	THEO	$g_\mu - 2$
		[105] KALINOWSKI	97	THEO	$W \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^0$
		[106] ABE	96K	CDF	$p\overline{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0$

[79] ABBIENDI 00H data collected at $\sqrt{s}$=189 GeV. The results hold over the full parameter space defined by $0 \le M_2 \le 2$ TeV, $|\mu| \le 500$ GeV, $m_0 \le 500$ GeV, A=$\pm M_2$, $\pm m_0$, and 0. The results of slepton searches from ABBIENDI 00G were used to help set constraints in the region of small m_0. The limit improves to 78 GeV for $\tan\beta$=1.5. See their Table 5 and Fig. 4 for the $\tan\beta$ and M_2 dependence of the limits. Updates ABBIENDI 99G.

[80] ABREU 00J data collected at $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons, jets plus leptons, multi-jets, or isolated photons. The parameter space is scanned in the domain $0 < M_2 < 3000$ GeV, $|\mu| < 200$ GeV, $1 < \tan\beta < 35$. The analysis includes the effects of gaugino cascade decays. Updates ABREU 99E.

[81] ABREU 00T searches for the production of charginos with small Δm_+ using data from $\sqrt{s}$= 130 to 189 GeV. They investigate final states with heavy stable charged particles, decay vertices inside the detector, and soft topologies with a photon from initital state radiation. The results are combined with the limits on prompt decays from ABREU 00J. The production and decay branching ratios are evaluated within the MSSM, assuming heavy sfermions. The parameter space is scanned in the domain $1 < \tan\beta < 50$ and, for $\Delta m_+ < 3$ GeV, for values of M_1, M_2, and μ such that $M_2 \le 2M_1 \le 10M_2$. The limit is obtained in the gaugino region. For higgsino-like charginos, the limit improves to 62.4 GeV, provided $m_{\tilde{f}} > m_{\tilde{\chi}^\pm}$. These limits include and update the results of ABREU 99Z.

[82] ABREU 00W combines data collected at $\sqrt{s}$=189 GeV with results from lower energies. The mass limit is obtained by constraining the MSSM parameter space with gaugino and sfermion mass universality at the GUT scale, using the results of negative direct searches for neutralinos (including cascade decays and $\tilde{\tau}\tau$ final states) from ABREU 01, for charginos from ABREU 00J and ABREU 00T (for all Δm_+), and for charged sleptons from ABREU 01B. The results hold for the full parameter space defined by all values of M_2 and $|\mu| \le 2$ TeV with the $\tilde{\chi}_1^0$ as LSP.

[83] ACCIARRI 00D data collected at $\sqrt{s}$=189 GeV. The results hold over the full parameter space defined by $0.7 \le \tan\beta \le 60$, $0 \le M_2 \le 2$ TeV, $|\mu| \le 2$ TeV $m_0 \le 500$ GeV. The results of slepton searches from ACCIARRI 99W are used to help set constraints in the region of small m_0. See their Figs. 5 for the $\tan\beta$ and M_2 dependence on the limits. See the text for the impact of a large B($\tilde{\chi}^\pm \rightarrow \tau \tilde{\nu}_\tau$) on the result. The region of small Δm_+ is excluded by the analysis of ACCIARRI 00K. Updates ACCIARRI 98F.

[84] ACCIARRI 00K searches for the production of charginos with small Δm_+ using data from $\sqrt{s}$=189 GeV. They investigate soft final states with a photon from initial state radiation. The results are combined with the limits on prompt decays from ACCIARRI 00D and from heavy stable charged particles from ACCIARRI 99L (see Heavy Charged Lepton Searches). The production and decay branching ratios are evaluated within the MSSM, assuming heavy sfermions. The parameter space is scanned in the domain 1<tanβ <50, 0.3 <M_1/M_2 <50, and 0< $|\mu|$ <2 TeV. The limit is obtained in the higgsino region and improves to 78.6 GeV for gaugino-like charginos. The limit is unchanged for light scalar quarks. For light $\widetilde{\tau}$ or $\widetilde{\nu}_\tau$, the limit is unchanged in the gaugino-like region and is lowered by 0.8 GeV in the higgsino-like case. For light $\widetilde{\mu}$ or $\widetilde{\nu}_\mu$, the limit is unchanged in the higgsino-like region and is lowered by 0.9 GeV in the gaugino-like region. No direct mass limits are obtained for light $\widetilde{e}$ or $\widetilde{\nu}_e$.

[85] BARATE 98X limit holds for all values of m_0 consistent with the slepton mass limits of BARATE 97N. The limit improves to 79 GeV for a mostly higgsino $\widetilde{\chi}_1^\pm$ (with $\Delta m > 5$ GeV) and to 85.5 GeV for a mostly gaugino $\widetilde{\chi}_1^\pm$ (μ=$-$500 GeV and $m_{\widetilde{\nu}} > 200$ GeV). The cases of $m_{\widetilde{\chi}_1^\pm} > m_{\widetilde{\nu}}$ or nonuniversal scalar mass or nonuniversal gaugino mass are also studied in the paper. Data collected at $\sqrt{s}$=161–172 GeV.

[86] ABREU 01C looked for τ pairs with $\not\!\!E$ at $\sqrt{s}$=183–189 GeV to search for the associated production of charginos, followed by the decay $\widetilde{\chi}^\pm \to \tau J$, J being an invisible massless particle. See Fig. 6 for the regions excluded in the (μ,M_2) plane.

[87] ABREU 01D searches for multi-jet events, expected in the case of prompt decays from R-parity violating $\overline{UDD}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with 6 or 10 jets, originating from direct or indirect decays. Limits are obtained in the M_2 versus μ plane and a limit on the chargino mass is derived from a scan over the parameters m_0 and tanβ.

[88] ABREU 01G use data from $\sqrt{s}$= 183–202 GeV. They look for final states with two acoplanar leptons, expected in GMSB when the $\widetilde{\tau}_1$ is the NLSP and assuming a short-lived $\widetilde{\chi}_1^\pm$. Limits are obtained in the plane ($m_{\widetilde{\tau}}$,$m_{\widetilde{\chi}_1^\pm}$) for different domains of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays. The limit above is valid for all values of $m_{\widetilde{G}}$ provided $m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\tau}_1} \geq 0.3$ GeV. Stronger limits are obtained for larger $m_{\widetilde{G}}$ or when the sleptons are degenerate, see their Fig. 4. Supersedes the results of ABREU 00V.

[89] ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from $\not\!R$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}_1^0$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00C in a scan of the parameter space assuing MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 99I.

[90] BARATE 01B searches for the production of charginos in the case of $\not\!R$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189–202 GeV. The search is performed for indirect decays, assuming one coupling at a time to be nonzero. Updates BARATE 00H.

[91] This ABREU 00J limit holds for $\Delta m_+ > 10$ GeV and $m_{\widetilde{\nu}} > 300$ GeV. For the other assumptions, see previous footnote to ABREU 00J in this Section. A limit of 94.2 GeV is obtained for Δm_+=1 GeV and $m_{\widetilde{\nu}} > m_{\widetilde{\chi}^\pm}$. Updates ABREU 99E.

[92] ABREU 00U searches for the production of charginos and neutralinos in the case of R-parity violation with $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons or jets plus leptons, assuming one coupling to be nonzero at the time and giving rise to direct or indirect decays. LImits are obtained in the M_2

versus μ plane and a limit on the neutralino mass is derived from a scan over the parameters m_0 and $\tan\beta$. Supersedes the results of ABREU 00I.

[93] ABREU 00V use data from $\sqrt{s}$= 183–189 GeV. They look for final states with two acoplanar leptons, expected in GMSB when the $\widetilde{\tau}_1$ is the NLSP and assuming a short-lived $\widetilde{\chi}_1^\pm$. Limits are obtained in the plane ($m_{\widetilde{\tau}}$,$m_{\widetilde{\chi}_1^\pm}$) for different domains of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. The limit above is valid for all values of $m_{\widetilde{G}}$.

[94] CHO 00B studied constraints on the MSSM spectrum from precision EW observables. Global fits favour charginos with masses at the lower bounds allowed by direct searches. Allowing for variations of the squark and slepton masses does not improve the fits.

[95] ABBIENDI 99T searches for the production of neutralinos in the case of R-parity violation with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings using data from $\sqrt{s}$=183 GeV. They investigate topologies with mulitiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. Mixed decays (where one particle has a direct, the other an indirect decay) are also considered for the $\overline{UDD}$ couplings. Upper limits on the cross section are derived which, combined with the constraint from the Z^0 width, allow to exclude regions in the M_2 versus μ plane for any coupling. Limits on the chargino mass are obtained for non-zero $LL\overline{E}$ couplings $> 10^{-5}$ and assuming decays via a W^*.

[96] ABE 99I looked for chargino and neutralino production, where the lightest neutralino in their decay products further decays into $\gamma\widetilde{G}$. The limit assumes the gaugino mass unification, and holds for $1 < \tan\beta < 25$, $M_2 < 200$ GeV, and all μ. ABE 99I is an expanded version of ABE 98L.

[97] MALTONI 99B studied the effect of light chargino-neutralino to the electroweak precision data with a particular focus on the case where they are nearly degenerate ($\Delta m_+ \sim 1$ GeV) which is difficult to exclude from direct collider searches. The quoted limit is for higgsino-like case while the bound improves to 56 GeV for wino-like case. The values of the limits presented here are obtained in an update to MALTONI 99B, as described in MALTONI 00.

[98] ABBOTT 98 studied the chargino and neutralino production, where the lightest neutralino in their decay products further decays into $\gamma\widetilde{G}$. The limit assumes the gaugino mass unification.

[99] ABBOTT 98C searches for trilepton final states (ℓ=e,μ). Efficiencies are calculated using mass relations in the Minimal Supergravity scenario, exploring the domain of parameter space defined by $m_{\widetilde{\chi}_1^\pm}$=$m_{\widetilde{\chi}_2^0}$ and $m_{\widetilde{\chi}_1^\pm}$=$2m_{\widetilde{\chi}_1^0}$. Results are presented in Fig. 1 as upper bounds on $\sigma(p\overline{p} \to \widetilde{\chi}_1^\pm \widetilde{\chi}_2^0)\times$B($3\ell$). Assuming equal branching ratio for all possible leptonic decays, limits range from 2.6 pb ($m_{\widetilde{\chi}_1^\pm}$=45 GeV) to 0.4 pb ($m_{\widetilde{\chi}_1^\pm}$=124 GeV) at 95%CL. Assuming a negligible decay rate of $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ to quarks, this corresponds to $m_{\widetilde{\chi}_1^\pm} > 103$ GeV.

[100] ABE 98J searches for trilepton final states (ℓ=e,μ). Efficiencies are calculated using mass relations in the Minimal Supergravity scenario, exploring the domain of parameter space defined by $1.1 < \tan\beta < 8$, $-1000 < \mu(\text{GeV}) < -200$, and $m_{\widetilde{q}}/m_{\widetilde{g}}$=1–2. In this region $m_{\widetilde{\chi}_1^\pm} \sim m_{\widetilde{\chi}_2^0}$ and $m_{\widetilde{\chi}_1^\pm} \sim 2m_{\widetilde{\chi}_1^0}$. Results are presented in Fig. 1 as upper bounds on $\sigma(p\overline{p} \to \widetilde{\chi}_1^\pm \widetilde{\chi}_2^0)\times$B($3\ell$). Limits range from 0.8 pb ($m_{\widetilde{\chi}_1^\pm}$=50 GeV) to 0.23 pb ($m_{\widetilde{\chi}_1^\pm}$=100 GeV) at 95%CL. The gaugino mass unification hypothesis and the assumed mass relation between squarks and gluinos define the value of the leptonic branching ratios. The quoted result corresponds to the best limit within the selected

range of parameters, obtained for $m_{\widetilde{q}} > m_{\widetilde{g}}$, $\tan\beta$=2, and μ=−600 GeV. Mass limits for different values of $\tan\beta$ and μ are given in Fig. 2.

[101] ACKERSTAFF 98K looked for dilepton+$\not{E}_T$ final states at $\sqrt{s}$=130–172 GeV. Limits on $\sigma(e^+ e^- \rightarrow \widetilde{\chi}_1^+ \widetilde{\chi}_1^-) \times \mathrm{B}^2(\ell)$, with $\mathrm{B}(\ell)=\mathrm{B}(\chi^+ \rightarrow \ell^+ \nu_\ell \chi_1^0)$ ($\mathrm{B}(\ell)=\mathrm{B}(\chi^+ \rightarrow \ell^+ \widetilde{\nu}_\ell)$), are given in Fig. 16 (Fig. 17).

[102] ACKERSTAFF 98L limit is obtained for $0 < M_2 < 1500$, $|\mu| < 500$ and $\tan\beta > 1$, but remains valid outside this domain. The dependence on the trilinear-coupling parameter A is studied, and found neglibible. The limit holds for the smallest value of m_0 consistent with scalar lepton constraints (ACKERSTAFF 97H) and for all values of m_0 where the condition $\Delta m_{\widetilde{\nu}} > 2.0$ GeV is satisfied. $\Delta m_\nu > 10$ GeV if $\widetilde{\chi}^\pm \rightarrow \ell \widetilde{\nu}_\ell$. The limit improves to 84.5 GeV for m_0=1 TeV. Data taken at $\sqrt{s}$=130–172 GeV.

[103] ACKERSTAFF 98V excludes the light gluino with universal gaugino mass where charginos, neutralinos decay as $\widetilde{\chi}_1^\pm, \widetilde{\chi}_2^0 \rightarrow q\overline{q}\widetilde{g}$ from total hadronic cross sections at $\sqrt{s}$=130–172 GeV. See paper for the case of nonuniversal gaugino mass.

[104] CARENA 97 studied the constraints on chargino and sneutrino masses from muon $g-2$. The bound can be important for large $\tan\beta$.

[105] KALINOWSKI 97 studies the constraints on the chargino-neutralino parameter space from limits on $\Gamma(W \rightarrow \widetilde{\chi}_1^\pm \widetilde{\chi}_1^0)$ achievable at LEP2. This is relevant when $\widetilde{\chi}_1^\pm$ is "invisible," i.e., if $\widetilde{\chi}_1^\pm$ dominantly decays into $\widetilde{\nu}_\ell \ell^\pm$ with little energy for the lepton. Small otherwise allowed regions could be excluded.

[106] ABE 96K looked for tripleton events from chargino-neutralino production. The bound on $m_{\widetilde{\chi}_1^\pm}$ can reach up to 47 GeV for specific choices of parameters. The limits on the combined production cross section times 3-lepton branching ratios range between 1.4 and 0.4 pb, for $45 < m_{\widetilde{\chi}_1^\pm}(GeV)<100$. See the paper for more details on the parameter dependence of the results.

Long-lived $\widetilde{\chi}^\pm$ (Chargino) MASS LIMITS

Limits on charginos which leave the detector before decaying.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
none 2–93.0	95	[107] ABREU	00T	DLPH	$\widetilde{H}^\pm$ or $m_{\widetilde{\nu}} > m_{\widetilde{\chi}^\pm}$
>89.5	95	[108] ACKERSTAFF	98P	OPAL	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>83	95	[109] BARATE	97K	ALEP	
>28.2	95	ADACHI	90C	TOPZ	

[107] ABREU 00T searches for the production of heavy stable charged particles, identified by their ionization or Cherenkov radiation, using data from $\sqrt{s}$= 130 to 189 GeV. These limits include and update the results of ABREU 98P.

[108] ACKERSTAFF 98P bound assumes a heavy sneutrino $m_{\widetilde{\nu}} > 500$ GeV. Data collected at $\sqrt{s}$ = 130–183 GeV.

[109] BARATE 97K uses $e^+ e^-$ data collected at $\sqrt{s}$ = 130–172 GeV. Limit valid for $\tan\beta = \sqrt{2}$ and $m_{\widetilde{\nu}} > 100$ GeV. The limit improves to 86 GeV for $m_{\widetilde{\nu}} > 250$ GeV.

$\widetilde{\nu}$ (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 $\widetilde{\nu}_R$) is assumed to exist. It is possible that $\widetilde{\nu}$ could be the lightest supersymmetric particle (LSP).

We report here, but do not include in the Listings, the limits obtained from preliminary, unpublished constraints by the LEP Collaborations on the invisible width of the Z boson ($\Delta\Gamma_{\text{inv.}} < 2.0$ MeV, LEP 00): $m_{\widetilde{\nu}} > 43.7$ GeV ($N(\widetilde{\nu})$=1) and $m_{\widetilde{\nu}} > 44.7$ GeV ($N(\widetilde{\nu})$=3) .

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
$>$ 37.1	95	[110] ADRIANI 93M	L3	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1
$>$ 41	95	[111] DECAMP 92	ALEP	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=3
$>$ 36	95	ABREU 91F	DLPH	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1
$>$ 31.2	95	[112] ALEXANDER 91F	OPAL	$\Gamma(Z \rightarrow$ invisible); $N(\widetilde{\nu})$=1

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

$>$ 84	95	[113] BARATE 01B	ALEP	$\widetilde{\nu}_e$, $\not{R}$ decays, $\mu=-200$ GeV, $\tan\beta=2$
$>$ 64	95	[113] BARATE 01B	ALEP	$\widetilde{\nu}_{\mu,\tau}$, $\not{R}$ decays
		[114] ABBIENDI 00	OPAL	$\widetilde{\nu}_{e,\mu}$, $\not{R}$, $LL\overline{E}$ or $LQ\overline{D}$ decays
none 100–264	95	[115] ABBIENDI 00R	OPAL	$\widetilde{\nu}_{\mu,\tau}$, $\not{R}$, (s+t)-channel
none 100–200	95	[116] ABBIENDI 00R	OPAL	$\widetilde{\nu}_{\tau}$, $\not{R}$, s-channel
		[117] ABREU 00S	DLPH	$\widetilde{\nu}_{\ell}$, $\not{R}$, (s+t)-channel
$>$ 76.5	95	[118] ABREU 00U	DLPH	$\widetilde{\nu}_{\ell}$, $\not{R}$ ($LL\overline{E}$)
$>$ 61	95	[119] ABREU 00W	DLPH	all $\tan\beta \leq 40$, all m_0
none 50–210	95	[120] ACCIARRI 00P	L3	$\widetilde{\nu}_{\mu,\tau}$, $\not{R}$, s-channel
none 50–210	95	[121] BARATE 00I	ALEP	$\widetilde{\nu}_{\mu,\tau}$, $\not{R}$, (s+t)-channel
none 90–210	95	[122] BARATE 00I	ALEP	$\widetilde{\nu}_{\tau}$, $\not{R}$, s-channel
none 100–160	95	[123] ABBIENDI 99	OPAL	$\widetilde{\nu}_e$, $\not{R}$, t-channel
$\neq m_Z$	95	[124] ACCIARRI 97U	L3	$\widetilde{\nu}_{\tau}$, $\not{R}$, s-channel
none 125–180	95	[124] ACCIARRI 97U	L3	$\widetilde{\nu}_{\tau}$, $\not{R}$, s-channel
		[125] CARENA 97	THEO	$g_{\mu} - 2$
$>$ 46.0	95	[126] BUSKULIC 95E	ALEP	$N(\widetilde{\nu})$=1, $\widetilde{\nu} \rightarrow \nu\nu\ell\overline{\ell}'$
none 20–25000		[127] BECK 94	COSM	Stable $\widetilde{\nu}$, dark matter
<600		[128] FALK 94	COSM	$\widetilde{\nu}$ LSP, cosmic abundance
none 3–90	90	[129] SATO 91	KAMI	Stable $\widetilde{\nu}_e$ or $\widetilde{\nu}_{\mu}$, dark matter
none 4–90	90	[129] SATO 91	KAMI	Stable $\widetilde{\nu}_{\tau}$, dark matter

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

[111] DECAMP 92 limit is from $\Gamma(\text{invisible})/\Gamma(\ell\ell) = 5.91 \pm 0.15$ ($N_{\nu} = 2.97 \pm 0.07$).

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

[113] BARATE 01B searches for the production of sneutrinos in the case of $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189–202 GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be nonzero. The limit holds for indirect $\widetilde{\nu}$ decays via $\overline{UDD}$ couplings. Stronger limits are reached for ($\widetilde{\nu}_e$,$\widetilde{\nu}_{\mu,\tau}$) for $LL\overline{E}$ direct (98,86) GeV or indirect (94,83) GeV and for $LQ\overline{D}$ direct ($-$,77) GeV or indirect (89,75) GeV couplings. For $LL\overline{E}$ decays, use is made of the bound $m_{\widetilde{\chi}^0_1} > 23$ GeV from BARATE 98S. See also Fig. 3 for limits on $\widetilde{\nu}_{\mu,\tau}$ from s-channel production and indirect decay. Supersedes the results from BARATE 00H.

[114] ABBIENDI 00 searches for the production of sneutrinos in the case of R-parity violation with $LL\overline{E}$ or $LQ\overline{D}$ couplings, using data from $\sqrt{s}$=183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. For non-zero $LL\overline{E}$ couplings, they obtain limits on the electron sneutrino mass of 88 GeV for direct decays and of 87 GeV for indirect decays with a low mass χ_1^0. For non-zero $LQ\overline{D}$ couplings, the limits are 86 GeV for indirect decays of $\widetilde{\nu}_e$ with a low mass χ_1^0 and 80 GeV for direct decays of $\widetilde{\nu}_e$. There exists a region of small Δm, of varying size, for which no limit is obtained, see Fig. 20. It is assumed that $\tan\beta$=1.5 and μ=$-$200 GeV. For muon sneutrinos, direct decays via $LL\overline{E}$ couplings lead to a 66 GeV mass limit and via $LQ\overline{D}$ couplings to a 58 GeV limit.

[115] ABBIENDI 00R studied the effect of s- and t-channel τ or μ sneutrino exchange in $e^+e^- \rightarrow e^+e^-$ at $\sqrt{s}$=130–189 GeV, via the R-parity violating coupling $\lambda_{1i1}L_1L_ie_1$ (i=2 or 3). The limits quoted here hold for λ_{1i1} >0.13, and supersede the results of ABBIENDI 99. See Fig. 11 for limits on $m_{\widetilde{\nu}}$ versus coupling.

[116] ABBIENDI 00R studied the effect of s-channel τ sneutrino exchange in $e^+e^- \rightarrow \mu^+\mu^-$ at $\sqrt{s}$=130–189 GeV, in presence of the R-parity violating couplings $\lambda_{i3i}L_iL_3e_i$ (i=1 and 2), with λ_{131}=λ_{232}. The limits quoted here hold for $\lambda_{131} > 0.09$, and supersede the results of ABBIENDI 99. See Fig. 12 for limits on $m_{\widetilde{\nu}}$ versus coupling.

[117] ABREU 00S searches for anomalies in the production cross sections and forward-backward asymmetries of the $\ell^+\ell^-(\gamma)$ final states (ℓ=e,μ,τ) from e^+e^- collisions at $\sqrt{s}$=130–189 GeV. Limits are set on the s- and t-channel exchange of sneutrinos in the presence of $\not{R}$ with $\lambda LL\overline{E}$ couplings. For points between the energies at which data were taken, information is obtained from events in which a photon was radiated. Exclusion limits in the (λ,$m_{\widetilde{\nu}}$) plane are given in Fig. 5. These limits include and update the results of ABREU 99A.

[118] ABREU 00U searches for the pair production of sneutrinos with a decay involving R-parity violating $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons, assuming one coupling to be nonzero at the time and giving rise to direct or indirect decays. The limits, valid for each individual flavor, are determined by the indirect decays and assume a neutralino mass limit of 30 GeV, also derived in ABREU 00U. Better limits for specific flavors and for specific $\not{R}$ couplings can be obtained and are discussed in the paper. Supersedes the results of ABREU 00I.

[119] ABREU 00W combines data collected at $\sqrt{s}$=189 GeV with results from lower energies. The mass limit is obtained by constraining the MSSM parameter space with gaugino and sfermion mass universality at the GUT scale, using the results of negative direct searches for neutralinos (including cascade decays and $\widetilde{\tau}\tau$ final states) from ABREU 01, for charginos from ABREU 00J and ABREU 00T (for all Δm_+), and for charged sleptons from ABREU 01B. The results hold for the full parameter space defined by all values of M_2 and $|\mu| \leq 2$ TeV with the $\widetilde{\chi}_1^0$ as LSP.

[120] ACCIARRI 00P use the dilepton total cross sections and asymmetries at $\sqrt{s}$=m_Z and $\sqrt{s}$=130–189 GeV data to set limits on the effect of $\not{R}$ $LL\overline{E}$ couplings giving rise to μ or τ sneutrino exchange. See their Fig. 5 for limits on the sneutrino mass versus couplings.

[121] BARATE 00I studied the effect of s-channel and t-channel τ or μ sneutrino exchange in $e^+e^- \rightarrow e^+e^-$ at $\sqrt{s}$= 130–183 GeV, via the R-parity violating coupling $\lambda_{1i1}L_1L_ie_1^c$ (i=2 or 3). The limits quoted here hold for $\lambda_{1i1} > 0.1$. See their Fig. 15 for limits as a function of the coupling.

[122] BARATE 00I studied the effect of s-channel τ sneutrino exchange in $e^+e^- \rightarrow \mu^+\mu^-$ at $\sqrt{s}$= 130–183 GeV, in presence of the R-parity violating coupling $\lambda_{i3i}L_iL_3e_i^c$ (i=1 and 2). The limits quoted here hold for $\sqrt{|\lambda_{131}\lambda_{232}|} > 0.2$. See their Fig. 16 for limits as a function of the coupling.

[123] ABBIENDI 99 studied the effect of t-channel electron sneutrino exchange in $e^+e^- \rightarrow \tau^+\tau^-$ at $\sqrt{s}$=130–183 GeV, in presence of the R-parity violating couplings $\lambda_{131}L_1L_3e_1^c$. The limits quoted here hold for $\lambda_{131} > 0.6$.

[124] ACCIARRI 97U studied the effect of the *s*-channel tau-sneutrino exchange in $e^+e^- \to e^+e^-$ at $\sqrt{s}=m_Z$ and $\sqrt{s}$=130–172 GeV, via the *R*-parity violating coupling $\lambda_{131}L_1L_ie_1^c$. The limits quoted here hold for $\lambda_{131} > 0.05$. Similar limits were studied in $e^+e^- \to \mu^+\mu^-$ together with $\lambda_{232}L_2L_3e_2^c$ coupling.

[125] CARENA 97 studied the constraints on chargino and sneutrino masses from muon $g-2$. The bound can be important for large tanβ.

[126] BUSKULIC 95E looked for $Z \to \widetilde{\nu}\overline{\widetilde{\nu}}$, where $\widetilde{\nu} \to \nu\chi_1^0$ and χ_1^0 decays via *R*-parity violating interactions into two leptons and a neutrino.

[127] 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.

[128] 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.

[129] 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.

CHARGED SLEPTONS

This section contains limits on charged scalar leptons ($\widetilde{\ell}$, with ℓ=e,μ,τ). Studies of width and decays of the Z boson (use is made here of $\Delta\Gamma_{\text{inv}} < 2.0$ MeV, LEP 00) conclusively rule out $m_{\widetilde{\ell}_R} < 40$ GeV (41 GeV for $\widetilde{\ell}_L$) , independently of decay modes, for each individual slepton. The limits improve to 43 GeV (43.5 GeV for $\widetilde{\ell}_L$) assuming all 3 flavors to be degenerate. Limits on higher mass sleptons depend on model assumptions and on the mass splitting $\Delta m = m_{\widetilde{\ell}} - m_{\widetilde{\chi}_1^0}$. The mass and composition of $\widetilde{\chi}_1^0$ may affect the selectron production rate in e^+e^- collisions through *t*-channel exchange diagrams. Production rates are also affected by the potentially large mixing angle of the lightest mass eigenstate $\widetilde{\ell}_1$=$\widetilde{\ell}_R$ sinθ_ℓ + $\widetilde{\ell}_L$ cosθ_ℓ. It is generally assumed that only $\widetilde{\tau}$ may have significant mixing. The coupling to the Z vanishes for θ_ℓ=0.82. In the high-energy limit of e^+e collisions the interference between γ and Z exchange leads to a minimal cross section for θ_ℓ=0.91, a value which is sometimes used in the following entries relative to data taken at LEP2. When limits on $m_{\widetilde{\ell}_R}$ are quoted, it is understood that limits on $m_{\widetilde{\ell}_L}$ are usually at least as strong.

Possibly open decays involving gauginos other than $\widetilde{\chi}_1^0$ will affect the detection efficiencies. Unless otherwise stated, the limits presented here result from the study of $\widetilde{\ell}^+\widetilde{\ell}^-$ production, with production rates and decay properties derived from the MSSM. Limits made obsolete by the recent analyses of e^+e^- collisions at energies above 161 GeV have been removed from this compilation, and can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this Review.

For decays with final state gravitinos ($\widetilde{G}$), $m_{\widetilde{G}}$ is assumed to be negligible relative to all other masses.

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
none 30–87	95	[130] ABREU 01	DLPH	$\Delta m > 20$ GeV, $\tilde{e}^+_R \tilde{e}^-_R$
>92	95	[131] BARATE 01	ALEP	$\Delta m > 10$ GeV, $\tilde{e}^+_R \tilde{e}^-_R$
>87.1	95	[132] ABBIENDI 00G	OPAL	$\Delta m > 5$ GeV, $\tilde{e}^+_R \tilde{e}^-_R$
>85.0	95	[133] ACCIARRI 99W	L3	$\Delta m > 7$ GeV, $\tilde{e}^+_R \tilde{e}^-_R$

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
>88.5	95	[134] BARATE 01B	ALEP	$\tilde{e}_R$, $\not{R}$ decays, $\mu = -200$ GeV, $\tan\beta = 2$
>72	95	[135] ABBIENDI 00	OPAL	$\tilde{e}^+_R \tilde{e}^-_R$, $\not{R}$, light $\tilde{\chi}^0_1$
>77	95	[136] ABBIENDI 00J	OPAL	$\Delta m > 5$ GeV, $\tilde{e}^+_R \tilde{e}^-_R$
>83	95	[137] ABREU 00U	DLPH	$\tilde{e}_R$, $\not{R}$ $(LL\overline{E})$
>67	95	[138] ABREU 00V	DLPH	$\tilde{e}_R \tilde{e}_R$ ($\tilde{e}_R \rightarrow e\tilde{G}$), $m_{\tilde{G}} > 10$ eV
>87	95	[139] ABREU 00W	DLPH	$1 \leq \tan\beta \leq 40$, $\Delta m > 10$ GeV, all m_0
>85	95	[140] BARATE 00G	ALEP	$\tilde{\ell}_R \rightarrow \ell\tilde{G}$, any $\tau(\tilde{\ell}_R)$
>29.5	95	[141] ACCIARRI 99I	L3	$\tilde{e}_R$, $\not{R}$, $\tan\beta \geq 2$
>56	95	[142] ACCIARRI 98F	L3	$\Delta m > 5$ GeV, $\tilde{e}^+_R \tilde{e}^-_R$, $\tan\beta \geq 1.41$
>77	95	[143] BARATE 98K	ALEP	Any Δm, $\tilde{e}^+_R \tilde{e}^-_R$, $\tilde{e}_R \rightarrow e\gamma\tilde{G}$
>77	95	[144] BREITWEG 98	ZEUS	$m_{\tilde{q}} = m_{\tilde{e}}$, $m(\tilde{\chi}^0_1) = 40$ GeV
>63	95	[145] AID 96C	H1	$m_{\tilde{q}} = m_{\tilde{e}}$, $m_{\tilde{\chi}^0_1} = 35$ GeV

[130] ABREU 01 looked for acoplanar dielectron + $\not{E}$ final states at $\sqrt{s} = 130$–189 GeV. The limit assumes $\mu = -200$ GeV and $\tan\beta = 1.5$ in the calculation of the production cross section, and B($\tilde{e} \rightarrow e\tilde{\chi}^0_1$)=100%. See Fig. 8a for limits in the ($m_{\tilde{e}_R}$,$m_{\tilde{\chi}^0_1}$) plane. These limits include and update the results of ABREU 99C.

[131] BARATE 01 looked for acoplanar dielectron + $\not{E}_T$ final states at 189 to 202 GeV. The limit assumes $\mu = -200$ GeV and $\tan\beta = 2$ for the production cross section and 100% branching ratio for $\tilde{e} \rightarrow e\tilde{\chi}^0_1$. See their Fig. 1 for the dependence of the limit on Δm. These limits include and update the results of BARATE 99Q.

[132] ABBIENDI 00G looked for acoplanar dielectron + $\not{E}_T$ final states at $\sqrt{s} = 183$–189 GeV. The limit assumes $\mu < -100$ GeV and $\tan\beta = 1.5$ for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\tilde{e} \rightarrow e\tilde{\chi}^0_1$. See their Fig. 14 for the dependence of the limit on Δm and $\tan\beta$. Updates ABBIENDI 00J.

[133] ACCIARRI 99W looked for acoplanar dielectron $\not{E}_T$ final states at $\sqrt{s} = 130$–189 GeV. The limit assumes $\mu = -200$ GeV and $\tan\beta = \sqrt{2}$ for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\tilde{e} \rightarrow e\tilde{\chi}^0_1$. The scan of parameter space, covering the region $1 < \tan\beta < 60$, $M_2 < 2$ TeV, $|\mu| < 2$ TeV, $m_0 < 500$ GeV, leads to an absolute lower limit of 65.5 GeV. See their Figs. 5–6 for the dependence of the limit on Δm and $\tan\beta$. Updates ACCIARRI 99H.

[134] BARATE 01B searches for the production of selectrons in the case of $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s} = 189$–202 GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be nonzero. The limit holds for indirect decays mediated by $\overline{UDD}$ couplings with $\Delta m > 10$ GeV. Limits are also given for $LL\overline{E}$ direct ($m_{\tilde{e}_R} > 92$ GeV) and indirect decays ($m_{\tilde{e}_R} > 93$ GeV for $m_{\tilde{\chi}^0_1} > 23$ GeV from BARATE 98S) and for $LQ\overline{D}$ indirect decays ($m_{\tilde{e}_R} > 89$ GeV with $\Delta m > 10$ GeV). Supersedes the results from BARATE 00H.

[135] ABBIENDI 00 searches for the production of selectrons in the case of R-parity violation with $LL\overline{E}$ or $LQ\overline{D}$ couplings, using data from $\sqrt{s}$=183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. For non-zero $LL\overline{E}$ couplings, they obtain limits on the selectron mass of 84 GeV both for direct decays and for indirect decays with a low mass $\widetilde{\chi}^0_1$. For non-zero $LQ\overline{D}$ couplings, the limits are 72 GeV for indirect decays of $\widetilde{e}_R$ with a low mass $\widetilde{\chi}^0_1$ and 76 GeV for direct decays of $\widetilde{e}_L$. It is assumed that tanβ=1.5 and μ=−200 GeV.

[136] ABBIENDI 00J looked for acoplanar dielectron + $\not\!\!E_T$ final states at $\sqrt{s}$= 161–183 GeV. The limit assumes $\mu < -100$ GeV and tanβ=1.5 for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\widetilde{e} \to e\widetilde{\chi}^0_1$. See their Fig. 12 for the dependence of the limit on Δm and tanβ.

[137] ABREU 00U studies decays induced by R-parity violating $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons, assuming one coupling at the time to be nonzero and giving rise to indirect decays. The limits assume a neutralino mass limit of 30 GeV, also derived in ABREU 00U. Updates ABREU 00I.

[138] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as a function of $m_{\widetilde{G}}$, from a scan of the GMSB parameters space, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

[139] ABREU 00W combines data collected at $\sqrt{s}$=189 GeV with results from lower energies. The mass limit is obtained by constraining the MSSM parameter space with gaugino and sfermion mass universality at the GUT scale, using the results of negative direct searches for neutralinos (including cascade decays and $\widetilde{\tau}\tau$ final states) from ABREU 01, for charginos from ABREU 00J and ABREU 00T (for all Δm_+), and for charged sleptons from ABREU 01B. The results hold for the full parameter space defined by all values of M_2 and $|\mu| \leq 2$ TeV with the $\widetilde{\chi}^0_1$ as LSP.

[140] BARATE 00G combines the search for acoplanar dileptons, leptons with large impact parameters, kinks, and stable heavy-charged tracks, assuming 3 flavors of degenerate sleptons, produced in the s channel. Data colleced at $\sqrt{s}$=189 GeV.

[141] ACCIARRI 99I establish indirect limits on $m_{\widetilde{e}_R}$ from the regions excluded in the M_2 versus m_0 plane by their chargino and neutralino searches at $\sqrt{s}$=130–183 GeV. The situations where the $\widetilde{\chi}^0_1$ is the LSP (indirect decays) and where a $\widetilde{\ell}$ is the LSP (direct decays) were both considered. The weakest limit, quoted above, comes from direct decays with $\overline{UDD}$ couplings; $LL\overline{E}$ couplings or indirect decays lead to a stronger limit.

[142] ACCIARRI 98F looked for acoplanar dielectron+$\not\!\!E_T$ final states at $\sqrt{s}$=130–172 GeV. The limit assumes μ=−200 GeV, and zero efficiecny for decays other than $\widetilde{e}_R \to e\widetilde{\chi}^0_1$. See their Fig. 6 for the dependence of the limit on Δm.

[143] BARATE 98K looked for $e^+e^-\gamma\gamma + \not\!\!E$ final states at $\sqrt{s}$= 161–184 GeV. The limit assumes μ=−200 GeV and tanβ=2 for the evaluation of the production cross section. See Fig. 4 for limits on the $(m_{\widetilde{e}_R}, m_{\widetilde{\chi}^0_1})$ plane and for the effect of cascade decays.

[144] BREITWEG 98 used positron+jet events with missing energy and momentum to look for $e^+ q \to \widetilde{e}\widetilde{q}$ via gaugino-like neutralino exchange with decays into $(e\widetilde{\chi}^0_1)(q\widetilde{\chi}^0_1)$. See paper for dependences in $m(\widetilde{q})$, $m(\widetilde{\chi}^0_1)$.

[145] AID 96C used positron+jet events with missing energy and momentum to look for $e^+ q \to \widetilde{e}\widetilde{q}$ via neutralino exchange with decays into $(e\widetilde{\chi}^0_1)(q\widetilde{\chi}^0_1)$. See the paper for dependences on $m_{\widetilde{q}}$, $m_{\widetilde{\chi}^0_1}$.

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
none 30–80	95	[146] ABREU 01	DLPH	$\Delta m > 5$ GeV, $\widetilde{\mu}^+_R \widetilde{\mu}^-_R$
>85	95	[147] BARATE 01	ALEP	$\Delta m > 10$ GeV, $\widetilde{\mu}^+_R \widetilde{\mu}^-_R$
>82.3	95	[148] ABBIENDI 00G	OPAL	$\Delta m > 3$ GeV, $\widetilde{\mu}^+_R \widetilde{\mu}^-_R$
>76.6	95	[149] ACCIARRI 99W	L3	$\Delta m > 5$ GeV, $\widetilde{\mu}^+_R \widetilde{\mu}^-_R$

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
>81	95	[150] BARATE 01B	ALEP	$\widetilde{\mu}_R$, $\not{R}$ decays
>50	95	[151] ABBIENDI 00	OPAL	$\widetilde{\mu}^+_R \widetilde{\mu}^-_R$, $\not{R}$, $\Delta m > 5$ GeV
>65	95	[152] ABBIENDI 00J	OPAL	$\Delta m >2$ GeV, $\widetilde{\mu}^+_R \widetilde{\mu}^-_R$
>83	95	[153] ABREU 00U	DLPH	$\widetilde{\mu}_R$, $\not{R}$ ($LL\overline{E}$)
>80	95	[154] ABREU 00V	DLPH	$\widetilde{\mu}_R \widetilde{\mu}_R$ ($\widetilde{\mu}_R \rightarrow \mu \widetilde{G}$), $m_{\widetilde{G}} >8$ eV
>77	95	[155] BARATE 98K	ALEP	Any Δm, $\widetilde{\mu}^+_R \widetilde{\mu}^-_R$, $\widetilde{\mu}_R \rightarrow \mu \gamma \widetilde{G}$

[146] ABREU 01 looked for acoplanar dimuon + $\not{E}$ final states at $\sqrt{s}$=130–189 GeV. The limit assumes B($\widetilde{\mu} \rightarrow \mu \widetilde{\chi}^0_1$)=100%. See Fig. 8b for limits on the ($m_{\widetilde{\mu}_R}$,$m_{\widetilde{\chi}^0_1}$) plane. These limits include and update the results of ABREU 99C.

[147] BARATE 01 looked for acoplanar dimuon + $\not{E}_T$ final states at 189 to 202 GeV. The limit assumes 100% branching ratio for $\widetilde{\mu} \rightarrow \mu \widetilde{\chi}^0_1$. See their Fig. 1 for the dependence of the limit on Δm. These limits include and update the results of BARATE 99Q.

[148] ABBIENDI 00G looked for acoplanar dimuon + $\not{E}_T$ final states at $\sqrt{s}$=183–189 GeV. The limit assumes B($\widetilde{\mu} \rightarrow \mu \widetilde{\chi}^0_1$)=1. Using decay branching ratios derived from the MSSM, a lower limit of 81.7 GeV is obtained for $\mu < -100$ GeV and tanβ=1.5. See their Figs. 12 and 15 for the dependence of the limits on the branching ratio and on Δm.

[149] ACCIARRI 99W looked for acoplanar dimuon + $\not{E}_T$ final states at $\sqrt{s}$=189 GeV. The limit assumes μ=$-$200 GeV and tanβ=$\sqrt{2}$ and zero efficiency for decays other than $\widetilde{\mu} \rightarrow \mu \widetilde{\chi}^0_1$. See their Fig. 5 for the dependence of the limit on Δm and tanβ.

[150] BARATE 01B searches for the production of smuons in the case of $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189–202 GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be nonzero. The limit holds for direct decays mediated by $\not{R}$ $LL\overline{E}$ couplings and improves to 92 GeV for indirect decays (for $m_{\widetilde{\chi}^0_1} > 23$ GeV from BARATE 98S). Limits are also given for $LQ\overline{D}$ direct ($m_{\widetilde{\mu}_L} > 79$ GeV) and indirect decays ($m_{\widetilde{\mu}_R} > 86$ GeV) and for $\overline{UDD}$ indirect decays ($m_{\widetilde{\mu}_R} > 82.5$ GeV), assuming $\Delta m >$10 GeV for the indirect decays. Supersedes the results from BARATE 00H.

[151] ABBIENDI 00 searches for the production of smuons in the case of R-parity violation with $LL\overline{E}$ or $LQ\overline{D}$ couplings, using data from $\sqrt{s}$=183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. For non-zero $LL\overline{E}$ couplings, they obtain limits on the smuon mass of 66 GeV for direct decays and of 74 GeV for indirect decays with a low mass $\widetilde{\chi}^0_1$. For non-zero $LQ\overline{D}$ couplings, the limits are 50 GeV for indirect decays of $\widetilde{\mu}_R$ with a low mass $\widetilde{\chi}^0_1$ and 64 GeV for direct decays of $\widetilde{\mu}_L$. It is assumed that tanβ=1.5 and μ=$-$200 GeV.

[152] ABBIENDI 00J looked for acoplanar dimuon + $\not{E}_T$ final states at $\sqrt{s}$= 161–183 GeV. The limit assumes B($\widetilde{\mu} \rightarrow \mu \widetilde{\chi}^0_1$)=1. Using decay branching ratios derived from the MSSM, a lower limit of 65 GeV is obtained for $\mu < -100$ GeV and tanβ=1.5. See their Figs. 10 and 13 for the dependence of the limit on the branching ratio and on Δm.

[153] ABREU 00U studies decays induced by R-parity violating $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons, assuming one coupling at the time to be nonzero and giving rise to indirect decays. The limits, valid for each individual flavor, assume a neutralino mass limit of 30 GeV, also derived in ABREU 00U. Updates ABREU 00I.

[154] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

[155] BARATE 98K looked for $\mu^+\mu^-\gamma\gamma + \not\!\!E$ final states at $\sqrt{s}$= 161–184 GeV. See Fig. 4 for limits on the ($m_{\widetilde{\mu}_R}$,$m_{\widetilde{\chi}^0_1}$) plane and for the effect of cascade decays.

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
none 12.5–73	95	[156] ABREU 01	DLPH	$\Delta m >$ 10 GeV, all θ_τ
none m_τ − 12.5	95	[156] ABREU 01	DLPH	$\Delta m > m_\tau$, all θ_τ
>70	95	[157] BARATE 01	ALEP	$\Delta m >$ 10 GeV, $\theta_\tau=\pi/2$
>68	95	[157] BARATE 01	ALEP	$\Delta m >$ 10 GeV, θ_τ=0.91
>81.0	95	[158] ABBIENDI 00G	OPAL	$\Delta m >$ 8 GeV, $\theta_\tau=\pi/2$
>71.5	95	[159] ACCIARRI 99W	L3	$\Delta m >$ 12 GeV, $\theta_\tau=\pi/2$
>60	95	[159] ACCIARRI 99W	L3	8 < Δm < 42 GeV, θ_τ=0.91
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>75	95	[160] ABREU 01G	DLPH	$\widetilde{\tau}_R \to \tau\widetilde{G}$, all $\tau(\widetilde{\tau}_R)$
>73	95	[161] BARATE 01B	ALEP	$\widetilde{\tau}_R$, $\not\!R$ decays
>66	95	[162] ABBIENDI 00	OPAL	$\widetilde{\tau}^+_R\widetilde{\tau}^-_R$, $\not\!R$, light $\widetilde{\chi}^0_1$
>64	95	[163] ABBIENDI 00J	OPAL	$\Delta m >$10 GeV, $\widetilde{\tau}^+_R\widetilde{\tau}^-_R$
>83	95	[164] ABREU 00U	DLPH	$\widetilde{\tau}_R$, $\not\!R$ ($LL\overline{E}$)
>84	95	[165] ABREU 00V	DLPH	$\widetilde{\ell}_R\widetilde{\ell}_R$ ($\widetilde{\ell}_R \to \ell\widetilde{G}$), $m_{\widetilde{G}}$ >9 eV
>73	95	[166] ABREU 00V	DLPH	$\widetilde{\tau}_1\widetilde{\tau}_1$ ($\widetilde{\tau}_1 \to \tau\widetilde{G}$), all $\tau(\widetilde{\tau}_1)$
>67	95	[167] BARATE 00G	ALEP	$\widetilde{\tau}_R \to \tau\widetilde{G}$, any $\tau(\widetilde{\tau}_R)$
>52	95	[168] BARATE 98K	ALEP	Any Δm, $\theta_\tau=\pi/2$, $\widetilde{\tau}_R \to \tau\gamma\widetilde{G}$

[156] ABREU 01 looked for acoplanar ditaus + $\not\!\!E$ final states at $\sqrt{s}$=130–189 GeV. A dedicated search was made for low-mass $\widetilde{\tau}$s decoupling from the Z^0. The limit assumes B($\widetilde{\tau} \to \tau\widetilde{\chi}^0_1$)=100%. See Figs. 8c and 8d for limits on the ($m_{\widetilde{\tau}}$,$m_{\widetilde{\chi}^0_1}$) plane and as a function of the mixing angle. The limit in the high-mass region improves to 75 GeV for $\widetilde{\tau}_R$. These limits include and update the results of ABREU 99C.

[157] BARATE 01 looked for acoplanar ditau + $\not\!\!E_T$ final states at 189 to 202 GeV. A slight excess (with 1.2% probability) of events is observed relative to the expected SM background. The limit assumes 100% branching ratio for $\widetilde{\tau} \to \tau\widetilde{\chi}^0_1$. See their Fig. 1 for the dependence of the limit on Δm. These limits include and update the results of BARATE 99Q.

[158] ABBIENDI 00G looked for acoplanar ditau + $\not\!\!E_T$ final states at $\sqrt{s}$=183–189 GeV. The limit assumes B($\widetilde{\tau} \to \tau\widetilde{\chi}^0_1$)=1. Using decay branching ratios derived from the MSSM, a lower limit of 75.9 at $\Delta m >$ 7 GeV is obtained for $\mu < -100$ GeV and tanβ=1.5. See their Figs. 13 and 16 for the dependence of the limits on the branching ratio and on Δm.

[159] ACCIARRI 99W looked for acoplanar ditau + $\not\!\!E_T$ final states at $\sqrt{s}$=189 GeV. See their Fig. 5 for the dependence of the limit on Δm and tanβ.

[160] ABREU 01G use data from $\sqrt{s}$= 130–202 GeV to search for tracks with large impact parameter or visible decay vertices and for heavy-charged stable particles. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays. The above limit is reached for the stau decaying promptly and would be reduced by about 1 GeV for stau mixing yielding the minimal cross section. Stronger limits are obtained for longer lifetimes, see their Fig. 3. Supersedes the results of ABREU 00V.

[161] BARATE 01B searches for the production of staus in the case of $\not{R}$ prompt decays with $LL\overline{E}$ or $LQ\overline{D}$ couplings at $\sqrt{s}$=189–202 GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be nonzero. The limit holds for indirect decays mediated by $\not{R}$ $LQ\overline{D}$ couplings with $\Delta m > 10$ GeV. Limits are also given for $LL\overline{E}$ direct ($m_{\widetilde{\tau}_R} > 81$ GeV) and indirect decays ($m_{\widetilde{\tau}_R} > 91$ GeV for $m_{\widetilde{\chi}^0_1} > 23$ GeV from BARATE 98S. Supersedes the results from BARATE 00H.

[162] ABBIENDI 00 searches for the production of staus in the case of R-parity violation with $LL\overline{E}$ or $LQ\overline{D}$ couplings, using data from $\sqrt{s}$=183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. For non-zero $LL\overline{E}$ couplings, they obtain limits on the stau mass of 66 GeV both for direct decays and for indirect decays with a low mass χ^0_1. For non-zero $LQ\overline{D}$ couplings, the limits are 66 GeV for indirect decays of $\widetilde{\tau}_R$ with a low mass χ^0_1 and 63 GeV for direct decays of $\widetilde{\tau}_L$. It is assumed that tanβ=1.5 and μ=$-$200 GeV.

[163] ABBIENDI 00J looked for acoplanar ditau + $\not{E}_T$ final states at $\sqrt{s}$= 161–183 GeV. The limit assumes B($\widetilde{\tau} \rightarrow \tau\widetilde{\chi}^0_1$)=1. Using decay branching ratios derived from the MSSM, a lower limit of 60 GeV at $\Delta m >$9 GeV is obtained for $\mu < -100$ GeV and tanβ=1.5. See their Figs. 11 and 14 for the dependence of the limit on the branching ratio and on Δm.

[164] ABREU 00U studies decays induced by R-parity violating $LL\overline{E}$ couplings, using data from $\sqrt{s}$=189 GeV. They investigate topologies with multiple leptons, assuming one coupling at the time to be nonzero and giving rise to indirect decays. The limits, valid for each individual flavor, assume a neutralino mass limit of 30 GeV, also derived in ABREU 00U. Updates ABREU 00I.

[165] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. The above limit assumes the degeneracy of stau and smuon. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

[166] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. The above limit is reached for the stau mixing yielding the minimal cross section and decaying promptly. Stronger limits are obtained for longer lifetimes or for $\widetilde{\tau}_R$; see their Fig. 11. For $10 \leq m_{\widetilde{G}} \leq 310$ eV, the whole range $2 \leq m_{\widetilde{\tau}_1} \leq 80$ GeV is excluded. Supersedes the results of ABREU 99C and ABREU 99F.

[167] BARATE 00G combines the search for acoplanar ditaus, taus with large impact parameters, kinks, and stable heavy-charged tracks. Staus are also looked for in the decay chain $\widetilde{\chi}^0_1 \rightarrow \widetilde{\tau}\tau \rightarrow \tau\tau\widetilde{G}$; see paper for results. Data colleced at $\sqrt{s}$=189 GeV.

[168] BARATE 98K looked for $\tau^+\tau^-\gamma\gamma + \not{E}$ final states at $\sqrt{s}$= 161–184 GeV. See Fig. 4 for limits on the ($m_{\widetilde{\tau}_R}$,$m_{\widetilde{\chi}^0_1}$) plane and for the effect of cascade decays.

Degenerate Charged Sleptons

Unless stated otherwise in the comment lines or in the footnotes, the following limits assume 3 families of degenerate charged sleptons.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>93	95	[169] BARATE	01	ALEP	$\Delta m > 10$ GeV, $\widetilde{\ell}^+_R \widetilde{\ell}^-_R$
>70	95	[169] BARATE	01	ALEP	all Δm, $\widetilde{\ell}^+_R \widetilde{\ell}^-_R$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>83	95	[170] ABBIENDI	01	OPAL	$e^+ e^- \rightarrow \widetilde{\ell}_1 \widetilde{\ell}_1$, GMSB, $\tan\beta=2$
		[171] ABREU	01	DLPH	$\widetilde{\ell} \rightarrow \ell \widetilde{\chi}^0_2$, $\widetilde{\chi}^0_2 \rightarrow \gamma \widetilde{\chi}^0_1$, $\ell=e,\mu$
>80	95	[172] ABREU	01G	DLPH	$\widetilde{\ell}_R \rightarrow \ell \widetilde{G}$, all $\tau(\widetilde{\ell}_R)$
>68.8	95	[173] ACCIARRI	01	L3	$\widetilde{\ell}_R$, $\not{R}$, $0.7 \leq \tan\beta \leq 40$
>84	95	[174,175] ABREU	00V	DLPH	$\widetilde{\ell}_R \widetilde{\ell}_R$ ($\widetilde{\ell}_R \rightarrow \ell \widetilde{G}$), $m_{\widetilde{G}} > 9$ eV

[169] BARATE 01 looked for acoplanar dilepton + $\not{E}_T$ and single electron (for $\widetilde{e}_R \widetilde{e}_L$) final states at 189 to 202 GeV. The limit assumes $\mu=-200$ GeV and $\tan\beta=2$ for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\widetilde{\ell} \rightarrow \ell \widetilde{\chi}^0_1$. The slepton masses are determined from the GUT relations without stau mixing. See their Fig. 1 for the dependence of the limit on Δm.

[170] ABBIENDI 01 looked for final states with $\gamma\gamma\not{E}$, $\ell\ell\not{E}$, with possibly additional activity and four leptons + $\not{E}$ to search for prompt decays of $\widetilde{\chi}^0_1$ or $\widetilde{\ell}_1$ in GMSB. They derive limits in the plane ($m_{\widetilde{\chi}^0_1}$,$m_{\widetilde{\tau}_1}$), see Fig. 6, allowing either the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}_1$ to be the NLSP. Two scenarios are considered: $\tan\beta=2$ with the 3 sleptons degenerate in mass and $\tan\beta=20$ where the $\widetilde{\tau}_1$ is lighter than the other sleptons. Data taken at $\sqrt{s}$=189 GeV. For $\tan\beta=20$, the obtained limits are $m_{\widetilde{\tau}_1} > 69$ GeV and $m_{\widetilde{e}_1,\widetilde{\mu}_1} > 88$ GeV.

[171] ABREU 01 looked for acoplanar dilepton + diphoton + $\not{E}$ final states from $\widetilde{\ell}$ cascade decays at $\sqrt{s}$=130–189 GeV. See Fig. 9 for limits on the (μ,M_2) plane for $m_{\widetilde{\ell}}$=80 GeV, $\tan\beta=1.0$, and assuming degeneracy of $\widetilde{\mu}$ and $\widetilde{e}$.

[172] ABREU 01G use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices and for heavy-charged stable particles. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays. The above limit is reached for prompt decays and assumes the degeneracy of the sleptons. For limits at differerent $m_{\widetilde{G}}$, see their Fig. 3. Supersedes the results of ABREU 00V.

[173] ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from $\not{R}$ prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or $\overline{UDD}$ couplings at $\sqrt{s}$=189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00C in a scan of the parameter space assuing MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 99I.

[174] ABREU 00V use data from $\sqrt{s}$= 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

[175] The above limit assumes the degeneracy of stau and smuon.

Long-lived $\widetilde{\ell}$ (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. Selectron limits from e^+e^- collisions in the continuum depend on MSSM parameters because of the additional neutralino exchange contribution.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
none 2–87.5	95	[176] ABREU	00Q	DLPH	$\widetilde{\mu}_R$, $\widetilde{\tau}_R$
>81.2	95	[177] ACCIARRI	99H	L3	$\widetilde{\mu}_R$, $\widetilde{\tau}_R$
>82.5	95	[178] ACKERSTAFF	98P	OPAL	$\widetilde{\mu}_R$, $\widetilde{\tau}_R$
>81	95	[179] BARATE	98K	ALEP	$\widetilde{\mu}_R$, $\widetilde{\tau}_R$

[176] ABREU 00Q searches for the production of pairs of heavy, charged stable particles in e^+e^- annihilation at $\sqrt{s}=$ 130–189 GeV. The upper bound improves to 88 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$. These limits include and update the results of ABREU 98P.

[177] ACCIARRI 99H searched for production of pairs of back-to-back heavy charged particles at $\sqrt{s}$=130–183 GeV. The upper bound improves to 82.2 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$.

[178] ACKERSTAFF 98P bound improves to 83.5 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$. Data collected at $\sqrt{s}$ = 130–183 GeV.

[179] The BARATE 98K mass limit improves to 82 GeV for $\widetilde{\mu}_L$,$\widetilde{\tau}_L$. Data collected at $\sqrt{s}$=161–184 GeV.

$\widetilde{q}$ (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.

Limits from e^+e^- collisions depend on the mixing angle of the lightest mass eigenstate $\widetilde{q}_1=\widetilde{q}_R\sin\theta_q+\widetilde{q}_L\cos\theta_q$. It is usually assumed that only the sbottom and stop squarks have non-trivial mixing angles (see the stop and sbottom sections). Here, unless otherwise noted, squarks are always taken to be either left/right degenerate, or purely of left or right type. Data from Z decays have set squark mass limits above 40 GeV, in the case of $\widetilde{q} \to q\widetilde{\chi}_1$ decays if $\Delta m=m_{\widetilde{q}} - m_{\widetilde{\chi}^0_1} \gtrsim 5$ GeV. For smaller values of Δm, current constraints on the invisible width of the Z ($\Delta\Gamma_{\text{inv}} < 2.0$ MeV, LEP 00) exclude $m_{\widetilde{u}_{L,R}} < 44$ GeV, $m_{\widetilde{d}_R} < 33$ GeV, $m_{\widetilde{d}_L} < 44$ GeV and, assuming all squarks degenerate, $m_{\widetilde{q}} < 45$ GeV.

Limits which are obsolete relative to the current results are not included in this compilation, and can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this *Review*.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$>$ 97	95	[180] BARATE	01	ALEP	$e^+e^- \to \widetilde{q}\overline{\widetilde{q}}$, $\Delta m > 6$ GeV
>250	95	[181] ABBOTT	99L	D0	$\tan\beta=2$, $\mu<0$, $A=0$
$>$ 91.5	95	[182] ACCIARRI	99V	L3	$\Delta m > 10$ GeV, $e^+e^- \to \widetilde{q}\overline{\widetilde{q}}$
>224	95	[183] ABE	96D	CDF	$m_{\widetilde{g}} \leq m_{\widetilde{q}}$; with cascade decays

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

> 82	95	[184] BARATE	01B	ALEP	$\tilde{u}_R$, $\not{R}$ decays
> 68	95	[184] BARATE	01B	ALEP	$\tilde{d}_R$, $\not{R}$ decays
>390	95	[185] ACCIARRI	00P	L3	$e^+e^- \rightarrow q\overline{q}$, $\not{R}$, λ=0.3
>200	95	[186] BARATE	00I	ALEP	$e^+e^- \rightarrow q\overline{q}$, $\not{R}$, λ=0.3
none 150–280	95	[187] BREITWEG	00E	ZEUS	$\not{R}$, $LQ\overline{D}$, $\lambda' \geq 0.3$
>240	95	[188] ABBOTT	99	D0	$\tilde{q} \rightarrow \tilde{\chi}^0_2 X \rightarrow \tilde{\chi}^0_1 \gamma X$, $m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1} > 20$ GeV
>320	95	[188] ABBOTT	99	D0	$\tilde{q} \rightarrow \tilde{\chi}^0_1 X \rightarrow \tilde{G} \gamma X$
>243	95	[189] ABBOTT	99K	D0	any $m_{\tilde{g}}$, $\not{R}$, tanβ=2, $\mu < 0$
>200	95	[190] ABE	99M	CDF	$p\overline{p} \rightarrow \tilde{q}\tilde{q}$, $\not{R}$
>140	95	[191] ACKERSTAFF	98V	OPAL	$e^+e^- \rightarrow q\overline{q}$, $\not{R}$, λ=0.3
> 77	95	[192] BREITWEG	98	ZEUS	$m_{\tilde{q}}$=$m_{\tilde{e}}$, $m(\tilde{\chi}^0_1)$= 40 GeV
		[193] DATTA	97	THEO	$\tilde{\nu}$'s lighter than $\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_2$
>216	95	[194] DERRICK	97	ZEUS	$ep \rightarrow \tilde{q}$, $\tilde{q} \rightarrow \mu j$ or τj, $\not{R}$
none 130–573	95	[195] HEWETT	97	THEO	$q\tilde{g} \rightarrow \tilde{q}$, $\tilde{q} \rightarrow q\tilde{g}$, with a light gluino
none 190–650	95	[196] TEREKHOV	97	THEO	$qg \rightarrow \tilde{q}\tilde{g}$, $\tilde{q} \rightarrow q\tilde{g}$, with a light gluino
>215	95	[197] AID	96	H1	$e^+p \rightarrow \tilde{q}$, $\not{R}$, λ=0.3
>150	95	[197] AID	96	H1	$e^+p \rightarrow \tilde{q}$; $\not{R}$, λ=0.1
> 63	95	[198] AID	96C	H1	$m_{\tilde{q}}$=$m_{\tilde{e}}$, $m_{\tilde{\chi}^0_1}$=35 GeV
none 330–400	95	[199] TEREKHOV	96	THEO	$ug \rightarrow \tilde{u}\tilde{g}$, $\tilde{u} \rightarrow u\tilde{g}$ with a light gluino
>176	95	[200] ABACHI	95C	D0	Any $m_{\tilde{g}}$ <300 GeV; with cascade decays
		[201] ABE	95T	CDF	$\tilde{q} \rightarrow \tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 \gamma$
> 90	90	[202] ABE	92L	CDF	Any $m_{\tilde{g}}$ <410 GeV; with cascade decay
>100		[203] ROY	92	RVUE	$p\overline{p} \rightarrow \tilde{q}\tilde{q}$; $\not{R}$
		[204] NOJIRI	91	COSM	

[180] BARATE 01 looked for acoplanar dijets + $\not{E}_T$ final states at 189 to 202 GeV. The limit assumes B($\tilde{q} \rightarrow q\tilde{\chi}^0_1$)=1, with $\Delta m = m_{\tilde{q}} - m_{\tilde{\chi}^0_1}$. It applies to tan$\beta$=4, μ=−400 GeV. See their Fig. 2 for the exclusion in the ($m_{\tilde{q}}$,$m_{\tilde{g}}$) plane. These limits include and update the results of BARATE 99Q.

[181] ABBOTT 99L consider events with three or more jets and large $\not{E}_T$. Spectra and decay rates are evaluated in the framework of minimal Supergravity, assuming five flavors of degenerate squarks, and scanning the space of the universal gaugino ($m_{1/2}$) and scalar (m_0) masses. See their Figs. 2–3 for the dependence of the limit on the relative value of $m_{\tilde{q}}$ and $m_{\tilde{g}}$.

[182] ACCIARRI 99V assumes four degenerate flavors and B($\tilde{q} \rightarrow q\tilde{\chi}^0_1$)=1, with Δm=$m_{\tilde{q}} - m_{\tilde{\chi}^0_1}$. The bound is reduced to 90 GeV if production of only $\tilde{q}_R$ states is considered. See their Fig. 7 for limits in the ($m_{\tilde{q}}$,$m_{\tilde{\chi}^0_1}$) plane. Data collected at $\sqrt{s}$=189 GeV.

[183] 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 tanβ = 4.0, μ = −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.

[184] BARATE 01B searches for the production of squarks in the case of $\not{R}$ prompt decays with $LL\overline{E}$ indirect or $\overline{UDD}$ direct couplings at $\sqrt{s}$=189–202 GeV. The limit holds for direct decays mediated by $\not{R}$ $\overline{UDD}$ couplings. Limits are also given for $LL\overline{E}$ indirect decays ($m_{\widetilde{u}_R} > 90$ GeV and $m_{\widetilde{d}_R} > 89$ GeV). Supersedes the results from BARATE 00H.

[185] ACCIARRI 00P studied the effect on hadronic cross sections of t-channel down-type squark exchange via R-parity violating coupling $\lambda'_{1jk} L_1 Q_j d^c_k$. The limit here refers to the case j=*1,2*, and holds for λ'_{1jk}=0.3. Data collected at $\sqrt{s}$=130–189 GeV, superseding the results of ACCIARRI 98J.

[186] BARATE 00I studied the effect on hadronic cross sections and charge asymmetries of t-channel down-type squark exchange via R-parity violating coupling $\lambda'_{1jk} L_1 Q_j d^c_k$. The limit here refers to the case j=*1,2*, and holds for λ'_{1jk}=0.3. A 50 GeV limit is found for up-type squarks with k=3. Data collected at $\sqrt{s}$= 130–183 GeV.

[187] BREITWEG 00E searches for squark exchange in $e^+ p$ collisions, mediated by $\not{R}$ couplings $LQ\overline{D}$ and leading to final states with an identified e^+ and ≥ 1 jet. The limit is for 2nd or 3rd generation up-type squarks.

[188] ABBOTT 99 searched for $\gamma \not{E}_T + \geq 2$ jet final states, and set limits on $\sigma(p\overline{p} \rightarrow \widetilde{q}+X)\cdot B(\widetilde{q} \rightarrow \gamma \not{E}_T X)$. The quoted limits correspond to $m_{\widetilde{g}} \geq m_{\widetilde{q}}$, with $B(\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1 \gamma)$=1 and $B(\widetilde{\chi}^0_1 \rightarrow \widetilde{G}\gamma)$=1, respectively. They improve to 310 GeV (360 GeV in the case of $\gamma \widetilde{G}$ decay) for $m_{\widetilde{g}}$=$m_{\widetilde{q}}$.

[189] ABBOTT 99K uses events with an electron pair and four jets to search for the decay of the $\widetilde{\chi}^0_1$ LSP via $\not{R}$ $LQ\overline{D}$ couplings. The particle specrum and decay branching ratios are taken in the framework of minimal supergravity. An excluded region at 95% CL is obtained in the (m_0,$m_{1/2}$) plane under the assumption that A_0=0, $\mu < 0$, tanβ=2 and any one of the couplings $\lambda'_{1jk} > 10^{-3}$ (j=1,2 and k=1,2,3) and from which the above limit is computed. For equal mass squarks and gluinos, the corresponding limit is 277 GeV. The results are essentially independent of A_0, but the limit deteriorates rapidly with increasing tanβ or μ >0.

[190] ABE 99M looked in 107 pb^{-1} of $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV for events with like sign dielectrons and two or more jets from the sequential decays $\widetilde{q} \rightarrow q\widetilde{\chi}^0_1$ and $\widetilde{\chi}^0_1 \rightarrow eq\overline{q}'$, assuming $\not{R}$ coupling $L_1 Q_j D^c_k$, with j=2,3 and k=1,2,3. They assume five degenerate squark flavors, $B(\widetilde{q} \rightarrow q\widetilde{\chi}^0_1)$=1, $B(\widetilde{\chi}^0_1 \rightarrow eq\overline{q}')$=0.25 for both e^+ and e^-, and $m_{\widetilde{g}} \geq$ 200 GeV. The limit is obtained for $m_{\widetilde{\chi}^0_1} \geq m_{\widetilde{q}}/2$ and improves for heavier gluinos or heavier χ^0_1.

[191] ACKERSTAFF 98V and ACCIARRI 98J studied the interference of t-channel squark ($\widetilde{d}_R$) exchange via R-parity violating $\lambda'_{1jk} L_1 Q_j d^c_k$ coupling in $e^+ e^- \rightarrow q\overline{q}$. The limit is for λ'_{1jk}=0.3. See paper for related limits on $\widetilde{u}_L$ exchange. Data collected at $\sqrt{s}$=130–172 GeV.

[192] BREITWEG 98 used positron+jet events with missing energy and momentum to look for $e^+ q \rightarrow \widetilde{e}\widetilde{q}$ via gaugino-like neutralino exchange with decays into $(e\widetilde{\chi}^0_1)(q\widetilde{\chi}^0_1)$. See paper for dependences in $m_{\widetilde{e}}$, $m_{\widetilde{\chi}^0_1}$.

[193] DATTA 97 argues that the squark mass bound by ABACHI 95C can be weakened by 10–20 GeV if one relaxes the assumption of the universal scalar mass at the GUT-scale so that the $\widetilde{\chi}^\pm_1$,$\widetilde{\chi}^0_2$ in the squark cascade decays have dominant and invisible decays to $\widetilde{\nu}$.

[194] DERRICK 97 looked for lepton-number violating final states via R-parity violating couplings $\lambda'_{ijk} L_i Q_j d_k$. When $\lambda'_{11k}\lambda'_{ijk} \neq 0$, the process $e u \rightarrow \widetilde{d}^*_k \rightarrow \ell_i u_j$ is possible. When $\lambda'_{1j1}\lambda'_{ijk} \neq 0$, the process $e\overline{d} \rightarrow \widetilde{u}^*_j \rightarrow \ell_i \overline{d}_k$ is possible. 100% branching fraction $\widetilde{q} \rightarrow \ell j$ is assumed. The limit quoted here corresponds to $\widetilde{t} \rightarrow \tau q$ decay, with λ'=0.3. For different channels, limits are slightly better. See Table 6 in their paper.

[195] HEWETT 97 reanalyzed the limits on possilbe resonances in di-jet mode ($\widetilde{q} \rightarrow q\widetilde{g}$) from ALITTI 93 quoted in "Limits for Excited q (q^*) from Single Production," ABE 96 in "SCALE LIMITS for Contact Interactions: $\Lambda(qqqq)$," and unpublished CDF, DØ bounds. The bound applies to the gluino mass of 5 GeV, and improves for lighter gluino. The analysis has gluinos in parton distribution function.

[196] TEREKHOV 97 improved the analysis of TEREKHOV 96 by including di-jet angular distributions in the analysis.

[197] AID 96 looked for first-generation squarks as s-channel resonances singly produced in $e^+ p$ collision via the R-parity violating coupling in the superpotential $W=\lambda' L_1 Q_1 d^c_1$. The degeneracy of squarks $\widetilde{Q}_1$ and $\widetilde{d}_1$ is assumed. Eight different channels of possible squark decays are considered.

[198] AID 96C used positron+jet events with missing energy and momentum to look for $e^+ q \rightarrow \widetilde{e}\widetilde{q}$ via neutralino exchange with decays into $(e\widetilde{\chi}^0_1)(q\widetilde{\chi}^0_1)$. See the paper for dependences on $m_{\widetilde{e}}$, $m_{\widetilde{\chi}^0_1}$.

[199] TEREKHOV 96 reanalyzed the limits on possible resonances in di-jet mode ($\widetilde{u} \rightarrow u\widetilde{g}$) from ABE 95N quoted in "MASS LIMITS for g_A (axigluon)." The bound applies only to the case with a light gluino.

[200] 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.

[201] 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.

[202] 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($\widetilde{q} \rightarrow q\widetilde{\gamma}$) = 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.

[203] 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.

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

Long-lived $\widetilde{q}$ (Squark) MASS LIMIT

The following are bounds on long-lived scalar quarks, assumed to hadronise into hadrons with lifetime long enough to escape the detector prior to a possible decay. Limits may depend on the mixing angle of mass eigenstates: $\widetilde{q}_1 = \widetilde{q}_L \cos\theta_q + \widetilde{q}_R \sin\theta_q$. The coupling to the Z^0 boson vanishes for up-type squarks when θ_u=0.98, and for down type squarks when θ_d=1.17.

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
none 2–85	95	[205] ABREU 98P	DLPH	$\widetilde{u}_L$
none 2–81	95	[205] ABREU 98P	DLPH	$\widetilde{u}_R$
none 2–80	95	[205] ABREU 98P	DLPH	$\widetilde{u}$, θ_u=0.98
none 2–83	95	[205] ABREU 98P	DLPH	$\widetilde{d}_L$
none 5–40	95	[205] ABREU 98P	DLPH	$\widetilde{d}_R$
none 5–38	95	[205] ABREU 98P	DLPH	$\widetilde{d}$, θ_d=1.17

[205] ABREU 98P assumes that 40% of the squarks will hadronise into a charged hadron, and 60% into a neutral hadron which deposits most of its energy in hadron calorimeter. Data collected at $\sqrt{s}$=130–183 GeV.

$\widetilde{b}$ (Sbottom) MASS LIMIT

Limits in e^+e^- depend on the mixing angle of the mass eigenstate $\widetilde{b}_1 = \widetilde{b}_L \cos\theta_b + \widetilde{b}_R \sin\theta_b$. Coupling to the Z vanishes for $\theta_b \sim 1.17$. As a consequence, no absolute constraint in the mass region $\lesssim$ 40 GeV is available in the literature at this time from e^+e^- collisions. In the Listings below, we use $\Delta m = m_{\widetilde{b}_1} - m_{\widetilde{\chi}^0_1}$.

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
>91	95	[206] BARATE 01	ALEP	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, θ_b=0, $\Delta m > 8$ GeV
none 3.5–4.5	95	[207] SAVINOV 01	CLEO	$\widetilde{B}$ meson
>87	95	[208] ABREU,P 00D	DLPH	$\widetilde{b} \rightarrow b\widetilde{\chi}^0$, θ_b= 0, $\Delta m > 15$ GeV
>62	95	[208] ABREU,P 00D	DLPH	$\widetilde{b} \rightarrow b\widetilde{\chi}^0$, θ_b= 1.17, $\Delta m > 15$ GeV
none 80–145		[209] AFFOLDER 00D	CDF	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ <50 GeV
>89.8	95	[210] ABBIENDI 99M	OPAL	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, θ_b=0, $\Delta m > 10$ GeV
>74.9	95	[210] ABBIENDI 99M	OPAL	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, θ_b=1.17, $\Delta m > 10$ GeV
>84	95	[211] ACCIARRI 99V	L3	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, θ_b=0, $\Delta m > 15$ GeV
>61	95	[211] ACCIARRI 99V	L3	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, θ_b=1.17, $\Delta m > 15$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>72	95	[212] ABREU 01D	DLPH	$\not{R}(\overline{UDD})$, all $\Delta m > 5$ GeV, θ_b=0
>71.5	95	[213] BARATE 01B	ALEP	$\widetilde{b}_L$, $\not{R}$ decays, $\Delta m > 10$ GeV
none 52–115	95	[214] ABBOTT 99F	D0	$\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1} < 20$ GeV

[206] BARATE 01 looked for b-tagged acoplanar dijets + $\not{E}_T$ final states at 189 to 202 GeV. The limit assumes B($\widetilde{b} \rightarrow b\widetilde{\chi}^0_1$)=1. See their Fig. 2 for the dependence of the limit on Δm and θ_b. These limits include and update the results of BARATE 99Q.

[207] SAVINOV 01 use data taken at $\sqrt{s}$=10.52 GeV, below the $B\overline{B}$ threshold. They look for events with a pair of leptons with opposite charge and a fully reconstructed hadronic D or D^* decay. These could originate from production of a light-sbottom hadron followed by $\widetilde{B} \rightarrow D^{(*)}\ell^-\widetilde{\nu}$, in case the $\widetilde{\nu}$ is the LSP, or $\widetilde{B} \rightarrow D^{(*)}\pi\ell^-$, in case of $\not{R}$. The

mass range 3.5 $\leq M(\widetilde{B}) \leq$ 4.5 GeV was explored, assuming 100% branching ratio for either of the decays. In the $\widetilde{\nu}$ LSP scenario, the limit holds only for $M(\widetilde{\nu})$ less than about 1 GeV and for the D^* decays it is reduced to the range 3.9–4.5 GeV. For the $\not{R}$ decay, the whole range is excluded.

[208] ABREU,P 00D looked for $\widetilde{b}$ pair production at $\sqrt{s}$=130–189 GeV. See Fig. 7 for other choices of Δm. These limits include and update the results of ABREU 99C.

[209] AFFOLDER 00D search for final states with 2 or 3 jets and $\not{E}_T$, one jet with a b tag. See their Fig. 3 for the mass exclusion in the $m_{\widetilde{t}}$, $m_{\widetilde{\chi}_1^0}$ plane.

[210] ABBIENDI 99M looked for events with two acoplanar jets and $\not{p}_T$. See Fig. 4 and Table 5 for the dependence on the limit on Δm and θ_b. Data taken at $\sqrt{s}$=161–189 GeV. These results supersede ACKERSTAFF 99.

[211] ACCIARRI 99V looked for events with two acoplanar b-tagged jets and $\not{p}_T$, at $\sqrt{s}$=189 GeV. See their Figs. 4 and 6 for the more general dependence of the limits on Δm and θ_b. Updates ACCIARRI 99C.

[212] ABREU 01D searches for multi-jet events, expected in the case of prompt decays from $\not{R}\ \overline{UDD}$ couplings and indirect decays, using data from $\sqrt{s}$=189 GeV. Limits are obtained in the plane of the squark mass versus $m_{\widetilde{\chi}_1^0}$. The mass limit is derived using the constraint on the neutralino mass from the same paper (see the section on unstable $\widetilde{\chi}_1^0$). See Fig. 9 for other choices of Δm.

[213] BARATE 01B searches for the production of $\widetilde{b}$ pairs couplings at $\sqrt{s}$=189–202 GeV. The limit holds for indirect decays mediated by $\not{R}\ \overline{UDD}$ couplings. It improves to 74 GeV for indirect decays mediated by $\not{R}\ LQ\overline{D}$ couplings. Supersedes the results from BARATE 99E and BARATE 98S.

[214] ABBOTT 99F looked for events with two jets, with or without an associated muon from b decay, and $\not{E}_T$. See Fig. 2 for the dependence of the limit on $m_{\widetilde{\chi}_1^0}$. No limit for $m_{\widetilde{\chi}_1^0} > 47$ GeV.

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

Limits depend on the decay mode. In $e^+ e^-$ collisions they also depend on the mixing angle of the mass eigenstate $\widetilde{t}_1 = \widetilde{t}_L \cos\theta_t + \widetilde{t}_R \sin\theta_t$. The coupling to the Z vanishes when θ_t = 0.98. In the Listings below, we use $\Delta m \equiv m_{\widetilde{t}_1} - m_{\widetilde{\chi}_1^0}$ or $\Delta m \equiv m_{\widetilde{t}_1} - m_{\widetilde{\nu}}$, depending on relevant decay mode. See also bounds in "$\widetilde{q}$ (Squark) MASS LIMIT." Previous obsolete limits are not included in this compilation, and can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this *Review*.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$>$ 83	95	[215] BARATE	01	ALEP	$\widetilde{t} \to c\widetilde{\chi}_1^0$, all θ_t, 6< $\Delta m <$ 40 GeV
$>$ 88	95	[215] BARATE	01	ALEP	$\widetilde{t} \to b\ell\widetilde{\nu}$, all θ_t, $\Delta m >$ 10 GeV
$>$ 84	95	[216] ABREU,P	00D	DLPH	$\widetilde{t} \to c\widetilde{\chi}^0$, θ_t= 0, $\Delta m >$ 15 GeV
$>$ 79	95	[216] ABREU,P	00D	DLPH	$\widetilde{t} \to c\widetilde{\chi}^0$, θ_t= 0.98, $\Delta m >$ 15 GeV

> 59	95	[217] BARATE	00P	ALEP	$\widetilde{t} \to \widetilde{\chi}^0_1 + c/u$, all Δm, all τ
> 86.4	95	[218] ABBIENDI	99M	OPAL	$\widetilde{t} \to c\widetilde{\chi}^0_1$, θ_t=0.98, $\Delta m > 5$ GeV
> 88.0	95	[218] ABBIENDI	99M	OPAL	$\widetilde{t} \to b\ell\widetilde{\nu}$, θ_t=0.98, $\Delta m > 10$ GeV
> 87.5	95	[218] ABBIENDI	99M	OPAL	$\widetilde{t} \to b\tau\widetilde{\nu}_\tau$, θ_t=0.98, $\Delta m >$ 10 GeV
> 81	95	[219] ACCIARRI	99V	L3	$\widetilde{t} \to c\widetilde{\chi}^0_1$, θ_t=0.96, $\Delta m > 15$ GeV
> 86	95	[219] ACCIARRI	99V	L3	$\widetilde{t} \to b\ell\widetilde{\nu}$, θ_t=0.96, $\Delta m > 15$ GeV
> 83	95	[219] ACCIARRI	99V	L3	$\widetilde{t} \to b\tau\widetilde{\nu}_\tau$, θ_t=0.96, $\Delta m >$ 15 GeV

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

> 74	95	[220] ABREU	01D	DLPH	$\not{R}(\overline{UDD})$, all $\Delta m > 5$ GeV, θ_t=0
> 59	95	[220] ABREU	01D	DLPH	$\not{R}(\overline{UDD})$, all $\Delta m > 5$ GeV, θ_t=0.98
		[221] AFFOLDER	01B	CDF	$t \to \widetilde{t}\chi^0_1$
> 71.5	95	[222] BARATE	01B	ALEP	$\widetilde{t}_L$, $\not{R}$ decays
> 76	95	[223] ABBIENDI	00	OPAL	$\not{R}$, $(\overline{UDD})$, all θ_t
> 61	95	[224] ABREU	00I	DLPH	$\not{R}$ $(LL\overline{E})$, θ_t=0.98, $\Delta m > 4$ GeV
none 68–119	95	[225] AFFOLDER	00D	CDF	$\widetilde{t} \to c\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ <40 GeV
none 84–120	95	[226] AFFOLDER	00G	CDF	$\widetilde{t}_1 \to b\ell\widetilde{\nu}$, $m_{\widetilde{\nu}}$ <45
>120	95	[227] ABE	99M	CDF	$p\overline{p} \to \widetilde{t}_1\widetilde{t}_1$, $\not{R}$
none 61–91	95	[228] ABACHI	96B	D0	$\widetilde{t} \to c\widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1}$ <30 GeV
none 9–24.4	95	[229] AID	96	H1	$ep \to \widetilde{t}\widetilde{t}$, $\not{R}$ decays
>138	95	[230] AID	96	H1	$ep \to \widetilde{t}$, $\not{R}$, $\lambda\cos\theta_t > 0.03$
> 45		[231] CHO	96	RVUE	B^0-$\overline{B}^0$ and ϵ, θ_t= 0.98, tanβ <2
none 11–41	95	[232] BUSKULIC	95E	ALEP	$\not{R}$ $(LL\overline{E})$, θ_t=0.98
none 6.0–41.2	95	AKERS	94K	OPAL	$\widetilde{t} \to c\widetilde{\chi}^0_1$, θ_t=0, Δm >2 GeV
none 5.0–46.0	95	AKERS	94K	OPAL	$\widetilde{t} \to c\widetilde{\chi}^0_1$, θ_t=0, Δm >5 GeV
none 11.2–25.5	95	AKERS	94K	OPAL	$\widetilde{t} \to c\widetilde{\chi}^0_1$, θ_t=0.98, Δm >2 GeV
none 7.9–41.2	95	AKERS	94K	OPAL	$\widetilde{t} \to c\widetilde{\chi}^0_1$, θ_t=0.98, Δm >5 GeV
none 7.6–28.0	95	[233] SHIRAI	94	VNS	$\widetilde{t} \to c\widetilde{\chi}^0_1$, any θ_t, Δm >10 GeV
none 10–20	95	[233] SHIRAI	94	VNS	$\widetilde{t} \to c\widetilde{\chi}^0_1$, any θ_t, $\Delta m > 2.5$ GeV

[215] BARATE 01 looked for acoplanar dijets + $\not{E}_T$ and, in the calse of $b\ell\widetilde{\nu}$ final states, two leptons. All limits assume 100% branching ratios for the respective decay modes, with flavor independent rates for leptons in the case of semi-leptonic decays. For the mode $b\ell\widetilde{\nu}$, the limit uses the exclusion $m_{\widetilde{\nu}} > 43$ GeV. See their Fig. 2 for the dependence of the limit on Δm and θ_t. Data taken at 189 to 202 GeV. These limits include and update the results of BARATE 99Q.

[216] ABREU,P 00D looked for $\widetilde{t}$ pair production at $\sqrt{s}$=130–189 GeV. See Fig. 6 for other choices of Δm. These limits include and update the results of ABREU 99C.

[217] BARATE 00P use data from $\sqrt{s}$= 189–202 GeV to explore the region of small mass difference between the stop and the neutralino by searching heavy stable charged particles or tracks with large impact parameters. For prompt decays, they make use of acoplanar

jets from BARATE 99Q, updated up to 202 GeV. The limit is reached for Δm=1.6 GeV and a decay length of 1 cm. If the MSSM relation between the decay width and Δm is used, the limit improves to 63 GeV. It is set for Δm=1.9 GeV. tanβ=2.6, and $\theta_{\widetilde{t}}$=0.98, and large negative μ.

[218] ABBIENDI 99M looked for events with two acoplanar jets, $\not{p}_T$, and, in the case of $b\ell\widetilde{\nu}$ ($b\tau\widetilde{\nu}$) final states, two leptons (taus). Limits for θ_t are $\sim$ 2.5 GeV stronger. In the case of $c\widetilde{\chi}_1^0$ decays, the limits with $\Delta m > 10$ GeV improve to 90.3 for θ_t=0 and 87.2 for θ_t=0.98. See Figs. 2–3 and Table 4 for the more general dependence of the limits on Δm. Data taken at $\sqrt{s}$=161–189 GeV. All limits assume 100% branching ratio for the respective decay modes. These results supersede ACKERSTAFF 99.

[219] ACCIARRI 99V looked for events with two acoplanar jets, $\not{p}_T$ and, in the case of $b\ell\widetilde{\nu}$ ($b\tau\widetilde{\nu}$) final states, two leptons (taus). The limits for θ_t=0 improve to 88, 89, and 88 GeV, respectively. See their Figs. 4–6 for the more general dependence of the limits on Δm and θ_t. Data taken at $\sqrt{s}$=189 GeV. All limits assume 100% branching ratio for the respective decay modes. Updates ACCIARRI 99C.

[220] ABREU 01D searches for multi-jet events, expected in the case of prompt decays from $\not{R}$ $\overline{UDD}$ couplings and indirect decays, using data from $\sqrt{s}$=189 GeV. Limits are obtained in the plane of the squark mass versus $m_{\widetilde{\chi}_1^0}$. The mass limit is derived using the constraint on the neutralino mass from the same paper (see the section on unstable $\widetilde{\chi}_1^0$). See Fig. 9 for other choices of Δm.

[221] AFFOLDER 01B searches for decays of the top quark into stop and LSP, in $t\overline{t}$ events. Limits on the stop mass as a function of the LSP mass and of the decay branching ratio are shown in Fig. 3. They exclude branching ratios in excess of 45% for SLP masses up to 40 GeV.

[222] BARATE 01B searches for the production of $\widetilde{t}$ pairs couplings at $\sqrt{s}$=189–202 GeV. The limit holds for indirect decays mediated by $\not{R}$ $\overline{UDD}$ couplings. It improves to 84 GeV for indirect decays mediated by $\not{R}$ $LQ\overline{D}$ couplings and to 93 GeV for direct decays assuming B($\widetilde{t}_L \rightarrow q\tau$)=100%. Supersedes the results from BARATE 00H and BARATE 99E.

[223] ABBIENDI 00 searches for the production of stop in the case of R-parity violation with $\overline{UDD}$ or $LQ\overline{D}$ couplings, using data from $\sqrt{s}$=183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero. For mass exclusion limits relative to $LQ\overline{D}$-induced decays, see their Table 5.

[224] ABREU 00I searches for the production of stop in the case of R-parity violation wiht $LL\overline{E}$ couplings, for which only indirect decays are allowed. They investigate topologies with jets plus leptons in data from $\sqrt{s}$=183 GeV. The lower bound on the stop mass assumes a neutralino mass limit of 27 GeV, also derived in ABREU 00I.

[225] AFFOLDER 00D search for final states with 2 or 3 jets and $\not{E}_T$, one jet with a c tag. See their Fig. 2 for the mass exclusion in the ($m_{\widetilde{t}}$,$m_{\widetilde{\chi}_1^0}$) plane. The maximum excluded $m_{\widetilde{t}}$ value is 119 GeV, for $m_{\widetilde{\chi}_1^0}$= 40 GeV.

[226] AFFOLDER 00G searches for $\widetilde{t}_1\widetilde{t}_1^*$ production, with $\widetilde{t}_1 \rightarrow b\ell\widetilde{\nu}$, leading to topologies with ≥ 1 isolated lepton (e or μ), $\not{E}_T$, and ≥ 2 jets with ≥ 1 tagged as b quark by a secondary vertex. See Fig. 4 for the excluded mass range as a function of $m_{\widetilde{\nu}}$. Cross-section limits for $\widetilde{t}_1\widetilde{t}_1^*$, with $\widetilde{t}_1 \rightarrow b\chi_1^{\pm}$ ($\chi_1^{\pm} \rightarrow \ell^{\pm}\nu\widetilde{\chi}_1^0$), are given in Fig. 2.

[227] ABE 99M looked in 107 pb^{-1} of $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV for events with like sign dielectrons and two or more jets from the sequential decays $\widetilde{q} \rightarrow q\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^0 \rightarrow eq\overline{q}'$, assuming $\not{R}$ coupling $L_1Q_jD_k^c$, with j=2,3 and k=1,2,3. They assume B($\widetilde{t}_1 \rightarrow c\widetilde{\chi}_1^0$)=1, B($\widetilde{\chi}_1^0 \rightarrow eq\overline{q}'$)=0.25 for both e^+ and e^-, and $m_{\widetilde{\chi}_1^0} \geq m_{\widetilde{t}_1}/2$. The limit improves for heavier $\widetilde{\chi}_1^0$.

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

[229] AID 96 considers photoproduction of $\widetilde{t}\,\widetilde{t}$ pairs, with 100% R-parity violating decays of $\widetilde{t}$ to $e\,q$, with q=d, s, or b quarks.

[230] AID 96 considers production and decay of $\widetilde{t}$ via the R-parity violating coupling $\lambda' L_1 Q_3 d^c_1$.

[231] CHO 96 studied the consistency among the B^0-$\overline{B}^0$ mixing, ϵ in K^0-$\overline{K}^0$ mixing, and the measurements of V_{cb}, V_{ub}/V_{cb}. For the range 25.5 GeV$<m_{\widetilde{t}_1}<m_Z/2$ left by AKERS 94K for $\theta_t = 0.98$, and within the allowed range in M_2-μ parameter space from chargino, neutralino searches by ACCIARRI 95E, they found the scalar top contribution to B^0-$\overline{B}^0$ mixing and ϵ to be too large if tanβ <2. For more on their assumptions, see the paper and their reference 10.

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

[233] 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.

Heavy $\widetilde{g}$ (Gluino) MASS LIMIT

For $m_{\widetilde{g}} > 60$–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.

VALUE (GeV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
>190	95	[234] ABBOTT 99L	D0	tanβ=2, μ <0, A=0
>260	95	[234] ABBOTT 99L	D0	$m_{\widetilde{g}}$=$m_{\widetilde{q}}$
>173	95	[235] ABE 97K	CDF	Any $m_{\widetilde{q}}$; with cascade decays
>216	95	[235] ABE 97K	CDF	$m_{\widetilde{q}}$=$m_{\widetilde{g}}$; with cascade decays
>224	95	[236] ABE 96D	CDF	$m_{\widetilde{q}} = m_{\widetilde{g}}$; with cascade decays
>154	95	[236] ABE 96D	CDF	$m_{\widetilde{g}}$ <$m_{\widetilde{q}}$; with cascade decays
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>240	95	[237] ABBOTT 99	D0	$\widetilde{g} \to \widetilde{\chi}^0_2 X \to \widetilde{\chi}^0_1 \gamma X$, $m_{\widetilde{\chi}^0_2} - m_{\widetilde{\chi}^0_1} > 20$ GeV
>320	95	[237] ABBOTT 99	D0	$\widetilde{g} \to \widetilde{\chi}^0_1 X \to \widetilde{G}\gamma X$
>227	95	[238] ABBOTT 99K	D0	any $m_{\widetilde{q}}$, $\not{R}$, tanβ=2, $\mu < 0$
>212	95	[239] ABACHI 95C	D0	$m_{\widetilde{g}} \geq m_{\widetilde{q}}$; with cascade decays
>144	95	[239] ABACHI 95C	D0	Any $m_{\widetilde{q}}$; with cascade decays
		[240] ABE 95T	CDF	$\widetilde{g} \to \widetilde{\chi}^0_2 \to \widetilde{\chi}^0_1 \gamma$
		[241] HEBBEKER 93	RVUE	e^+e^- jet analyses
>218	90	[242] ABE 92L	CDF	$m_{\widetilde{q}} \leq m_{\widetilde{g}}$; with cascade decay
>100		[243] ROY 92	RVUE	$p\overline{p} \to \widetilde{g}\widetilde{g}$; $\not{R}$
		[244] NOJIRI 91	COSM	
none 4–53	90	[245] ALBAJAR 87D	UA1	Any $m_{\widetilde{q}} > m_{\widetilde{g}}$
none 4–75	90	[245] ALBAJAR 87D	UA1	$m_{\widetilde{q}} = m_{\widetilde{g}}$
none 16–58	90	[246] ANSARI 87D	UA2	$m_{\widetilde{q}} \lesssim 100$ GeV

[234] ABBOTT 99L consider events with three or more jets and large $\not{E}_T$. Spectra and decay rates are evaluated in the framework of minimal Supergravity, assuming five flavors of

degenerate squarks, and scanning the space of the universal gaugino ($m_{1/2}$) and scalar (m_0) masses See their Figs. 2–3 for the dependence of the limit on the relative value of $m_{\widetilde{q}}$ and $m_{\widetilde{g}}$.

[235] ABE 97K searched for production of gluinos and five degenerate squarks in events with three or more jets but no electrons or muons and missing transverse energy $\not{E}_T > 60$ GeV. The limit for any $m_{\widetilde{q}}$ is for μ=$-$200 GeV and tanβ=2, and that for $m_{\widetilde{q}}$=$m_{\widetilde{g}}$ is for μ=$-$400 GeV and tanβ=4. Different choices for tanβ and μ lead to changes of the order of $\pm$10 GeV in the limits. See Footnote [16] of the paper for more details on the assumptions.

[236] 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.

[237] ABBOTT 99 searched for $\gamma \not{E}_T + \ \geq 2$ jet final states, and set limits on $\sigma(p\overline{p} \rightarrow \widetilde{g}+\text{X})\cdot\text{B}(\widetilde{g} \rightarrow \ \gamma\not{E}_T\text{X})$. The quoted limits correspond to $m_{\widetilde{q}} \geq m_{\widetilde{g}}$, with $\text{B}(\widetilde{\chi}^0_2 \rightarrow \widetilde{\chi}^0_1\gamma)$=1 and $\text{B}(\widetilde{\chi}^0_1 \rightarrow \ \widetilde{G}\gamma)$=1, respectively. They improve to 310 GeV (360 GeV in the case of $\gamma\widetilde{G}$ decay) for $m_{\widetilde{g}}$=$m_{\widetilde{q}}$.

[238] ABBOTT 99K uses events with an electron pair and four jets to search for the decay of the $\widetilde{\chi}^0_1$ LSP via $\not{R}$ $LQ\overline{D}$ couplings. The particle specrum and decay branching ratios are taken in the framework of minimal supergravity. An excluded region at 95% CL is obtained in the (m_0,$m_{1/2}$) plane under the assumption that A_0=0, $\mu < 0$, tanβ=2 and any one of the couplings $\lambda^{'}_{1jk} > 10^{-3}$ (j=1,2 and k=1,2,3) and from which the above limit is computed. For equal mass squarks and gluinos, the corresponding limit is 277 GeV. The results are essentially independent of A_0, but the limit deteriorates rapidly with increasing tanβ or μ >0.

[239] 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.

[240] 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.

[241] 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 $\pm$ 1.1 is obtained, which is compared to that with a light gluino, N=8.

[242] 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).

[243] 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.

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

[245] The limits of ALBAJAR 87D are from $p\overline{p} \rightarrow \ \widetilde{g}\widetilde{g}\text{X}$ ($\widetilde{g} \rightarrow \ q\overline{q}\widetilde{\gamma}$) 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.

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

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Long-lived/light $\tilde{g}$ (Gluino) MASS LIMIT

Limits on light gluinos ($m_{\tilde{g}} < 5$ GeV), or gluinos which leave the detector before decaying.

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

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
		[247] MAFI	00	THEO	$pp \to$ jets + $\not{p}_T$
		[248] ALAVI-HARATI	99E	KTEV	$pN \to R^0$, with $R^0 \to \rho^0\tilde{\gamma}$ and $R^0 \to \pi^0\tilde{\gamma}$
		[249] BAER	99	RVUE	Stable $\tilde{g}$ hadrons
		[250] FANTI	99	NA48	$p\text{Be} \to R^0 \to \eta\tilde{\gamma}$
		[251] ACKERSTAFF	98V	OPAL	$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$
		[252] ADAMS	97B	KTEV	$pN \to R^0 \to \rho^0\tilde{\gamma}$
		[253] ALBUQUERQ...	97	E761	$R^+(uud\tilde{g}) \to S^0(uds\tilde{g})\pi^+$, $X^-(ssd\tilde{g}) \to S^0\pi^-$
>6.3	95	[254] BARATE	97L	ALEP	Color factors
>5	99	[255] CSIKOR	97	RVUE	β function, $Z \to$ jets
>1.5	90	[256] DEGOUVEA	97	THEO	$Z \to jjjj$
		[257] FARRAR	96	RVUE	$R^0 \to \pi^0\tilde{\gamma}$
none 1.9–13.6	95	[258] AKERS	95R	OPAL	Z decay into a long-lived $(\tilde{g}q\bar{q})^{\pm}$
<0.7		[259] CLAVELLI	95	RVUE	quarkonia
none 1.5–3.5		[260] CAKIR	94	RVUE	$\Upsilon(1S) \to \gamma +$ gluinonium
not 3–5		[261] LOPEZ	93C	RVUE	LEP
≈ 4		[262] CLAVELLI	92	RVUE	α_s running
		[263] ANTONIADIS	91	RVUE	α_s running
>1		[264] ANTONIADIS	91	RVUE	$pN \to$ missing energy
		[265] NAKAMURA	89	SPEC	R-Δ^{++}
>3.8	90	[266] ARNOLD	87	EMUL	π^- (350 GeV). $\sigma \simeq A^1$
>3.2	90	[266] ARNOLD	87	EMUL	π^- (350 GeV). $\sigma \simeq A^{0.72}$
none 0.6–2.2	90	[267] TUTS	87	CUSB	$\Upsilon(1S) \to \gamma +$ gluinonium
none 1 –4.5	90	[268] ALBRECHT	86C	ARG	$1 \times 10^{-11} \lesssim \tau \lesssim 1 \times 10^{-9}$s
none 1–4	90	[269] BADIER	86	BDMP	$1 \times 10^{-10} < \tau < 1 \times 10^{-7}$s
none 3–5		[270] BARNETT	86	RVUE	$p\bar{p} \to$ gluino gluino gluon
none		[271] VOLOSHIN	86	RVUE	If (quasi) stable; $\tilde{g}uud$
none 0.5–2		[272] COOPER-...	85B	BDMP	For $m_{\tilde{q}}$=300 GeV
none 0.5–4		[272] COOPER-...	85B	BDMP	For $m_{\tilde{q}}$ <65 GeV
none 0.5–3		[272] COOPER-...	85B	BDMP	For $m_{\tilde{q}}$=150 GeV
none 2–4		[273] DAWSON	85	RVUE	$\tau > 10^{-7}$ s
none 1–2.5		[273] DAWSON	85	RVUE	For $m_{\tilde{q}}$=100 GeV
none 0.5–4.1	90	[274] FARRAR	85	RVUE	FNAL beam dump

>1	[275] GOLDMAN	85	RVUE	Gluononium
>1–2	[276] HABER	85	RVUE	
	[277] BALL	84	CALO	
	[278] BRICK	84	RVUE	
	[279] FARRAR	84	RVUE	
>2	[280] BERGSMA	83C	RVUE	For $m_{\tilde q}$ <100 GeV
	[281] CHANOWITZ	83	RVUE	$\tilde g u \overline{d}$, $\tilde g u u d$
>2–3	[282] KANE	82	RVUE	Beam dump
>1.5–2	FARRAR	78	RVUE	R-hadron

[247] MAFI 00 reanalyzed CDF data assuming a stable heavy gluino as the LSP, with model for R-hadron-nucleon scattering. Gluino masses between 35 GeV and 115 GeV are excluded based on the CDF Run I data. Combined with the analysis of BAER 99, this allows a LSP gluino mass between 25 and 35 GeV if the probability of fragmentation into charged R-hadron $P>1/2$. The cosmological exclusion of such a gluino LSP are assumed to be avoided as in BAER 99. Gluino could be NLSP with $\tau_{\tilde g} \sim 100$ yrs, and decay to gluon gravitino.

[248] ALAVI-HARATI 99E looked for R^0 bound states, yielding $\pi^+\pi^-$ or π^0 in the final state. The experiment is senstive to values of $\Delta m = m_{R^0} - m_{\tilde\gamma}$ larger than 280 MeV and 140 MeV for the two decay modes, respectively, and to R^0 mass and lifetime in the ranges 0.8–5 GeV and 10^{-10}–10^{-3} s. The limits obtained depend on B($R^0 \to \pi^+\pi^-$ photino) and B($R^0 \to \pi^0$ photino) on the value of $m_{R^0}/m_{\tilde\gamma}$, and on the ratio of production rates $\sigma(R^0)/\sigma(K^0_L)$. See Figures in the paper for the excluded R^0 production rates as a function of Δm, R^0 mass and lifetime. Using the production rates expected from perturbative QCD, and assuming dominance of the above decay channels over the suitable phase space, R^0 masses in the range 0.8–5 GeV are excluded at 90%CL for a large fraction of the sensitive lifetime region. ALAVI-HARATI 99E updates and supersedes the results of ADAMS 97B.

[249] BAER 99 set constraints on the existence of stable $\tilde g$ hadrons, in the mass range $m_{\tilde g} > 3$ GeV. They argue that strong-interaction effects in the low-energy annihilation rates could leave small enough relic densities to evade cosmological constraints up to $m_{\tilde g} < 10$ TeV. They consider jet+$\not\!\!E_T$ as well as heavy-ionizing charged-particle signatures from production of stable $\tilde g$ hadrons at LEP and Tevatron, developing modes for the energy loss of $\tilde g$ hadrons inside the detectors. Results are obtained as a function of the fragmentation probability P of the $\tilde g$ into a charged hadron. For $P< 1/2$, and for various energy-loss models, OPAL and CDF data exclude gluinos in the $3 < m_{\tilde g}(\text{GeV}) < 130$ mass range. For $P> 1/2$, gluinos are excluded in the mass ranges $3 < m_{\tilde g}(\text{GeV}) < 23$ and $50 < m_{\tilde g}(\text{GeV}) < 200$.

[250] FANTI 99 looked for R^0 bound states yielding high P_T $\eta \to 3\pi^0$ decays. The experiment is sensitive to a region of R^0 mass and lifetime in the ranges of 1–5 GeV and 10^{-10}–10^{-3} s. The limits obtained depend on B($R^0 \to \eta\tilde\gamma$), on the value of $m_{R^0}/m_{\tilde\gamma}$, and on the ratio of production rates $\sigma(R^0)/\sigma(K^0_L)$. See Fig. 6–7 for the excluded production rates as a function of R^0 mass and lifetime.

[251] ACKERSTAFF 98V excludes the light gluino with universal gaugino mass where charginos, neutralinos decay as $\tilde\chi^\pm_1, \tilde\chi^0_2 \to q\overline{q}\tilde g$ from total hadronic cross sections at $\sqrt{s}$=130–172 GeV. See paper for the case of nonuniversal gaugino mass.

[252] ADAMS 97B looked for $\rho^0 \to \pi^+\pi^-$ as a signature of $R^0 = (\tilde g g)$ bound states. The experiment is sensitive to an R^0 mass range of 1.2–4.5 GeV and to a lifetime range of 10^{-10}–10^{-3} sec. Precise limits depend on the assumed value of $m_{R^0}/m_{\tilde\gamma}$. See Fig. 7 for the excluded mass and lifetime region.

[253] ALBUQUERQUE 97 looked for weakly decaying baryon-like states which contain a light gluino, following the suggestions in FARRAR 96. See their Table 1 for limits on the production fraction. These limits exclude gluino masses in the range 100–600 MeV for the predicted lifetimes (FARRAR 96) and production rates, which are assumed to be comparable to those of strange or charmed baryons.

[254] BARATE 97L studied the QCD color factors from four-jet angular correlations and the differential two-jet rate in Z decay. Limit obtained from the determination of $n_f = 4.24 \pm 0.29 \pm 1.15$, assuming T_F/C_F=3/8 and C_A/C_F=9/4.

[255] CSIKOR 97 combined the α_s from $\sigma(e^+e^- \rightarrow$ hadron), τ decay, and jet analysis in Z decay. They exclude a light gluino below 5 GeV at more than 99.7%CL.

[256] DEGOUVEA 97 reaanalyzed AKERS 95A data on Z decay into four jets to place constraints on a light stable gluino. The mass limit corresponds to the pole mass of 2.8 GeV. The analysis, however, is limited to the leading-order QCD calculation.

[257] FARRAR 96 studied the possible R^0=($\widetilde{g}g$) component in Fermilab E799 experiment and used its bound B($K^0_L \rightarrow \pi^0\nu\overline{\nu}) \leq 5.8 \times 10^{-5}$ to place constraints on the combination of R^0 production cross section and its lifetime.

[258] 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%.

[259] 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.

[260] CAKIR 94 reanalyzed TUTS 87 and later unpublished data from CUSB to exclude pseudo-scalar gluinonium $\eta_{\widetilde{g}}(\widetilde{g}\widetilde{g})$ of mass below 7 GeV. it was argued, however, that the perturbative QCD calculation of the branching fraction $\Upsilon \rightarrow \eta_{\widetilde{g}}\gamma$ is unreliable for $m_{\eta_{\widetilde{g}}} < 3$ GeV. The gluino mass is defined by $m_{\widetilde{g}}$=$(m_{\eta_{\widetilde{q}}})/2$. The limit holds for any gluino lifetime.

[261] 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.

[262] 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.

[263] 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.

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

[265] NAKAMURA 89 searched for a long-lived ($\tau \gtrsim 10^{-7}$ s) charge-($\pm$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.

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

[267] 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.

[268] 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.

[269] 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.

[270] 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.

[271] 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.

[272] 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.

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

[274] 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.

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

[276] 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.

[277] 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.

[278] BRICK 84 reanalyzed FNAL 147 GeV HBC data for R-$\Delta(1232)^{++}$ with $\tau > 10^{-9}$ s and $p_{\text{lab}} > 2$ 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.

[279] 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.

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

[281] 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.

[282] 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.

LIGHT $\widetilde{G}$ (Gravitino) MASS LIMITS FROM COLLIDER EXPERIMENTS

The following are bounds on light ($\ll$ 1 eV) gravitino indirectly inferred from its coupling to matter suppressed by the gravitino decay constant.

Unless otherwise stated, all limits assume that other supersymmetric particles besides the gravitino are too heavy to be produced. The gravitino is assumed to be undetected and to give rise to a missing energy ($\not{E}$) signature.

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$> 8.7 \times 10^{-6}$	95	[283] ABBIENDI	01B	OPAL	$e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$
$>10.0 \times 10^{-6}$	95	[284] ABREU	00Z	DLPH	$e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$
$>11 \times 10^{-6}$	95	[285] AFFOLDER	00J	CDF	$p\overline{p} \rightarrow \widetilde{G}\widetilde{G}$ +jet
$> 8.9 \times 10^{-6}$	95	[284] ACCIARRI	99R	L3	$e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$
$> 7.9 \times 10^{-6}$	95	[286] ACCIARRI	98V	L3	$e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$
$> 8.3 \times 10^{-6}$	95	[286] BARATE	98J	ALEP	$e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$

[283] ABBIENDI 01B searches for $\gamma\not{E}$ final states from $\sqrt{s}$=189 GeV.

[284] ABREU 00Z, ACCIARRI 99R search for $\gamma\not{E}$ final states using data from $\sqrt{s}$=189 GeV.

[285] AFFOLDER 00J searches for final states with an energetic jet (from quark or gluon) and large $\not{E}_T$ from undetected gravitinos.

[286] Searches for $\gamma\not{E}$ final states at $\sqrt{s}$=183 GeV.

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. • • •				
	[287] ABBOTT	00G	D0	$p\overline{p} \rightarrow 3\ell + \not{E}_T$, $\not{R}$, $LL\overline{E}$
	[288] ABREU,P	00C	DLPH	$e^+e^- \rightarrow \gamma + S/P$
	[289] ABACHI	97	D0	$\gamma\gamma X$
	[290] BARBER	84B	RVUE	
	[291] HOFFMAN	83	CNTR	$\pi p \rightarrow n(e^+e^-)$

[287] ABBOTT 00G searches for trilepton final states (ℓ=e,μ) with $\not{E}_T$ from the indirect decay of gauginos via $LL\overline{E}$ couplings. Efficiences are computed for all possible production and decay modes of SUSY particles in the framework of the Minimal Supergravity scenario. See Figs. 1–4 for excluded regions in the $m_{1/2}$ versus m_0 plane.

[288] ABREU,P 00C look for the *CP*-even (*S*) and *CP*-odd (*P*) scalar partners of the goldstino, expected to be produced in association with a photon. The *S*/*P* decay into two photons or into two gluons and both the tri-photon and the photon + two jets topologies are investigated. Upper limits on the production cross section are shown in Fig. 5 and the excluded regions in Fig. 6. Data collected at $\sqrt{s}$= 189–202 GeV.

[289] ABACHI 97 searched for $p\overline{p} \rightarrow \gamma\gamma \not{E}_T + X$ as supersymmetry signature. It can be caused by selectron, sneutrino, or neutralino production with a radiative decay of their decay products. They placed limits on cross sections.

[290] 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.

[291] HOFFMAN 83 set CL = 90% limit $d\sigma/dt$ B$(e^+e^-) < 3.5 \times 10^{-32}$ 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

ABBIENDI	01	PL B501 12	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01B	EPJ C18 253	G. Abbiendi *et al.*	(OPAL Collab.)
ABREU	01	EPJ C19 29	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	01B	CERN-EP 2000-133 EPJ C (to be publ.)	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	01C	PL B502 24	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	01D	PL B500 22	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	01G	PL B503 34	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	01	EPJ C19 397	M. Acciarri *et al.*	(L3 Collab.)
AFFOLDER	01B	PR D63 091101	T. Affolder *et al.*	(CDF Collab.)
BARATE	01	PL B499 67	R. Barate *et al.*	(ALEPH Collab.)
BARATE	01B	EPJ C19 415	R. Barate *et al.*	(ALEPH Collab.)
BARATE	01C	PL B499 53	R. Barate *et al.*	(ALEPH Collab.)
SAVINOV	01	PR D63 051101	V. Savinov *et al.*	(CLEO Collab.)
ABBIENDI	00	EPJ C12 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	00G	EPJ C14 51	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	00H	EPJ C14 187	G. Abbiendi *et al.*	(OPAL Collab.)
Also	00Y	EPJ C16 707 (erratum)	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	00J	EPJ C12 551	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	00R	EPJ C13 553	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	00Y	EPJ C16 707 (erratum)	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	00G	PR D62 071701R	B. Abbott *et al.*	(D0 Collab.)
ABREU	00I	EPJ C13 591	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00J	PL B479 129	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00Q	PL B478 65	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00S	PL B485 45	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00T	PL B485 95	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00U	PL B487 36	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00V	EPJ C16 211	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00W	PL B489 38	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00Z	EPJ C17 53	P. Abreu *et al.*	(DELPHI Collab.)
ABREU,P	00C	PL B494 203	P. Abreu *et al.*	(DELPHI Collab.)
ABREU,P	00D	PL B496 59	P. Abreu *et al.*	(DELPHI Collab.)
ABUSAIDI	00	PRL 84 5699	R. Abusaidi *et al.*	(CDMS Collab.)
ACCIARRI	00C	EPJ C16 1	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00D	PL B472 420	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00K	PL B482 31	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00P	PL B489 81	M. Acciarri *et al.*	(L3 Collab.)
AFFOLDER	00D	PRL 84 5704	T. Affolder *et al.*	(CDF Collab.)
AFFOLDER	00G	PRL 84 5273	T. Affolder *et al.*	(CDF Collab.)
AFFOLDER	00J	PRL 85 1378	T. Affolder *et al.*	(CDF Collab.)
BARATE	00G	EPJ C16 71	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00H	EPJ C13 29	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00I	EPJ C12 183	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00P	PL B488 234	R. Barate *et al.*	(ALEPH Collab.)
BREITWEG	00E	EPJ C16 253	J. Breitweg *et al.*	(ZEUS Collab.)
CHO	00B	NP B574 623	G.-C. Cho, K. Hagiwara	
ELLIS	00	PR D62 075010	J. Ellis *et al.*	
FENG	00	PL B482 388	J.L. Feng, K.T. Matchev, F. Wilczek	
LEP	00	CERN-EP-2000-016	LEP Collabs.	(ALEPH, DELPHI, L3, OPAL, SLD+)
MAFI	00	PR D62 035003	A. Mafi, S. Raby	
MALTONI	00	PL B476 107	M. Maltoni *et al.*	
PDG	00	EPJ C15 1	D.E. Groom *et al.*	
ABBIENDI	99	EPJ C6 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	99F	EPJ C8 23	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	99G	EPJ C8 255	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	99M	PL B456 95	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	99T	EPJ C11 619	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	99	PRL 82 29	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	99F	PR D60 031101	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	99K	PRL 83 4476	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	99L	PRL 83 4937	B. Abbott *et al.*	(D0 Collab.)
ABE	99I	PR D59 092002	F. Abe *et al.*	(CDF Collab.)
ABE	99M	PRL 83 2133	F. Abe *et al.*	(CDF Collab.)
ABREU	99A	EPJ C11 383	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99C	EPJ C6 385	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99D	EPJ C6 371	P. Abreu *et al.*	(DLEPHI Collab.)
ABREU	99E	PL B446 75	P. Abreu *et al.*	(DELPHI Collab.)
Also	99N	PL B451 447 (erratum)	P. Abreu *et al.*	(DELPHI Collab.)

ABREU	99F	EPJ C7 595	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99Z	EPJ C11 1	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	99C	PL B445 428	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99H	PL B456 283	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99I	PL B459 354	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99L	PL B462 354	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99R	PL B470 268	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99V	PL B471 308	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99W	PL B471 280	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	99	EPJ C6 225	K. Ackerstaff *et al.*	(OPAL Collab.)
ALAVI-HARATI	99E	PRL 83 2128	A. Alavi-Harati *et al.*	(KTeV Collab.)
AMBROSIO	99	PR D60 082002	M. Ambrosio *et al.*	(Macro Collab.)
BAER	99	PR D59 075002	H. Baer, K. Cheung, J.F. Gunion	
BARATE	99E	EPJ C7 383	R. Barate *et al.*	(ALEPH Collab.)
BARATE	99P	EPJ C11 193	R. Barate *et al.*	(ALEPH Collab.)
BARATE	99Q	PL B469 303	R. Barate *et al.*	(ALEPH Collab.)
FANTI	99	PL B446 117	V. Fanti *et al.*	(CERN NA48 Collab.)
MALTONI	99B	PL B463 230	M. Maltoni, M.I. Vysotsky	
ABBOTT	98	PRL 80 442	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	98C	PRL 80 1591	B. Abbott *et al.*	(D0 Collab.)
ABE	98J	PRL 80 5275	F. Abe *et al.*	(CDF Collab.)
ABE	98L	PRL 81 1791	F. Abe *et al.*	(CDF Collab.)
ABREU	98	EPJ C1 1	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	98P	PL B444 491	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	98F	EPJ C4 207	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	98J	PL B433 163	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	98V	PL B444 503	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	98K	EPJ C4 47	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98L	EPJ C2 213	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98P	PL B433 195	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98V	EPJ C2 441	K. Ackerstaff *et al.*	(OPAL Collab.)
BARATE	98H	PL B420 127	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98J	PL B429 201	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98K	PL B433 176	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98S	EPJ C4 433	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98X	EPJ C2 417	R. Barate *et al.*	(ALEPH Collab.)
BREITWEG	98	PL B434 214	J. Breitweg *et al.*	(ZEUS Collab.)
ELLIS	98	PR D58 095002	J. Ellis *et al.*	
ELLIS	98B	PL B444 367	J. Ellis, T. Falk, K. Olive	
PDG	98	EPJ C3 1	C. Caso *et al.*	
ABACHI	97	PRL 78 2070	S. Abachi *et al.*	(D0 Collab.)
ABE	97K	PR D56 R1357	F. Abe *et al.*	(CDF Collab.)
ABREU	97J	ZPHY C74 577	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	97U	PL B414 373	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	97H	PL B396 301	K. Ackerstaff *et al.*	(OPAL Collab.)
ADAMS	97B	PRL 79 4083	J. Adams *et al.*	(KTeV Collab.)
ALBUQUERQ...	97	PRL 78 3252	I.F. Albuquerque *et al.*	(FNAL E761 Collab.)
BARATE	97K	PL B405 379	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97L	ZPHY C76 1	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97N	PL B407 377	R. Barate *et al.*	(ALEPH Collab.)
BOTTINO	97	PL B402 113	A. Bottino *et al.*	(TORI, LAPP, GENO+)
CARENA	97	PL B390 234	M. Carena, G.F. Giudice, C.E.M. Wagner	
CSIKOR	97	PRL 78 4335	F. Csikor, Z. Fodor	(EOTV, CERN)
DATTA	97	PL B395 54	A. Datta, M. Guchait, N. Parua	(ICTP, TATA)
DEGOUVEA	97	PL B400 117	A. de Gouvea, H. Murayama	
DERRICK	97	ZPHY C73 613	M. Derrick *et al.*	(ZEUS Collab.)
EDSJO	97	PR D56 1879	J. Edsjo, P. Gondolo	
ELLIS	97	PL B394 354	J. Ellis, J.L. Lopez, D.V. Nanopoulos	
ELLIS	97C	PL B413 355	J. Ellis *et al.*	
HEWETT	97	PR D56 5703	J.L. Hewett, T.G. Rizzo, M.A. Doncheski	
KALINOWSKI	97	PL B400 112	J. Kalinowski, P. Zerwas	
TEREKHOV	97	PL B412 86	I. Terekhov	(ALAT)
ABACHI	96	PRL 76 2228	S. Abachi *et al.*	(D0 Collab.)
ABACHI	96B	PRL 76 2222	S. Abachi *et al.*	(D0 Collab.)
ABE	96	PRL 77 438	F. Abe *et al.*	(CDF Collab.)
ABE	96D	PRL 76 2006	F. Abe *et al.*	(CDF Collab.)
ABE	96K	PRL 76 4307	F. Abe *et al.*	(CDF Collab.)
AID	96	ZPHY C71 211	S. Aid *et al.*	(H1 Collab.)
AID	96C	PL B380 461	S. Aid *et al.*	(H1 Collab.)

CHO	96	PL B372 101	G.C. Cho, Y. Kizukuri, N. Oshimo	(TOKAH, OCH)
ELLIS	96B	PL B388 97	J. Ellis *et al.*	(CERN, MINN)
FARRAR	96	PRL 76 4111	G.R. Farrar	(RUTG)
TEREKHOV	96	PL B385 139	I. Terkhov, L. Clavelli	(ALAT)
ABACHI	95C	PRL 75 618	S. Abachi *et al.*	(D0 Collab.)
ABE	95N	PRL 74 3538	F. Abe *et al.*	(CDF Collab.)
ABE	95T	PRL 75 613	F. Abe *et al.*	(CDF Collab.)
ACCIARRI	95E	PL B350 109	M. Acciarri *et al.*	(L3 Collab.)
AKERS	95A	ZPHY C65 367	R. Akers *et al.*	(OPAL Collab.)
AKERS	95R	ZPHY C67 203	R. Akers *et al.*	(OPAL Collab.)
BUSKULIC	95E	PL B349 238	D. Buskulic *et al.*	(ALEPH Collab.)
CLAVELLI	95	PR D51 1117	L. Clavelli, P.W. Coulter	(ALAT)
FALK	95	PL B354 99	T. Falk, K.A. Olive, M. Srednicki	(MINN, UCSB)
LOSECCO	95	PL B342 392	J.M. LoSecco	(NDAM)
AKERS	94K	PL B337 207	R. Akers *et al.*	(OPAL Collab.)
BECK	94	PL B336 141	M. Beck *et al.*	(MPIH, KIAE, SASSO)
CAKIR	94	PR D50 3268	M.B. Cakir, G.R. Farrar	(RUTG)
FALK	94	PL B339 248	T. Falk, K.A. Olive, M. Srednicki	(UCSB, MINN)
SHIRAI	94	PRL 72 3313	J. Shirai *et al.*	(VENUS Collab.)
ADRIANI	93M	PRPL 236 1	O. Adriani *et al.*	(L3 Collab.)
ALITTI	93	NP B400 3	J. Alitti *et al.*	(UA2 Collab.)
CLAVELLI	93	PR D47 1973	L. Clavelli, P.W. Coulter, K.J. Yuan	(ALAT)
DREES	93	PR D47 376	M. Drees, M.M. Nojiri	(DESY, SLAC)
FALK	93	PL B318 354	T. Falk *et al.*	(UCB, UCSB, MINN)
HEBBEKER	93	ZPHY C60 63	T. Hebbeker	(CERN)
KELLEY	93	PR D47 2461	S. Kelley *et al.*	(TAMU, ALAH)
LOPEZ	93C	PL B313 241	J.L. Lopez, D.V. Nanopoulos, X. Wang	(TAMU, HARC+)
MIZUTA	93	PL B298 120	S. Mizuta, M. Yamaguchi	(TOHO)
MORI	93	PR D48 5505	M. Mori *et al.*	(KEK, NIIG, TOKY, TOKA+)
ABE	92L	PRL 69 3439	F. Abe *et al.*	(CDF Collab.)
BOTTINO	92	MPL A7 733	A. Bottino *et al.*	(TORI, ZARA)
Also	91	PL B265 57	A. Bottino *et al.*	(TORI, INFN)
CLAVELLI	92	PR D46 2112	L. Clavelli	(ALAT)
DECAMP	92	PRPL 216 253	D. Decamp *et al.*	(ALEPH Collab.)
LOPEZ	92	NP B370 445	J.L. Lopez, D.V. Nanopoulos, K.J. Yuan	(TAMU)
MCDONALD	92	PL B283 80	J. McDonald, K.A. Olive, M. Srednicki	(LISB+)
ROY	92	PL B283 270	D.P. Roy	(CERN)
ABREU	91F	NP B367 511	P. Abreu *et al.*	(DELPHI Collab.)
AKESSON	91	ZPHY C52 219	T. Akesson *et al.*	(HELIOS Collab.)
ALEXANDER	91F	ZPHY C52 175	G. Alexander *et al.*	(OPAL Collab.)
ANTONIADIS	91	PL B262 109	I. Antoniadis, J. Ellis, D.V. Nanopoulos	(EPOL+)
BOTTINO	91	PL B265 57	A. Bottino *et al.*	(TORI, INFN)
GELMINI	91	NP B351 623	G.B. Gelmini, P. Gondolo, E. Roulet	(UCLA, TRST)
GRIEST	91	PR D43 3191	K. Griest, D. Seckel	
KAMIONKOW...	91	PR D44 3021	M. Kamionkowski	(CHIC, FNAL)
MORI	91B	PL B270 89	M. Mori *et al.*	(Kamiokande Collab.)
NOJIRI	91	PL B261 76	M.M. Nojiri	(KEK)
OLIVE	91	NP B355 208	K.A. Olive, M. Srednicki	(MINN, UCSB)
ROSZKOWSKI	91	PL B262 59	L. Roszkowski	(CERN)
SATO	91	PR D44 2220	N. Sato *et al.*	(Kamiokande Collab.)
ADACHI	90C	PL B244 352	I. Adachi *et al.*	(TOPAZ Collab.)
GRIEST	90	PR D41 3565	K. Griest, M. Kamionkowski, M.S. Turner	(UCB+)
NAKAMURA	89	PR D39 1261	T.T. Nakamura *et al.*	(KYOT, TMTC)
OLIVE	89	PL B230 78	K.A. Olive, M. Srednicki	(MINN, UCSB)
OLIVE	88	PL B205 553	K.A. Olive, M. Srednicki	(MINN, UCSB)
SREDNICKI	88	NP B310 693	M. Srednicki, R. Watkins, K.A. Olive	(MINN, UCSB)
ALBAJAR	87D	PL B198 261	C. Albajar *et al.*	(UA1 Collab.)
ANSARI	87D	PL B195 613	R. Ansari *et al.*	(UA2 Collab.)
ARNOLD	87	PL B186 435	R.G. Arnold *et al.*	(BRUX, DUUC, LOUC+)
NG	87	PL B188 138	K.W. Ng, K.A. Olive, M. Srednicki	(MINN, UCSB)
TUTS	87	PL B186 233	P.M. Tuts *et al.*	(CUSB Collab.)
ALBRECHT	86C	PL 167B 360	H. Albrecht *et al.*	(ARGUS Collab.)
BADIER	86	ZPHY C31 21	J. Badier *et al.*	(NA3 Collab.)
BARNETT	86	NP B267 625	R.M. Barnett, H.E. Haber, G.L. Kane	(LBL, UCSC+)
GAISSER	86	PR D34 2206	T.K. Gaisser, G. Steigman, S. Tilav	(BART, DELA)
VOLOSHIN	86	SJNP 43 495 Translated from YAF 43 779.	M.B. Voloshin, L.B. Okun	(ITEP)

COOPER-...	85B	PL 160B 212	A.M. Cooper-Sarkar *et al.*	(WA66 Collab.)
DAWSON	85	PR D31 1581	S. Dawson, E. Eichten, C. Quigg	(LBL, FNAL)
FARRAR	85	PRL 55 895	G.R. Farrar	(RUTG)
GOLDMAN	85	Physica 15D 181	T. Goldman, H.E. Haber	(LANL, UCSC)
HABER	85	PRPL 117 75	H.E. Haber, G.L. Kane	(UCSC, MICH)
BALL	84	PRL 53 1314	R.C. Ball *et al.*	(MICH, FIRZ, OSU, FNAL+)
BARBER	84B	PL 139B 427	J.S. Barber, R.E. Shrock	(STON)
BRICK	84	PR D30 1134	D.H. Brick *et al.*	(BROW, CAVE, IIT+)
ELLIS	84	NP B238 453	J. Ellis *et al.*	(CERN)
FARRAR	84	PRL 53 1029	G.R. Farrar	(RUTG)
BERGSMA	83C	PL 121B 429	F. Bergsma *et al.*	(CHARM Collab.)
CHANOWITZ	83	PL 126B 225	M.S. Chanowitz, S. Sharpe	(UCB, LBL)
GOLDBERG	83	PRL 50 1419	H. Goldberg	(NEAS)
HOFFMAN	83	PR D28 660	C.M. Hoffman *et al.*	(LANL, ARZS)
KRAUSS	83	NP B227 556	L.M. Krauss	(HARV)
VYSOTSKII	83	SJNP 37 948	M.I. Vysotsky	(ITEP)
		Translated from YAF 37 1597.		
KANE	82	PL 112B 227	G.L. Kane, J.P. Leveille	(MICH)
CABIBBO	81	PL 105B 155	N. Cabibbo, G.R. Farrar, L. Maiani	(ROMA, RUTG)
FARRAR	78	PL 76B 575	G.R. Farrar, P. Fayet	(CIT)
Also	78B	PL 79B 442	G.R. Farrar, P. Fayet	(CIT)