[6] 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.

[7] 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.

[8] 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.

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

[10] 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.

[11] 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.

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

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

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

VALUE	DOCUMENT ID		TECN	COMMENT
none 100 eV – 15 GeV	SREDNICKI	88	COSM	$\widetilde{\gamma}$; $m_{\widetilde{f}}$=100 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	DREES	93	COSM	Minimal supergravity
	FALK	93	COSM	Sfermion mixing
	KELLEY	93	COSM	Minimal supergravity
	MIZUTA	93	COSM	Co-annihilation
	ELLIS	92F	COSM	Minimal supergravity
	KAWASAKI	92	COSM	Minimal supergravity, m_0=A=0
	LOPEZ	92	COSM	Minimal supergravity, m_0=A=0
	MCDONALD	92	COSM	
	NOJIRI	91	COSM	Minimal supergravity
	[13] OLIVE	91	COSM	
	ROSZKOWSKI	91	COSM	
	ELLIS	90	COSM	
	[14] GRIEST	90	COSM	
	[15] GRIFOLS	90	ASTR	$\widetilde{\gamma}$; SN 1987A
	KRAUSS	90	COSM	
	[13] OLIVE	89	COSM	
> 100 eV	[16] ELLIS	88B	ASTR	$\widetilde{\gamma}$; SN 1987A
none 100 eV – (5–7) GeV	SREDNICKI	88	COSM	$\widetilde{\gamma}$; $m_{\widetilde{f}}$=60 GeV
none 100 eV–5 GeV	ELLIS	84	COSM	$\widetilde{\gamma}$; for $m_{\widetilde{f}}$=100 GeV
	GOLDBERG	83	COSM	$\widetilde{\gamma}$
	[17] KRAUSS	83	COSM	$\widetilde{\gamma}$
	VYSOTSKII	83	COSM	$\widetilde{\gamma}$

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

[14] 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.

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

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

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

$\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$ (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 $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, and $\widetilde{\chi}_4^0$. $\widetilde{\chi}_1^0$ is the lightest supersymmetric particle (LSP); see $\widetilde{\chi}_1^0$ 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 $e^+e^- \rightarrow \widetilde{\chi}_i^0\widetilde{\chi}_j^0$. Often limits are given as contour plots in the $m_{\widetilde{\chi}^0} - m_{\widetilde{e}}$ plane vs other parameters. When specific assumptions are made, e.g, the neutralino is a pure photino ($\widetilde{\gamma}$), pure z-ino ($\widetilde{Z}$), or pure neutral higgsino ($\widetilde{H}^0$), the neutralinos will be labelled as such.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 45	95	[18] DECAMP	92	ALEP	$\widetilde{\chi}_2^0$, tanβ >3
> 45	95	[19] HIDAKA	91	RVUE	$\widetilde{\chi}_2^0$
> 70	95	[19] HIDAKA	91	RVUE	$\widetilde{\chi}_3^0$
>108	95	[19] HIDAKA	91	RVUE	$\widetilde{\chi}_4^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[20] ABREU	90G	DLPH	$Z \rightarrow \widetilde{\chi}^0\widetilde{\chi}^0$
		[21] AKRAWY	90N	OPAL	$Z \rightarrow \widetilde{\chi}^0\widetilde{\chi}^0$
> 57	90	[22] BAER	90	RVUE	$\widetilde{\chi}_3^0$; $\Gamma(Z)$; tanβ > 1
		[23] BARKLOW	90	MRK2	$Z \rightarrow \widetilde{\chi}_1^0\widetilde{\chi}_2^0$, $\widetilde{\chi}_2^0\widetilde{\chi}_2^0$
		[24] DECAMP	90K	ALEP	$Z \rightarrow \widetilde{\chi}^0\widetilde{\chi}^0$
> 41	95	[25] SAKAI	90	AMY	$e^+e^- \rightarrow \widetilde{H}_1^0\widetilde{H}_2^0$ ($\widetilde{H}_2^0 \rightarrow f\overline{f}\widetilde{H}_1^0$)
> 31	95	[26] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{Z}$ ($\widetilde{Z} \rightarrow q\overline{q}\widetilde{\gamma}$), $m_{\widetilde{e}}$ < 70 GeV
> 30	95	[27] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{Z}$ ($\widetilde{Z} \rightarrow q\overline{q}\widetilde{g}$)
> 31.3	95	[28] BEHREND	87B	CELL	$e^+e^- \rightarrow \widetilde{H}_1^0\widetilde{H}_2^0$ ($\widetilde{H}_2^0 \rightarrow f\overline{f}\widetilde{H}_1^0$)
> 22	95	[29] BEHREND	87B	CELL	$e^+e^- \rightarrow \gamma\widetilde{\gamma}\widetilde{Z}$ ($\widetilde{Z} \rightarrow \widetilde{\nu}\nu$)
		[30] AKERLOF	85	HRS	$e^+e^- \rightarrow \widetilde{\gamma}\widetilde{\chi}^0$ ($\widetilde{\chi}^0 \rightarrow q\overline{q}\widetilde{\gamma}$)
none 1–21	95	[31] BARTEL	85L	JADE	$e^+e^- \rightarrow \widetilde{H}_1^0\widetilde{H}_2^0$, $\widetilde{H}_2^0 \rightarrow f\overline{f}\widetilde{H}_1^0$
		[32] BEHREND	85	CELL	$e^+e^- \rightarrow$ monojet X
> 35	95	[33] ADEVA	84B	MRKJ	$e^+e^- \rightarrow \gamma\widetilde{Z}$ ($\widetilde{Z} \rightarrow \ell\overline{\ell}\widetilde{\gamma}$)
> 28	95	[34] BARTEL	84C	JADE	$e^+e^- \rightarrow \gamma\widetilde{Z}$ ($\widetilde{Z} \rightarrow f\overline{f}\widetilde{\gamma}$)
		[35] ELLIS	84	COSM	

[18] DECAMP 92 result is within minimal supersymmetry with gaugino-mass unification condition. For tanβ >2 the limit is >40 GeV; and it disappears for tanβ < 1.6.

[19] HIDAKA 91 limit obtained from LEP and preliminary CDF results (as analyzed in BAER 91) within minimal supersymmetry with gaugino-mass unification condition.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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