WIMPs and Other Particles Searches for

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GALACTIC WIMP SEARCHES
Cross-Section Limits for Dark Matter Particles (X^0) on Nuclei

These limits are for weakly-interacting stable particles that may constitute the invisible mass in the galaxy. Unless otherwise noted, a local mass density of 0.3 GeV/cm^3 is assumed; see each paper for velocity distribution assumptions. In the papers the limit is given as a function of the X^0 mass. Here we list limits only for typical mass values of 20 GeV, 100 GeV, and 1 TeV. Specific limits on supersymmetric dark matter particles may be found in the Supersymmetry section.

For m_{X^0} = 20 GeV

VALUE (nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] AHMED	09	CDMS	Ge
		[2] AALSETH	08	CGNT	Ge
		[3] ANGLE	08A	XE10	Xe
		[4] ALNER	07	ZEP2	Xe
		[5] LEE	07A	KIMS	CsI
		[6] AKERIB	06	CDMS	^{73}Ge, ^{29}Si
		[7] SHIMIZU	06A	CNTR	F (CaF_2)
		[8] ALNER	05	NAIA	NaI
		[9] BARNABE-HE...	05	PICA	F (C_4F_{10})
		[10] BENOIT	05	EDEL	^{73}Ge
		[11] GIRARD	05	SMPL	F (C_2ClF_5)
		[12] KLAPDOR-K...	05	HDMS	^{73}Ge (enriched)
		[13] MIUCHI	03	BOLO	LiF
		[14] TAKEDA	03	BOLO	NaF
< 0.08	90	[15] ANGLOHER	02	CRES	Al
		[16] BENOIT	00	EDEL	Ge
< 0.04	95	[17] KLIMENKO	98	CNTR	^{73}Ge, inel.
< 0.8		ALESSAND...	96	CNTR	O
< 6		ALESSAND...	96	CNTR	Te
< 0.02	90	[18] BELLI	96	CNTR	^{129}Xe, inel.
		[19] BELLI	96C	CNTR	^{129}Xe
< 0.004	90	[20] BERNABEI	96	CNTR	Na
< 0.3	90	[20] BERNABEI	96	CNTR	I
< 0.2	95	[21] SARSA	96	CNTR	Na
< 0.015	90	[22] SMITH	96	CNTR	Na
< 0.05	95	[23] GARCIA	95	CNTR	Natural Ge
< 0.1	95	QUENBY	95	CNTR	Na
<90	90	[24] SNOWDEN-...	95	MICA	^{16}O
< 4 $\times 10^3$	90	[24] SNOWDEN-...	95	MICA	^{39}K
< 0.7	90	BACCI	92	CNTR	Na
< 0.12	90	[25] REUSSER	91	CNTR	Natural Ge
< 0.06	95	CALDWELL	88	CNTR	Natural Ge

[1] AHMED 09 give $\sigma < 0.06$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[2] See their Fig. 2 for cross section limits for m_{X^0} between 4 and 10 GeV.

[3] ANGLE 08A give $\sigma < 0.6$ (0.007) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[4] ALNER 07 give $\sigma < 100$ (0.5) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[5] LEE 07A give $\sigma < 1$ (25) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[6] AKERIB 06 give $\sigma < 20$ (0.3) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section. See also AKERIB 05.

[7] SHIMIZU 06A give $\sigma < 2$ (30) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[8] ALNER 05 give $\sigma < 0.5$ (60) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[9] BARNABE-HEIDER 05 give $\sigma < 1.5$ (20) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[10] BENOIT 05 give $\sigma < 10$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[11] GIRARD 05 give $\sigma < 1.5$ pb (90% CL) for spin-dependent X^0-proton cross section.

[12] KLAPDOR-KLEINGROTHAUS 05 give $\sigma < 4$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[13] MIUCHI 03 give model-independent limit $\sigma <35$ pb (90% CL) for spin-dependent X^0-proton cross section.

[14] TAKEDA 03 give model-independent limit $\sigma < 0.03$ (0.6) nb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[15] ANGLOHER 02 limit is for spin-dependent WIMP-Aluminum cross section.

[16] BENOIT 00 find four event categories in Ge detectors and suggest that low-energy surface nuclear recoils can explain anomalous events reported by UKDMC and Saclay NaI experiments.

[17] KLIMENKO 98 limit is for inelastic scattering $X^0\ {}^{73}\text{Ge} \rightarrow X^0\ {}^{73}\text{Ge}^*$ (13.26 keV).

[18] BELLI 96 limit for inelastic scattering $X^0\ {}^{129}\text{Xe} \rightarrow X^0\ {}^{129}\text{Xe}^*$(39.58 keV).

[19] BELLI 96C use background subtraction and obtain $\sigma < 150$ pb (< 1.5 fb) (90% CL) for spin-dependent (independent) X^0-proton cross section. The confidence level is from R. Bernabei, private communication, May 20, 1999.

[20] BERNABEI 96 use pulse shape discrimination to enhance the possible signal. The limit here is from R. Bernabei, private communication, September 19, 1997.

[21] SARSA 96 search for annual modulation of WIMP signal. See SARSA 97 for details of the analysis. The limit here is from M.L. Sarsa, private communication, May 26, 1997.

[22] SMITH 96 use pulse shape discrimination to enhance the possible signal. A dark matter density of 0.4 GeV cm^{-3} is assumed.

[23] GARCIA 95 limit is from the event rate. A weaker limit is obtained from searches for diurnal and annual modulation.

[24] SNOWDEN-IFFT 95 look for recoil tracks in an ancient mica crystal. Similar limits are also given for ^{27}Al and ^{28}Si. See COLLAR 96 and SNOWDEN-IFFT 96 for discussion on potential backgrounds.

[25] REUSSER 91 limit here is changed from published (0.04) after reanalysis by authors. J.L. Vuilleumier, private communication, March 29, 1996.

For m_{χ^0} = 100 GeV

VALUE (nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[26] AHMED	09	CDMS	Ge
		[27] ANGLE	08A	XE10	Xe
		[28] BEDNYAKOV	08	RVUE	Ge
		[29] ALNER	07	ZEP2	Xe
		[30] LEE	07A	KIMS	CsI
		[31] MIUCHI	07	CNTR	F (CF_4)
		[32] AKERIB	06	CDMS	^{73}Ge, ^{29}Si
		[33] SHIMIZU	06A	CNTR	F (CaF_2)
		[34] ALNER	05	NAIA	NaI
		[35] BARNABE-HE...	05	PICA	F (C_4F_{10})
		[36] BENOIT	05	EDEL	^{73}Ge
		[37] GIRARD	05	SMPL	F (C_2ClF_5)
		[38] GIULIANI	05	RVUE	
		[39] GIULIANI	05A	RVUE	
		[40] KLAPDOR-K...	05	HDMS	^{73}Ge (enriched)
		[41] GIULIANI	04	RVUE	
		[42] GIULIANI	04A	RVUE	
		[43] MIUCHI	03	BOLO	LiF
		[44] MIUCHI	03	BOLO	LiF
		[45] TAKEDA	03	BOLO	NaF
$<$ 0.3	90	[46] ANGLOHER	02	CRES	Al
		[47] BELLI	02	RVUE	
		[48] BERNABEI	02C	DAMA	
		[49] GREEN	02	RVUE	
		[50] ULLIO	01	RVUE	
		[51] BENOIT	00	EDEL	Ge
$<$ 0.004	90	[52] BERNABEI	00D		^{129}Xe, inel.
		[53] AMBROSIO	99	MCRO	
		[54] BRHLIK	99	RVUE	
$<$ 0.008	95	[55] KLIMENKO	98	CNTR	^{73}Ge, inel.
$<$ 0.08	95	[56] KLIMENKO	98	CNTR	^{73}Ge, inel.
$<$ 4		ALESSAND...	96	CNTR	O
$<$25		ALESSAND...	96	CNTR	Te
$<$ 0.006	90	[57] BELLI	96	CNTR	^{129}Xe, inel.
		[58] BELLI	96C	CNTR	^{129}Xe
$<$ 0.001	90	[59] BERNABEI	96	CNTR	Na
$<$ 0.3	90	[59] BERNABEI	96	CNTR	I
$<$ 0.7	95	[60] SARSA	96	CNTR	Na
$<$ 0.03	90	[61] SMITH	96	CNTR	Na
$<$ 0.8	90	[61] SMITH	96	CNTR	I
$<$ 0.35	95	[62] GARCIA	95	CNTR	Natural Ge
$<$ 0.6	95	QUENBY	95	CNTR	Na
$<$ 3	95	QUENBY	95	CNTR	I
$< 1.5 \times 10^2$	90	[63] SNOWDEN-...	95	MICA	^{16}O
$< 4 \times 10^2$	90	[63] SNOWDEN-...	95	MICA	^{39}K
$<$ 0.08	90	[64] BECK	94	CNTR	^{76}Ge

$<$ 2.5	90	BACCI	92	CNTR	Na
$<$ 3	90	BACCI	92	CNTR	I
$<$ 0.9	90	[65] REUSSER	91	CNTR	Natural Ge
$<$ 0.7	95	CALDWELL	88	CNTR	Natural Ge

[26] AHMED 09 give $\sigma < 0.02$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[27] ANGLE 08A give $\sigma < 0.9$ (0.01) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[28] BEDNYAKOV 08 reanalyze KLAPDOR-KLEINGROTHAUS 05 and BAUDIS 01 data and give $\sigma < 0.05$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[29] ALNER 07 give $\sigma < 15$ (0.08) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[30] LEE 07A give $\sigma < 0.2$ (6) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[31] MIUCHI 07 give $\sigma < 1 \times 10^4$ pb (90% CL) for spin-dependent X^0-proton cross section with a direction-sensitive detector.

[32] AKERIB 06 give $\sigma < 5$ (0.07) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section. See also AKERIB 05.

[33] SHIMIZU 06A give $\sigma < 2$ (30) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[34] ALNER 05 give $\sigma < 0.3$ (10) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[35] BARNABE-HEIDER 05 give $\sigma < 2$ (30) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[36] BENOIT 05 give $\sigma < 100$ (0.7) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[37] GIRARD 05 give $\sigma < 1.5$ pb (90% CL) for spin-dependent X^0-proton cross section.

[38] GIULIANI 05 analyzes the spin-independent X^0-nucleon cross section limits with both isoscalar and isovector couplings. See Figs. 3 and 4 for limits on the couplings.

[39] GIULIANI 05A analyze available data and give combined limits $\sigma < 0.7$ (0.2) pb for spin-dependent X^0-proton (neutron) cross section.

[40] KLAPDOR-KLEINGROTHAUS 05 give $\sigma < 1.5$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[41] GIULIANI 04 reanalyze COLLAR 00 data and give limits for spin-dependent X^0-proton and neutron couplings.

[42] GIULIANI 04A gives limits for spin-dependent X^0-proton and neutron couplings from existing data.

[43] MIUCHI 03 give model-independent limit for spin-dependent X^0-proton and neutron cross sections. See their Fig. 5.

[44] MIUCHI 03 give model-independent limit $\sigma <35$ pb (90% CL) for spin-dependent X^0-proton cross section.

[45] TAKEDA 03 give model-independent limit $\sigma < 0.04$ (0.8) nb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[46] ANGLOHER 02 limit is for spin-dependent WIMP-Aluminum cross section.

[47] BELLI 02 discuss dependence of the extracted WIMP cross section on the assumptions of the galactic halo structure.

[48] BERNABEI 02C analyze the DAMA data in the scenario in which X^0 scatters into a slightly heavier state as discussed by SMITH 01.

[49] GREEN 02 discusses dependence of extracted WIMP cross section limits on the assumptions of the galactic halo structure.

[50] ULLIO 01 disfavor the possibility that the BERNABEI 99 signal is due to spin-dependent WIMP coupling.

[51] BENOIT 00 find four event categories in Ge detectors and suggest that low-energy surface nuclear recoils can explain anomalous events reported by UKDMC and Saclay NaI experiments.

[52] BERNABEI 00D limit is for inelastic scattering $X^0\,{}^{129}\mathrm{Xe} \rightarrow X^0\,{}^{129}\mathrm{Xe}$ (39.58 keV).

[53] AMBROSIO 99 search for upgoing muon events induced by neutrinos originating from WIMP annihilations in the Sun and Earth.
[54] BRHLIK 99 discuss the effect of astrophysical uncertainties on the WIMP interpretation of the BERNABEI 99 signal.
[55] KLIMENKO 98 limit is for inelastic scattering X^0 ^{73}Ge $\rightarrow$ X^0 ^{73}Ge* (13.26 keV).
[56] KLIMENKO 98 limit is for inelastic scattering X^0 ^{73}Ge $\rightarrow$ X^0 ^{73}Ge* (66.73 keV).
[57] BELLI 96 limit for inelastic scattering X^0 ^{129}Xe $\rightarrow$ X^0 ^{129}Xe*(39.58 keV).
[58] BELLI 96C use background subtraction and obtain $\sigma < 0.35$ pb (< 0.15 fb) (90% CL) for spin-dependent (independent) X^0-proton cross section. The confidence level is from R. Bernabei, private communication, May 20, 1999.
[59] BERNABEI 96 use pulse shape discrimination to enhance the possible signal. The limit here is from R. Bernabei, private communication, September 19, 1997.
[60] SARSA 96 search for annual modulation of WIMP signal. See SARSA 97 for details of the analysis. The limit here is from M.L. Sarsa, private communication, May 26, 1997.
[61] SMITH 96 use pulse shape discrimination to enhance the possible signal. A dark matter density of 0.4 GeV cm^{-3} is assumed.
[62] GARCIA 95 limit is from the event rate. A weaker limit is obtained from searches for diurnal and annual modulation.
[63] SNOWDEN-IFFT 95 look for recoil tracks in an ancient mica crystal. Similar limits are also given for ^{27}Al and ^{28}Si. See COLLAR 96 and SNOWDEN-IFFT 96 for discussion on potential backgrounds.
[64] BECK 94 uses enriched ^{76}Ge (86% purity).
[65] REUSSER 91 limit here is changed from published (0.3) after reanalysis by authors. J.L. Vuilleumier, private communication, March 29, 1996.

For $m_{X^0} = 1$ TeV

VALUE (nb)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[66] AHMED	09	CDMS	Ge
		[67] ANGLE	08A	XE10	Xe
		[68] BEDNYAKOV	08	RVUE	Ge
		[69] ALNER	07	ZEP2	Xe
		[70] LEE	07A	KIMS	CsI
		[71] MIUCHI	07	CNTR	F (CF_4)
		[72] AKERIB	06	CDMS	^{73}Ge, ^{29}Si
		[73] ALNER	05	NAIA	NaI
		[74] BARNABE-HE...	05	PICA	F (C_4F_{10})
		[75] BENOIT	05	EDEL	^{73}Ge
		[76] GIRARD	05	SMPL	F (C_2ClF_5)
		[77] KLAPDOR-K...	05	HDMS	^{73}Ge (enriched)
		[78] MIUCHI	03	BOLO	LiF
		[79] TAKEDA	03	BOLO	NaF
$<$ 3	90	[80] ANGLOHER	02	CRES	Al
		[81] BENOIT	00	EDEL	Ge
		[82] BERNABEI	99D	CNTR	SIMP
		[83] DERBIN	99	CNTR	SIMP
$<$ 0.06	95	[84] KLIMENKO	98	CNTR	^{73}Ge, inel.
$<$ 0.4	95	[85] KLIMENKO	98	CNTR	^{73}Ge, inel.
$<$ 40		ALESSAND...	96	CNTR	O
$<$700		ALESSAND...	96	CNTR	Te

< 0.05	90	[86] BELLI	96	CNTR	^{129}Xe, inel.
< 1.5	90	[87] BELLI	96	CNTR	^{129}Xe, inel.
		[88] BELLI	96C	CNTR	^{129}Xe
< 0.01	90	[89] BERNABEI	96	CNTR	Na
< 9	90	[89] BERNABEI	96	CNTR	I
< 7	95	[90] SARSA	96	CNTR	Na
< 0.3	90	[91] SMITH	96	CNTR	Na
< 6	90	[91] SMITH	96	CNTR	I
< 6	95	[92] GARCIA	95	CNTR	Natural Ge
< 8	95	QUENBY	95	CNTR	Na
< 50	95	QUENBY	95	CNTR	I
$< 7 \times 10^2$	90	[93] SNOWDEN-...	95	MICA	^{16}O
$< 1 \times 10^3$	90	[93] SNOWDEN-...	95	MICA	^{39}K
< 0.8	90	[94] BECK	94	CNTR	^{76}Ge
< 30	90	BACCI	92	CNTR	Na
< 30	90	BACCI	92	CNTR	I
< 15	90	[95] REUSSER	91	CNTR	Natural Ge
< 6	95	CALDWELL	88	CNTR	Natural Ge

[66] AHMED 09 give $\sigma < 0.2$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[67] ANGLE 08A give $\sigma < 8$ (0.1) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[68] BEDNYAKOV 08 reanalyze KLAPDOR-KLEINGROTHAUS 05 and BAUDIS 01 data and give $\sigma < 0.25$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[69] ALNER 07 give $\sigma < 100$ (0.6) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[70] LEE 07A give $\sigma < 0.8$ (30) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[71] MIUCHI 07 give $\sigma < 4 \times 10^4$ pb (90% CL) for spin-dependent X^0-proton cross section with a direction-sensitive detector.

[72] AKERIB 06 give $\sigma < 30$ (0.5) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section. See also AKERIB 05.

[73] ALNER 05 give $\sigma < 1.5$ (40) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[74] BARNABE-HEIDER 05 give $\sigma < 15$ (200) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[75] BENOIT 05 give $\sigma < 600$ (4) pb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[76] GIRARD 05 give $\sigma < 10$ pb (90% CL) for spin-dependent X^0-proton cross section.

[77] KLAPDOR-KLEINGROTHAUS 05 give $\sigma < 10$ pb (90% CL) for spin-dependent X^0-neutron cross section.

[78] MIUCHI 03 give model-independent limit $\sigma <260$ pb (90% CL) for spin-dependent X^0-proton cross section.

[79] TAKEDA 03 give model-independent limit $\sigma < 0.15$ (4) nb (90% CL) for spin-dependent X^0-proton (neutron) cross section.

[80] ANGLOHER 02 limit is for spin-dependent WIMP-Aluminum cross section.

[81] BENOIT 00 find four event categories in Ge detectors and suggest that low-energy surface nuclear recoils can explain anomalous events reported by UKDMC and Saclay NaI experiments.

[82] BERNABEI 99D search for SIMPs (Strongly Interacting Massive Particles) in the mass range 10^3–10^{16} GeV. See their Fig. 3 for cross-section limits.

[83] DERBIN 99 search for SIMPs (Strongly Interacting Massive Particles) in the mass range 10^2–10^{14} GeV. See their Fig. 3 for cross-section limits.

[84] KLIMENKO 98 limit is for inelastic scattering $X^0\,{}^{73}\mathrm{Ge} \rightarrow X^0\,{}^{73}\mathrm{Ge}^*$ (13.26 keV).

[85] KLIMENKO 98 limit is for inelastic scattering $X^0\ {}^{73}\mathrm{Ge} \rightarrow X^0\ {}^{73}\mathrm{Ge}^*$ (66.73 keV).
[86] BELLI 96 limit for inelastic scattering $X^0\ {}^{129}\mathrm{Xe} \rightarrow X^0\ {}^{129}\mathrm{Xe}^*$(39.58 keV).
[87] BELLI 96 limit for inelastic scattering $X^0\ {}^{129}\mathrm{Xe} \rightarrow X^0\ {}^{129}\mathrm{Xe}^*$(236.14 keV).
[88] BELLI 96C use background subtraction and obtain $\sigma < 0.7$ pb ($<$ 0.7 fb) (90% CL) for spin-dependent (independent) X^0-proton cross section. The confidence level is from R. Bernabei, private communication, May 20, 1999.
[89] BERNABEI 96 use pulse shape discrimination to enhance the possible signal. The limit here is from R. Bernabei, private communication, September 19, 1997.
[90] SARSA 96 search for annual modulation of WIMP signal. See SARSA 97 for details of the analysis. The limit here is from M.L. Sarsa, private communication, May 26, 1997.
[91] SMITH 96 use pulse shape discrimination to enhance the possible signal. A dark matter density of 0.4 GeV cm^{-3} is assumed.
[92] GARCIA 95 limit is from the event rate. A weaker limit is obtained from searches for diurnal and annual modulation.
[93] SNOWDEN-IFFT 95 look for recoil tracks in an ancient mica crystal. Similar limits are also given for ^{27}Al and ^{28}Si. See COLLAR 96 and SNOWDEN-IFFT 96 for discussion on potential backgrounds.
[94] BECK 94 uses enriched ^{76}Ge (86% purity).
[95] REUSSER 91 limit here is changed from published (5) after reanalysis by authors. J.L. Vuilleumier, private communication, March 29, 1996.

CONCENTRATION OF STABLE PARTICLES IN MATTER

Concentration of Heavy (Charge +1) Stable Particles in Matter

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4 \times 10^{-17}$	95	[96] YAMAGATA	93	SPEC	Deep sea water, M=5–1600m_p
$<6 \times 10^{-15}$	95	[97] VERKERK	92	SPEC	Water, $M= 10^5$ to 3×10^7 GeV
$<7 \times 10^{-15}$	95	[97] VERKERK	92	SPEC	Water, $M= 10^4$, 6×10^7 GeV
$<9 \times 10^{-15}$	95	[97] VERKERK	92	SPEC	Water, $M= 10^8$ GeV
$<3 \times 10^{-23}$	90	[98] HEMMICK	90	SPEC	Water, $M = 1000m_p$
$<2 \times 10^{-21}$	90	[98] HEMMICK	90	SPEC	Water, $M = 5000m_p$
$<3 \times 10^{-20}$	90	[98] HEMMICK	90	SPEC	Water, $M = 10000m_p$
$<1. \times 10^{-29}$		SMITH	82B	SPEC	Water, M=30–400m_p
$<2. \times 10^{-28}$		SMITH	82B	SPEC	Water, M=12–1000m_p
$<1. \times 10^{-14}$		SMITH	82B	SPEC	Water, M >1000 m_p
$<(0.2–1.) \times 10^{-21}$		SMITH	79	SPEC	Water, M=6–350 m_p

[96] YAMAGATA 93 used deep sea water at 4000 m since the concentration is enhanced in deep sea due to gravity.
[97] VERKERK 92 looked for heavy isotopes in sea water and put a bound on concentration of stable charged massive particle in sea water. The above bound can be translated into into a bound on charged dark matter particle (5×10^6 GeV), assuming the local density, ρ=0.3 GeV/cm^3, and the mean velocity $\langle v \rangle$=300 km/s.
[98] See HEMMICK 90 Fig. 7 for other masses 100–10000 m_p.

Concentration of Heavy Stable Particles Bound to Nuclei

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.2 \times 10^{-11}$	95	[99] JAVORSEK	01	SPEC	Au, M= 3 GeV
$<6.9 \times 10^{-10}$	95	[99] JAVORSEK	01	SPEC	Au, M= 144 GeV
$<1 \times 10^{-11}$	95	[100] JAVORSEK	01B	SPEC	Au, M= 188 GeV
$<1 \times 10^{-8}$	95	[100] JAVORSEK	01B	SPEC	Au, M= 1669 GeV
$<6 \times 10^{-9}$	95	[100] JAVORSEK	01B	SPEC	Fe, M= 188 GeV
$<1 \times 10^{-8}$	95	[100] JAVORSEK	01B	SPEC	Fe, M= 647 GeV
$<4 \times 10^{-20}$	90	[101] HEMMICK	90	SPEC	C, $M = 100 m_p$
$<8 \times 10^{-20}$	90	[101] HEMMICK	90	SPEC	C, $M = 1000 m_p$
$<2 \times 10^{-16}$	90	[101] HEMMICK	90	SPEC	C, $M = 10000 m_p$
$<6 \times 10^{-13}$	90	[101] HEMMICK	90	SPEC	Li, $M = 1000 m_p$
$<1 \times 10^{-11}$	90	[101] HEMMICK	90	SPEC	Be, $M = 1000 m_p$
$<6 \times 10^{-14}$	90	[101] HEMMICK	90	SPEC	B, $M = 1000 m_p$
$<4 \times 10^{-17}$	90	[101] HEMMICK	90	SPEC	O, $M = 1000 m_p$
$<4 \times 10^{-15}$	90	[101] HEMMICK	90	SPEC	F, $M = 1000 m_p$
$< 1.5 \times 10^{-13}$/nucleon	68	[102] NORMAN	89	SPEC	$^{206}\mathrm{Pb} X^-$
$< 1.2 \times 10^{-12}$/nucleon	68	[102] NORMAN	87	SPEC	$^{56,58}\mathrm{Fe} X^-$

[99] JAVORSEK 01 search for (neutral) SIMPs (strongly interacting massive particles) bound to Au nuclei. Here M is the effective SIMP mass.

[100] JAVORSEK 01B search for (neutral) SIMPs (strongly interacting massive particles) bound to Au and Fe nuclei from various origins with exposures on the earth's surface, in a satellite, heavy ion collisions, etc. Here M is the mass of the anomalous nucleus. See also JAVORSEK 02.

[101] See HEMMICK 90 Fig. 7 for other masses 100–10000 m_p.

[102] Bound valid up to $m_{X^-} \sim$ 100 TeV.

LIMITS ON NEUTRAL PARTICLE PRODUCTION

Production Cross Section of Radiatively-Decaying Neutral Particle

VALUE (pb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<(0.043–0.17)	95	[103] ABBIENDI	00D	OPAL	$e^+ e^- \rightarrow X^0 Y^0$, $X^0 \rightarrow Y^0 \gamma$
<(0.05–0.8)	95	[104] ABBIENDI	00D	OPAL	$e^+ e^- \rightarrow X^0 X^0$, $X^0 \rightarrow Y^0 \gamma$
<(2.5–0.5)	95	[105] ACKERSTAFF	97B	OPAL	$e^+ e^- \rightarrow X^0 Y^0$, $X^0 \rightarrow Y^0 \gamma$
<(1.6–0.9)	95	[106] ACKERSTAFF	97B	OPAL	$e^+ e^- \rightarrow X^0 X^0$, $X^0 \rightarrow Y^0 \gamma$

[103] ABBIENDI 00D associated production limit is for m_{X^0}= 90–188 GeV, m_{Y^0}=0 at E_{cm}=189 GeV. See also their Fig. 9.

[104] ABBIENDI 00D pair production limit is for m_{X^0} = 45–94 GeV, m_{Y^0}=0 at E_{cm}=189 GeV. See also their Fig. 12.

[105] ACKERSTAFF 97B associated production limit is for m_{X^0} = 80–160 GeV, m_{Y^0}=0 from 10.0 pb^{-1} at E_{cm} = 161 GeV. See their Fig. 3(a).

[106] ACKERSTAFF 97B pair production limit is for m_{X^0} = 40–80 GeV, m_{Y^0}=0 from 10.0 pb^{-1} at E_{cm} = 161 GeV. See their Fig. 3(b).

Heavy Particle Production Cross Section

VALUE (cm^2/N)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
			[107] ADAMS	97B	KTEV	m= 1.2–5 GeV
$< 10^{-36}$–10^{-33}	90		[108] GALLAS	95	TOF	m= 0.5–20 GeV
$<(4–0.3) \times 10^{-31}$	95		[109] AKESSON	91	CNTR	m = 0–5 GeV
$<2 \times 10^{-36}$	90	0	[110] BADIER	86	BDMP	$\tau = (0.05–1.) \times 10^{-8}$s
$<2.5 \times 10^{-35}$		0	[111] GUSTAFSON	76	CNTR	$\tau > 10^{-7}$ s

[107] ADAMS 97B search for a hadron-like neutral particle produced in pN interactions, which decays into a ρ^0 and a weakly interacting massive particle. Upper limits are given for the ratio to K_L production for the mass range 1.2–5 GeV and lifetime 10^{-9}–10^{-4} s. See also our Light Gluino Section.

[108] GALLAS 95 limit is for a weakly interacting neutral particle produced in 800 GeV/c pN interactions decaying with a lifetime of 10^{-4}–10^{-8} s. See their Figs. 8 and 9. Similar limits are obtained for a stable particle with interaction cross section 10^{-29}–10^{-33} cm^2. See Fig. 10.

[109] AKESSON 91 limit is from weakly interacting neutral long-lived particles produced in pN reaction at 450 GeV/c performed at CERN SPS. Bourquin-Gaillard formula is used as the production model. The above limit is for $\tau > 10^{-7}$ s. For $\tau > 10^{-9}$ s, $\sigma < 10^{-30}$ cm^{-2}/nucleon is obtained.

[110] BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass >2 GeV. The limit applies for particle modes, $\mu^+\pi^-$, $\mu^+\mu^-$, $\pi^+\pi^-$X, $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass-τ plane for each mode.

[111] GUSTAFSON 76 is a 300 GeV FNAL experiment looking for heavy (m >2 GeV) long-lived neutral hadrons in the M4 neutral beam. The above typical value is for m = 3 GeV and assumes an interaction cross section of 1 mb. Values as a function of mass and interaction cross section are given in figure 2.

Production of New Penetrating Non-ν Like States in Beam Dump

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[112] LOSECCO	81	CALO	28 GeV protons

[112] No excess neutral-current events leads to σ(production) $\times$ σ(interaction)$\times$acceptance $< 2.26 \times 10^{-71}$ cm^4/nucleon^2 (CL = 90%) for light neutrals. Acceptance depends on models (0.1 to 4. $\times 10^{-4}$).

LIMITS ON JET-JET RESONANCES

Heavy Particle Production Cross Section in $p\overline{p}$

Limits are for a particle decaying to two hadronic jets.

Units(pb)	CL%	Mass(GeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
			[113] ABE	99F	CDF	1.8 TeV $p\overline{p} \rightarrow b\overline{b}+$ anything
			[114] ABE	97G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2 jets
<2603	95	200	[115] ABE	93G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2jets
< 44	95	400	[115] ABE	93G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2jets
< 7	95	600	[115] ABE	93G	CDF	1.8 TeV $p\overline{p} \rightarrow$ 2jets

[113] ABE 99F search for narrow $b\overline{b}$ resonances in $p\overline{p}$ collisions at E_{cm}=1.8 TeV. Limits on $\sigma(p\overline{p} \rightarrow X+$ anything)$\times$B($X \rightarrow b\overline{b}$) in the range 3–$10^3$ pb (95%CL) are given for m_X=200–750 GeV. See their Table I.

[114] ABE 97G search for narrow dijet resonances in $p\overline{p}$ collisions with 106 pb^{-1} of data at E_{cm} = 1.8 TeV. Limits on $\sigma(p\overline{p} \rightarrow X+$ anything)$\cdot$B($X \rightarrow jj$) in the range 10^4–10^{-1} pb (95%CL) are given for dijet mass m=200–1150 GeV with both jets having $|\eta| < 2.0$ and the dijet system having $|\cos\theta^*| < 0.67$. See their Table I for the list of limits. Supersedes ABE 93G.

[115] ABE 93G gives cross section times branching ratio into light (d, u, s, c, b) quarks for Γ = 0.02 M. Their Table II gives limits for M = 200–900 GeV and Γ = (0.02–0.2) M.

LIMITS ON CHARGED PARTICLES IN e^+e^-

Heavy Particle Production Cross Section in e^+e^-

Ratio to $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ unless noted. See also entries in Free Quark Search and Magnetic Monopole Searches.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
			[116] ACKERSTAFF	98P	OPAL	Q=1,2/3, m=45–89.5 GeV
			[117] ABREU	97D	DLPH	Q=1,2/3, m=45–84 GeV
			[118] BARATE	97K	ALEP	Q=1, m=45–85 GeV
$<2 \times 10^{-5}$	95		[119] AKERS	95R	OPAL	Q=1, m= 5–45 GeV
$<1 \times 10^{-5}$	95		[119] AKERS	95R	OPAL	Q=2, m= 5–45 GeV
$<2 \times 10^{-3}$	90		[120] BUSKULIC	93C	ALEP	Q=1, m=32–72 GeV
$<(10^{-2}$–1)	95		[121] ADACHI	90C	TOPZ	Q = 1, m = 1–16, 18–27 GeV
$<7 \times 10^{-2}$	90		[122] ADACHI	90E	TOPZ	Q = 1, m = 5–25 GeV
$<1.6 \times 10^{-2}$	95	0	[123] KINOSHITA	82	PLAS	Q=3–180, m <14.5 GeV
$<5.0 \times 10^{-2}$	90	0	[124] BARTEL	80	JADE	Q=(3,4,5)/3 2–12 GeV

[116] ACKERSTAFF 98P search for pair production of long-lived charged particles at E_{cm} between 130 and 183 GeV and give limits σ <(0.05–0.2) pb (95%CL) for spin-0 and spin-1/2 particles with m=45–89.5 GeV, charge 1 and 2/3. The limit is translated to the cross section at E_{cm}=183 GeV with the s dependence described in the paper. See their Figs. 2–4.

[117] ABREU 97D search for pair production of long-lived particles and give limits σ <(0.4–2.3) pb (95%CL) for various center-of-mass energies E_{cm}=130–136, 161, and 172 GeV, assuming an almost flat production distribution in $\cos\theta$.

[118] BARATE 97K search for pair production of long-lived charged particles at E_{cm} = 130, 136, 161, and 172 GeV and give limits σ <(0.2–0.4) pb (95%CL) for spin-0 and spin-1/2 particles with m=45–85 GeV. The limit is translated to the cross section at E_{cm}=172 GeV with the E_{cm} dependence described in the paper. See their Figs. 2 and 3 for limits on J = 1/2 and J = 0 cases.

[119] AKERS 95R is a CERN-LEP experiment with $W_{cm} \sim m_Z$. The limit is for the production of a stable particle in multihadron events normalized to $\sigma(e^+e^- \rightarrow$ hadrons). Constant phase space distribution is assumed. See their Fig. 3 for bounds for $Q = \pm 2/3$, $\pm 4/3$.

[120] BUSKULIC 93C is a CERN-LEP experiment with $W_{cm} = m_Z$. The limit is for a pair or single production of heavy particles with unusual ionization loss in TPC. See their Fig. 5 and Table 1.

[121] ADACHI 90C is a KEK-TRISTAN experiment with W_{cm} = 52–60 GeV. The limit is for pair production of a scalar or spin-1/2 particle. See Figs. 3 and 4.

[122] ADACHI 90E is KEK-TRISTAN experiment with W_{cm} = 52–61.4 GeV. The above limit is for inclusive production cross section normalized to $\sigma(e^+ e^- \rightarrow \mu^+ \mu^-)\cdot\beta(3-\beta^2)/2$, where $\beta = (1 - 4m^2/W^2_{cm})^{1/2}$. See the paper for the assumption about the production mechanism.

[123] KINOSHITA 82 is SLAC PEP experiment at W_{cm} = 29 GeV using lexan and ^{39}Cr plastic sheets sensitive to highly ionizing particles.

[124] BARTEL 80 is DESY-PETRA experiment with W_{cm} = 27–35 GeV. Above limit is for inclusive pair production and ranges between $1. \times 10^{-1}$ and $1. \times 10^{-2}$ depending on mass and production momentum distributions. (See their figures 9, 10, 11).

Branching Fraction of Z^0 to a Pair of Stable Charged Heavy Fermions

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<5 \times 10^{-6}$	95	[125] AKERS	95R	OPAL	m= 40.4–45.6 GeV
$<1 \times 10^{-3}$	95	AKRAWY	90O	OPAL	m = 29–40 GeV

[125] AKERS 95R give the 95% CL limit $\sigma(X\overline{X})/\sigma(\mu\mu) < 1.8\times10^{-4}$ for the pair production of singly- or doubly-charged stable particles. The limit applies for the mass range 40.4–45.6 GeV for $X^\pm$ and < 45.6 GeV for $X^{\pm\pm}$. See the paper for bounds for $Q = \pm2/3,\ \pm4/3$.

LIMITS ON CHARGED PARTICLES IN HADRONIC REACTIONS

Heavy Particle Production Cross Section

VALUE (nb)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.19	95		[126] AKTAS	04C	H1	m=3–10 GeV
<0.05	95		[127] ABE	92J	CDF	m=50–200 GeV
<30–130			[128] CARROLL	78	SPEC	m=2–2.5 GeV
<100		0	[129] LEIPUNER	73	CNTR	m=3–11 GeV

[126] AKTAS 04C look for charged particle photoproduction at HERA with mean c.m. energy of 200 GeV.

[127] ABE 92J look for pair production of unit-charged particles which leave detector before decaying. Limit shown here is for m=50 GeV. See their Fig. 5 for different charges and stronger limits for higher mass.

[128] CARROLL 78 look for neutral, $S = -2$ dihyperon resonance in $pp \rightarrow 2K^+X$. Cross section varies within above limits over mass range and p_{lab} = 5.1–5.9 GeV/c.

[129] LEIPUNER 73 is an NAL 300 GeV p experiment. Would have detected particles with lifetime greater than 200 ns.

Heavy Particle Production Differential Cross Section

VALUE ($cm^2 sr^{-1} GeV^{-1}$)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$<2.6 \times 10^{-36}$	90	0	[130] BALDIN	76	CNTR	−	Q= 1, m=2.1–9.4 GeV
$<2.2 \times 10^{-33}$	90	0	[131] ALBROW	75	SPEC	±	Q= ±1, m=4–15 GeV
$<1.1 \times 10^{-33}$	90	0	[131] ALBROW	75	SPEC	±	Q= ±2, m=6–27 GeV
$<8. \times 10^{-35}$	90	0	[132] JOVANOV...	75	CNTR	±	m=15–26 GeV
$<1.5 \times 10^{-34}$	90	0	[132] JOVANOV...	75	CNTR	±	Q= ±2, m=3–10 GeV
$<6. \times 10^{-35}$	90	0	[132] JOVANOV...	75	CNTR	±	Q= ±2, m=10–26 GeV

$<1. \times 10^{-31}$	90	0	[133] APPEL	74	CNTR	$\pm$	m=3.2–7.2 GeV
$<5.8 \times 10^{-34}$	90	0	[134] ALPER	73	SPEC	$\pm$	m=1.5–24 GeV
$<1.2 \times 10^{-35}$	90	0	[135] ANTIPOV	71B	CNTR	$-$	Q=$-$, m=2.2–2.8
$<2.4 \times 10^{-35}$	90	0	[136] ANTIPOV	71C	CNTR	$-$	Q=$-$, m=1.2–1.7, 2.1–4
$<2.4 \times 10^{-35}$	90	0	BINON	69	CNTR	$-$	Q=$-$, m=1–1.8 GeV
$<1.5 \times 10^{-36}$		0	[137] DORFAN	65	CNTR		Be target m=3–7 GeV
$<3.0 \times 10^{-36}$		0	[137] DORFAN	65	CNTR		Fe target m=3–7 GeV

[130] BALDIN 76 is a 70 GeV Serpukhov experiment. Value is per Al nucleus at $\theta = 0$. For other charges in range -0.5 to -3.0, CL = 90% limit is $(2.6 \times 10^{-36})/|(\text{charge})|$ for mass range (2.1–9.4 GeV) $\times$ $|(\text{charge})|$. Assumes stable particle interacting with matter as do antiprotons.

[131] ALBROW 75 is a CERN ISR experiment with E_{cm} = 53 GeV. θ = 40 mr. See figure 5 for mass ranges up to 35 GeV.

[132] JOVANOVICH 75 is a CERN ISR 26+26 and 15+15 GeV pp experiment. Figure 4 covers ranges $Q = 1/3$ to 2 and m = 3 to 26 GeV. Value is per GeV momentum.

[133] APPEL 74 is NAL 300 GeV pW experiment. Studies forward production of heavy (up to 24 GeV) charged particles with momenta 24–200 GeV ($-$charge) and 40–150 GeV (+charge). Above typical value is for 75 GeV and is per GeV momentum per nucleon.

[134] ALPER 73 is CERN ISR 26+26 GeV pp experiment. $p >$0.9 GeV, $0.2 < \beta < 0.65$.

[135] ANTIPOV 71B is from same 70 GeV p experiment as ANTIPOV 71C and BINON 69.

[136] ANTIPOV 71C limit inferred from flux ratio. 70 GeV p experiment.

[137] DORFAN 65 is a 30 GeV/c p experiment at BNL. Units are per GeV momentum per nucleus.

Long-Lived Heavy Particle Invariant Cross Section

VALUE (cm^2/GeV^2/N)	CL%	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$< 5–700 \times 10^{-35}$	90	[138] BERNSTEIN	88	CNTR		
$< 5–700 \times 10^{-37}$	90	[138] BERNSTEIN	88	CNTR		
$<2.5 \times 10^{-36}$	90	[139] THRON	85	CNTR	$-$	Q= 1, m=4–12 GeV
$<1. \times 10^{-35}$	90	[139] THRON	85	CNTR	+	Q= 1, m=4–12 GeV
$<6. \times 10^{-33}$	90	[140] ARMITAGE	79	SPEC		m=1.87 GeV
$<1.5 \times 10^{-33}$	90	[140] ARMITAGE	79	SPEC		m=1.5–3.0 GeV
		[141] BOZZOLI	79	CNTR	$\pm$	Q = (2/3, 1, 4/3, 2)
$<1.1 \times 10^{-37}$	90	[142] CUTTS	78	CNTR		m=4–10 GeV
$<3.0 \times 10^{-37}$	90	[143] VIDAL	78	CNTR		m=4.5–6 GeV

[138] BERNSTEIN 88 limits apply at x = 0.2 and p_T = 0. Mass and lifetime dependence of limits are shown in the regions: m = 1.5–7.5 GeV and $\tau = 10^{-8}$–2×10^{-6} s. First number is for hadrons; second is for weakly interacting particles.

[139] THRON 85 is FNAL 400 GeV proton experiment. Mass determined from measured velocity and momentum. Limits are for $\tau > 3 \times 10^{-9}$ s.

[140] ARMITAGE 79 is CERN-ISR experiment at E_{cm} = 53 GeV. Value is for x = 0.1 and p_T = 0.15. Observed particles at m = 1.87 GeV are found all consistent with being antideuterons.

[141] BOZZOLI 79 is CERN-SPS 200 GeV pN experiment. Looks for particle with τ larger than 10^{-8} s. See their figure 11–18 for production cross-section upper limits vs mass.

[142] CUTTS 78 is pBe experiment at FNAL sensitive to particles of $\tau > 5 \times 10^{-8}$ s. Value is for $-0.3 < x < 0$ and $p_T = 0.175$.
[143] VIDAL 78 is FNAL 400 GeV proton experiment. Value is for $x = 0$ and $p_T = 0$. Puts lifetime limit of $< 5 \times 10^{-8}$ s on particle in this mass range.

Long-Lived Heavy Particle Production (σ(Heavy Particle) / $\sigma(\pi)$)

VALUE	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<10^{-8}$		[144] NAKAMURA	89	SPEC	$\pm$	$Q = (-5/3, \pm 2)$
	0	[145] BUSSIERE	80	CNTR	$\pm$	$Q = (2/3, 1, 4/3, 2)$

[144] NAKAMURA 89 is KEK experiment with 12 GeV protons on Pt target. The limit applies for mass $\lesssim$ 1.6 GeV and lifetime $\gtrsim 10^{-7}$ s.
[145] BUSSIERE 80 is CERN-SPS experiment with 200–240 GeV protons on Be and Al target. See their figures 6 and 7 for cross-section ratio vs mass.

Production and Capture of Long-Lived Massive Particles

VALUE (10^{-36} cm^2)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<20 to 800	0	[146] ALEKSEEV	76	ELEC	τ=5 ms to 1 day
<200 to 2000	0	[146] ALEKSEEV	76B	ELEC	τ=100 ms to 1 day
<1.4 to 9	0	[147] FRANKEL	75	CNTR	τ=50 ms to 10 hours
<0.1 to 9	0	[148] FRANKEL	74	CNTR	τ=1 to 1000 hours

[146] ALEKSEEV 76 and ALEKSEEV 76B are 61–70 GeV p Serpukhov experiment. Cross section is per Pb nucleus.
[147] FRANKEL 75 is extension of FRANKEL 74.
[148] FRANKEL 74 looks for particles produced in thick Al targets by 300–400 GeV/c protons.

Long-Lived Particle Search at Hadron Collisions

Limits are for cross section times branching ratio.

VALUE (pb/nucleon)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<2	90	0	[149] BADIER	86	BDMP	$\tau = (0.05\text{–}1.) \times 10^{-8}$s

[149] BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass >2 GeV. The limit applies for particle modes, $\mu^+\pi^-$, $\mu^+\mu^-$, $\pi^+\pi^-$X, $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass-τ plane for each mode.

Long-Lived Heavy Particle Cross Section

VALUE (pb/sr)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<34	95	[150] RAM	94	SPEC	$1015 < m_{X^{++}} < 1085$ MeV
<75	95	[150] RAM	94	SPEC	$920 < m_{X^{++}} < 1025$ MeV

[150] RAM 94 search for a long-lived doubly-charged fermion X^{++} with mass between m_N and $m_N + m_\pi$ and baryon number +1 in the reaction $pp \rightarrow X^{++} n$. No candidate is found. The limit is for the cross section at 15° scattering angle at 460 MeV incident energy and applies for $\tau(X^{++}) \gg 0.1\,\mu$s.

LIMITS ON CHARGED PARTICLES IN COSMIC RAYS

Heavy Particle Flux in Cosmic Rays

VALUE ($cm^{-2}sr^{-1}s^{-1}$)	CL%	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$\sim 6 \times 10^{-9}$		2	[151] SAITO	90			$Q \simeq 14$, $m \simeq 370 m_p$
$< 1.4 \times 10^{-12}$	90	0	[152] MINCER	85	CALO		$m \geq 1$ TeV
			[153] SAKUYAMA	83B	PLAS		$m \sim 1$ TeV
$< 1.7 \times 10^{-11}$	99	0	[154] BHAT	82	CC		
$< 1. \times 10^{-9}$	90	0	[155] MARINI	82	CNTR	±	Q= 1, $m \sim 4.5 m_p$
$2. \times 10^{-9}$		3	[156] YOCK	81	SPRK	±	Q= 1, $m \sim 4.5 m_p$
		3	[156] YOCK	81	SPRK		Fractionally charged
3.0×10^{-9}		3	[157] YOCK	80	SPRK		$m \sim 4.5\ m_p$
$(4 \pm 1) \times 10^{-11}$		3	GOODMAN	79	ELEC		$m \geq 5$ GeV
$< 1.3 \times 10^{-9}$	90		[158] BHAT	78	CNTR	±	$m >$1 GeV
$< 1.0 \times 10^{-9}$		0	BRIATORE	76	ELEC		
$< 7. \times 10^{-10}$	90	0	YOCK	75	ELEC	±	$Q >7e$ or $< -7e$
$> 6. \times 10^{-9}$		5	[159] YOCK	74	CNTR		$m >$6 GeV
$< 3.0 \times 10^{-8}$		0	DARDO	72	CNTR		
$< 1.5 \times 10^{-9}$		0	TONWAR	72	CNTR		$m >$10 GeV
$< 3.0 \times 10^{-10}$		0	BJORNBOE	68	CNTR		$m >$5 GeV
$< 5.0 \times 10^{-11}$	90	0	JONES	67	ELEC		m=5–15 GeV

[151] SAITO 90 candidates carry about 450 MeV/nucleon. Cannot be accounted for by conventional backgrounds. Consistent with strange quark matter hypothesis.

[152] MINCER 85 is high statistics study of calorimeter signals delayed by 20–200 ns. Calibration with AGS beam shows they can be accounted for by rare fluctuations in signals from low-energy hadrons in the shower. Claim that previous delayed signals including BJORNBOE 68, DARDO 72, BHAT 82, SAKUYAMA 83B below may be due to this fake effect.

[153] SAKUYAMA 83B analyzed 6000 extended air shower events. Increase of delayed particles and change of lateral distribution above 10^{17} eV may indicate production of very heavy parent at top of atmosphere.

[154] BHAT 82 observed 12 events with delay $> 2. \times 10^{-8}$ s and with more than 40 particles. 1 eV has good hadron shower. However all events are delayed in only one of two detectors in cloud chamber, and could not be due to strongly interacting massive particle.

[155] MARINI 82 applied PEP-counter for TOF. Above limit is for velocity = 0.54 of light. Limit is inconsistent with YOCK 80 YOCK 81 events if isotropic dependence on zenith angle is assumed.

[156] YOCK 81 saw another 3 events with $Q = \pm1$ and m about $4.5 m_p$ as well as 2 events with $m > 5.3 m_p$, $Q = \pm0.75 \pm 0.05$ and $m > 2.8 m_p$, $Q = \pm0.70 \pm 0.05$ and 1 event with $m = (9.3 \pm 3.) m_p$, $Q = \pm0.89 \pm 0.06$ as possible heavy candidates.

[157] YOCK 80 events are with charge exactly or approximately equal to unity.

[158] BHAT 78 is at Kolar gold fields. Limit is for $\tau > 10^{-6}$ s.

[159] YOCK 74 events could be tritons.

Superheavy Particle (Quark Matter) Flux in Cosmic Rays

VALUE ($cm^{-2}sr^{-1}s^{-1}$)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<5 \times 10^{-16}$	90		[160] AMBROSIO	00B	MCRO	$m > 5 \times 10^{14}$ GeV
$<1.8 \times 10^{-12}$	90		[161] ASTONE	93	CNTR	$m \geq 1.5 \times 10^{-13}$gram
$<1.1 \times 10^{-14}$	90		[162] AHLEN	92	MCRO	$10^{-10} < m < 0.1$ gram
$<2.2 \times 10^{-14}$	90	0	[163] NAKAMURA	91	PLAS	$m > 10^{11}$ GeV
$<6.4 \times 10^{-16}$	90	0	[164] ORITO	91	PLAS	$m > 10^{12}$ GeV
$<2.0 \times 10^{-11}$	90		[165] LIU	88	BOLO	$m > 1.5 \times 10^{-13}$ gram
$<4.7 \times 10^{-12}$	90		[166] BARISH	87	CNTR	$1.4 \times 10^{8} < m < 10^{12}$ GeV
$<3.2 \times 10^{-11}$	90	0	[167] NAKAMURA	85	CNTR	$m > 1.5 \times 10^{-13}$gram
$<3.5 \times 10^{-11}$	90	0	[168] ULLMAN	81	CNTR	Planck-mass 10^{19}GeV
$<7. \times 10^{-11}$	90	0	[168] ULLMAN	81	CNTR	$m \leq 10^{16}$ GeV

[160] AMBROSIO 00B searched for quark matter ("nuclearites") in the velocity range $(10^{-5}$–$1)$ c. The listed limit is for 2×10^{-3} c.

[161] ASTONE 93 searched for quark matter ("nuclearites") in the velocity range $(10^{-3}$–$1)$ c. Their Table 1 gives a compilation of searches for nuclearites.

[162] AHLEN 92 searched for quark matter ("nuclearites"). The bound applies to velocity $< 2.5 \times 10^{-3}$ c. See their Fig. 3 for other velocity/c and heavier mass range.

[163] NAKAMURA 91 searched for quark matter in the velocity range $(4 \times 10^{-5}$–$1)$ c.

[164] ORITO 91 searched for quark matter. The limit is for the velocity range $(10^{-4}$–$10^{-3})$ c.

[165] LIU 88 searched for quark matter ("nuclearites") in the velocity range $(2.5 \times 10^{-3}$–$1)c$. A less stringent limit of 5.8×10^{-11} applies for $(1$–$2.5) \times 10^{-3}c$.

[166] BARISH 87 searched for quark matter ("nuclearites") in the velocity range $(2.7 \times 10^{-4}$–$5 \times 10^{-3})c$.

[167] NAKAMURA 85 at KEK searched for quark-matter. These might be lumps of strange quark matter with roughly equal numbers of u, d, s quarks. These lumps or nuclearites were assumed to have velocity of $(10^{-4}$–$10^{-3})$ c.

[168] ULLMAN 81 is sensitive for heavy slow singly charge particle reaching earth with vertical velocity 100–350 km/s.

Highly Ionizing Particle Flux

VALUE ($m^{-2}yr^{-1}$)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.4	95	0	KINOSHITA	81B	PLAS	Z/β 30–100

REFERENCES FOR Searches for WIMPs and Other Particles

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AALSETH	08	PRL 101 251301	C.E. Aalseth et al.	(CoGeNT Collab.)
ANGLE	08A	PRL 101 091301	J. Angle et al.	(XENON10 Collab.)
BEDNYAKOV	08	PAN 71 111	V.A. Bednyakov, H.P. Klapdor-Kleingrothaus, I.V. Krivosheina	
		Translated from YAF 71 112.		
ALNER	07	PL B653 161	G.J. Alner et al.	(ZEPLIN-II Collab.)
LEE	07A	PRL 99 091301	H.S. Lee et al.	(KIMS Collab.)
MIUCHI	07	PL B654 58	K. Miuchi et al.	
AKERIB	06	PR D73 011102R	D.S. Akerib et al.	(CDMS Collab.)
SHIMIZU	06A	PL B633 195	Y. Shimizu et al.	
AKERIB	05	PR D72 052009	D.S. Akerib et al.	(CDMS Collab.)
ALNER	05	PL B616 17	G.J. Alner et al.	(UK Dark Matter Collab.)
BARNABE-HE...	05	PL B624 186	M. Barnabe-Heider et al.	(PICASSO Collab.)
BENOIT	05	PL B616 25	A. Benoit et al.	(EDELWEISS Collab.)

GIRARD	05	PL B621 233	T.A. Girard *et al.*	(SIMPLE Collab.)
GIULIANI	05	PRL 95 101301	F. Giuliani	
GIULIANI	05A	PR D71 123503	F. Giuliani, T.A. Girard	
KLAPDOR-K...	05	PL B609 226	H.V. Klapdor-Kleingrothaus, I.V. Krivosheina, C. Tomei	
AKTAS	04C	EPJ C36 413	A. Atkas *et al.*	(H1 Collab.)
GIULIANI	04	PL B588 151	F. Giuliani, T.A. Girard	
GIULIANI	04A	PRL 93 161301	F. Giuliani	
MIUCHI	03	ASP 19 135	K. Miuchi *et al.*	
TAKEDA	03	PL B572 145	A. Takeda *et al.*	
ANGLOHER	02	ASP 18 43	G. Angloher *et al.*	(CRESST Collab.)
BELLI	02	PR D66 043503	P. Belli *et al.*	
BERNABEI	02C	EPJ C23 61	R. Bernabei *et al.*	(DAMA Collab.)
GREEN	02	PR D66 083003	A.M. Green	
JAVORSEK	02	PR D65 072003	D. Javorsek II *et al.*	
BAUDIS	01	PR D63 022001	L. Baudis *et al.*	(Heidelberg-Moscow Collab.)
JAVORSEK	01	PR D64 012005	D. Javorsek II *et al.*	
JAVORSEK	01B	PRL 87 231804	D. Javorsek II *et al.*	
SMITH	01	PR D64 043502	D. Smith, N. Weiner	
ULLIO	01	JHEP 0107 044	P. Ullio, M. Kamionkowski, P. Vogel	
ABBIENDI	00D	EPJ C13 197	G. Abbiendi *et al.*	(OPAL Collab.)
AMBROSIO	00B	EPJ C13 453	M. Ambrosio *et al.*	(MACRO Collab.)
BENOIT	00	PL B479 8	A. Benoit *et al.*	(EDELWEISS Collab.)
BERNABEI	00D	NJP 2 15	R. Bernabei *et al.*	(DAMA Collab.)
COLLAR	00	PRL 85 3083	J.I. Collar *et al.*	(SIMPLE Collab.)
ABE	99F	PRL 82 2038	F. Abe *et al.*	(CDF Collab.)
AMBROSIO	99	PR D60 082002	M. Ambrosio *et al.*	(Macro Collab.)
BERNABEI	99	PL B450 448	R. Bernabei *et al.*	(DAMA Collab.)
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DERBIN	99	PAN 62 1886	A.V. Derbin *et al.*	
		Translated from YAF 62 2034.		
ACKERSTAFF	98P	PL B433 195	K. Ackerstaff *et al.*	(OPAL Collab.)
KLIMENKO	98	JETPL 67 875	A.A. Klimenko *et al.*	
		Translated from ZETFP 67 835.		
ABE	97G	PR D55 R5263	F. Abe *et al.*	(CDF Collab.)
ABREU	97D	PL B396 315	P. Abreu *et al.*	(DELPHI Collab.)
ACKERSTAFF	97B	PL B391 210	K. Ackerstaff *et al.*	(OPAL Collab.)
ADAMS	97B	PRL 79 4083	J. Adams *et al.*	(FNAL KTeV Collab.)
BARATE	97K	PL B405 379	R. Barate *et al.*	(ALEPH Collab.)
SARSA	97	PR D56 1856	M.L. Sarsa *et al.*	(ZARA)
ALESSAND...	96	PL B384 316	A. Alessandrello *et al.*	(MILA, MILAI, SASSO)
BELLI	96	PL B387 222	P. Belli *et al.*	(DAMA Collab.)
Also		PL B389 783 (erratum)	P. Belli *et al.*	(DAMA Collab.)
BELLI	96C	NC 19C 537	P. Belli *et al.*	(DAMA Collab.)
BERNABEI	96	PL B389 757	R. Bernabei *et al.*	(DAMA Collab.)
COLLAR	96	PRL 76 331	J.I. Collar	(SCUC)
SARSA	96	PL B386 458	M.L. Sarsa *et al.*	(ZARA)
Also		PR D56 1856	M.L. Sarsa *et al.*	(ZARA)
SMITH	96	PL B379 299	P.F. Smith *et al.*	(RAL, SHEF, LOIC+)
SNOWDEN-...	96	PRL 76 332	D.P. Snowden-Ifft, E.S. Freeman, P.B. Price	(UCB)
AKERS	95R	ZPHY C67 203	R. Akers *et al.*	(OPAL Collab.)
GALLAS	95	PR D52 6	E. Gallas *et al.*	(MSU, FNAL, MIT, FLOR)
GARCIA	95	PR D51 1458	E. Garcia *et al.*	(ZARA, SCUC, PNL)
QUENBY	95	PL B351 70	J.J. Quenby *et al.*	(LOIC, RAL, SHEF+)
SNOWDEN-...	95	PRL 74 4133	D.P. Snowden-Ifft, E.S. Freeman, P.B. Price	(UCB)
Also		PRL 76 331	J.I. Collar	(SCUC)
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BECK	94	PL B336 141	M. Beck *et al.*	(MPIH, KIAE, SASSO)
RAM	94	PR D49 3120	S. Ram *et al.*	(TELA, TRIU)
ABE	93G	PRL 71 2542	F. Abe *et al.*	(CDF Collab.)
ASTONE	93	PR D47 4770	P. Astone *et al.*	(ROMA, ROMAI, CATA, FRAS)
BUSKULIC	93C	PL B303 198	D. Buskulic *et al.*	(ALEPH Collab.)
YAMAGATA	93	PR D47 1231	T. Yamagata, Y. Takamori, H. Utsunomiya	(KONAN)
ABE	92J	PR D46 R1889	F. Abe *et al.*	(CDF Collab.)
AHLEN	92	PRL 69 1860	S.P. Ahlen *et al.*	(MACRO Collab.)
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AKESSON	91	ZPHY C52 219	T. Akesson *et al.*	(HELIOS Collab.)
NAKAMURA	91	PL B263 529	S. Nakamura *et al.*	
ORITO	91	PRL 66 1951	S. Orito *et al.*	(ICEPP, WASCR, NIHO, ICRR)
REUSSER	91	PL B255 143	D. Reusser *et al.*	(NEUC, CIT, PSI)

ADACHI	90C	PL B244 352	I. Adachi *et al.*	(TOPAZ Collab.)
ADACHI	90E	PL B249 336	I. Adachi *et al.*	(TOPAZ Collab.)
AKRAWY	90O	PL B252 290	M.Z. Akrawy *et al.*	(OPAL Collab.)
HEMMICK	90	PR D41 2074	T.K. Hemmick *et al.*	(ROCH, MICH, OHIO+)
SAITO	90	PRL 65 2094	T. Saito *et al.*	(ICRR, KOBE)
NAKAMURA	89	PR D39 1261	T.T. Nakamura *et al.*	(KYOT, TMTC)
NORMAN	89	PR D39 2499	E.B. Norman *et al.*	(LBL)
BERNSTEIN	88	PR D37 3103	R.M. Bernstein *et al.*	(STAN, WISC)
CALDWELL	88	PRL 61 510	D.O. Caldwell *et al.*	(UCSB, UCB, LBL)
LIU	88	PRL 61 271	G. Liu, B. Barish	
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BADIER	86	ZPHY C31 21	J. Badier *et al.*	(NA3 Collab.)
MINCER	85	PR D32 541	A. Mincer *et al.*	(UMD, GMAS, NSF)
NAKAMURA	85	PL 161B 417	K. Nakamura *et al.*	(KEK, INUS)
THRON	85	PR D31 451	J.L. Thron *et al.*	(YALE, FNAL, IOWA)
SAKUYAMA	83B	LNC 37 17	H. Sakuyama, N. Suzuki	(MEIS)
Also		LNC 36 389	H. Sakuyama, K. Watanabe	(MEIS)
Also		NC 78A 147	H. Sakuyama, K. Watanabe	(MEIS)
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BHAT	82	PR D25 2820	P.N. Bhat *et al.*	(TATA)
KINOSHITA	82	PRL 48 77	K. Kinoshita, P.B. Price, D. Fryberger	(UCB+)
MARINI	82	PR D26 1777	A. Marini *et al.*	(FRAS, LBL, NWES, STAN+)
SMITH	82B	NP B206 333	P.F. Smith *et al.*	(RAL)
KINOSHITA	81B	PR D24 1707	K. Kinoshita, P.B. Price	(UCB)
LOSECCO	81	PL 102B 209	J.M. LoSecco *et al.*	(MICH, PENN, BNL)
ULLMAN	81	PRL 47 289	J.D. Ullman	(LEHM, BNL)
YOCK	81	PR D23 1207	P.C.M. Yock	(AUCK)
BARTEL	80	ZPHY C6 295	W. Bartel *et al.*	(JADE Collab.)
BUSSIERE	80	NP B174 1	A. Bussiere *et al.*	(BGNA, SACL, LAPP)
YOCK	80	PR D22 61	P.C.M. Yock	(AUCK)
ARMITAGE	79	NP B150 87	J.C.M. Armitage *et al.*	(CERN, DARE, FOM+)
BOZZOLI	79	NP B159 363	W. Bozzoli *et al.*	(BGNA, LAPP, SACL+)
GOODMAN	79	PR D19 2572	J.A. Goodman *et al.*	(UMD)
SMITH	79	NP B149 525	P.F. Smith, J.R.J. Bennett	(RHEL)
BHAT	78	PRAM 10 115	P.N. Bhat, P.V. Ramana Murthy	(TATA)
CARROLL	78	PRL 41 777	A.S. Carroll *et al.*	(BNL, PRIN)
CUTTS	78	PRL 41 363	D. Cutts *et al.*	(BROW, FNAL, ILL, BARI+)
VIDAL	78	PL 77B 344	R.A. Vidal *et al.*	(COLU, FNAL, STON+)
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		Translated from YAF 22 1021.		
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		Translated from YAF 23 1190.		
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BRIATORE	76	NC 31A 553	L. Briatore *et al.*	(LCGT, FRAS, FREIB)
GUSTAFSON	76	PRL 37 474	H.R. Gustafson *et al.*	(MICH)
ALBROW	75	NP B97 189	M.G. Albrow *et al.*	(CERN, DARE, FOM+)
FRANKEL	75	PR D12 2561	S. Frankel *et al.*	(PENN, FNAL)
JOVANOV...	75	PL 56B 105	J.V. Jovanovich *et al.*	(MANI, AACH, CERN+)
YOCK	75	NP B86 216	P.C.M. Yock	(AUCK, SLAC)
APPEL	74	PRL 32 428	J.A. Appel *et al.*	(COLU, FNAL)
FRANKEL	74	PR D9 1932	S. Frankel *et al.*	(PENN, FNAL)
YOCK	74	NP B76 175	P.C.M. Yock	(AUCK)
ALPER	73	PL 46B 265	B. Alper *et al.*	(CERN, LIVP, LUND, BOHR+)
LEIPUNER	73	PRL 31 1226	L.B. Leipuner *et al.*	(BNL, YALE)
DARDO	72	NC 9A 319	M. Dardo *et al.*	(TORI)
TONWAR	72	JPA 5 569	S.C. Tonwar, S. Naranan, B.V. Sreekantan	(TATA)
ANTIPOV	71B	NP B31 235	Y.M. Antipov *et al.*	(SERP)
ANTIPOV	71C	PL 34B 164	Y.M. Antipov *et al.*	(SERP)
BINON	69	PL 30B 510	F.G. Binon *et al.*	(SERP)
BJORNBOE	68	NC B53 241	J. Bjornboe *et al.*	(BOHR, TATA, BERN+)
JONES	67	PR 164 1584	L.W. Jones	(MICH, WISC, LBL, UCLA, MINN+)
DORFAN	65	PRL 14 999	D.E. Dorfan *et al.*	(COLU)