Searches for Massive Neutrinos and Lepton Mixing

MINIREVIEW GOES HERE

(A) Heavy Neutral Leptons

Stable Neutral Heavy Lepton MASS LIMITS

Note that LEP results in combination with REUSSER 91 exclude a fourth stable neutrino with $m <$ 2400 GeV.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>45.0	95	ABREU	92B	DLPH	Dirac
>39.5	95	ABREU	92B	DLPH	Majorana
>44.1	95	ALEXANDER	91F	OPAL	Dirac
>37.2	95	ALEXANDER	91F	OPAL	Majorana
none 3–100	90	SATO	91	KAM2	Kamiokande II
>42.8	95	[1] ADEVA	90S	L3	Dirac
>34.8	95	[1] ADEVA	90S	L3	Majorana
>42.7	95	DECAMP	90F	ALEP	Dirac

[1] ADEVA 90S limits for the heavy neutrino apply if the mixing with the charged leptons satisfies $|U_{1j}|^2 + |U_{2j}|^2 + |U_{3j}|^2 >\ 6.2\times10^{-8}$ at $m_{L^0} = 20$ GeV and $>\ 5.1\times10^{-10}$ for $m_{L^0} = 40$ GeV.

Neutral Heavy Lepton MASS LIMITS

Limits apply only to heavy lepton type given in comment at right of data Listings. See review above for description of types. L, e_P, μ_P, e_O, μ_O stand for sequential lepton, para-electron, para-muon, ortho-electron, ortho-muon respectively. For a review, see GAN 88.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
none 2.5–50	95	[2] ADRIANI	92I	L3	$\lvert U_{\tau \text{ or } \mu}\rvert^2\ < 3\times10^{-4}$
none 4–50	95	[2] ADRIANI	92I	L3	$\lvert U_{\tau}\rvert^2\ < 3\times10^{-4}$
>46.4	95	[3] ADEVA	90S	L3	Dirac
>45.1	95	[3] ADEVA	90S	L3	Majorana
>46.5	95	[4] AKRAWY	90L	OPAL	Coupling to e or μ
>45.7	95	[4] AKRAWY	90L	OPAL	Coupling to τ
>19.6	95	[5,6] BURCHAT	90	MRK2	Dirac, all $\lvert U_{\ell j}\rvert^2$
none 25–45.7	95	[5,7] DECAMP	90F	ALEP	Dirac $\lvert U_{\ell j}\rvert^2\ >\ 10^{-13}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>44.5	95	[8] ABREU	92B	DLPH	Dirac
>39.0	95	[8] ABREU	92B	DLPH	Majorana
>41	95	[5,6] BURCHAT	90	MRK2	Dirac, $\lvert U_{\ell j}\rvert^2\ >\ 10^{-10}$
none 8.2–26.5	95	[9] SHAW	89	AMY	Dirac L^0, $\lvert U_{ej}\rvert^2\ > 10^{-6}$
none 8.3–22.4	95	[9] SHAW	89	AMY	Majorana L^0, $\lvert U_{ej}\rvert^2\ > 10^{-6}$
none 8.1–24.9	95	[9] SHAW	89	AMY	Majorana L^0, $\lvert U_{\mu j}\rvert^2\ > 10^{-6}$
none 1.8–6.7	90	[10] AKERLOF	88	HRS	$\lvert U_{ej}\rvert^2=1$
none 1.8–6.4	90	[10] AKERLOF	88	HRS	$\lvert U_{\mu j}\rvert^2=1$
none 2.5–6.3	80	[10] AKERLOF	88	HRS	$\lvert U_{\tau j}\rvert^2=1$
none 0.6–34.6	95	[11] BEHREND	88C	CELL	$L^0=e^0_P$, $V-A$ coupling $\lvert U_{ej}\rvert^2=1$
none 0.4–37.4	95	[11] BEHREND	88C	CELL	$L^0=e^0_P$, $V+A$ coupling $\lvert U_{ej}\rvert^2=1$
none 0.25–14	90	[12] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2=1.$
none 0.25–10	90	[12] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2=0.1$

*CITATION: L. Montanet et al., Physical Review D50, 1173 (1994) and 1995 off-year partial update for the 1996 edition (URL: http://pdg.lbl.gov/)

none 0.25–7.7	90	[12] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2$=0.03
none 1.–2.	90	[13] WENDT	87	MRK2	$\lvert U_{e \text{ or } \mu j}\rvert^2$=0.1
none 2.2–4.	90	[13] WENDT	87	MRK2	$\lvert U_{e \text{ or } \mu j}\rvert^2$=0.001
none 2.3–3.	90	[13] WENDT	87	MRK2	$\lvert U_{\tau j}\rvert^2$=0.1
none 3.2–4.8	90	[13] WENDT	87	MRK2	$\lvert U_{\tau j}\rvert^2$=0.001
none 0.3–0.9	90	[14] BADIER	86	CNTR	$\lvert U_{e j}\rvert^2$=0.8
none 0.33–2.0	90	[14] BADIER	86	CNTR	$\lvert U_{e j}\rvert^2$=0.03
none 0.6–0.7	90	[14] BADIER	86	CNTR	$\lvert U_{\mu j}\rvert^2$=0.8
none 0.6–2.0	90	[14] BADIER	86	CNTR	$\lvert U_{\mu j}\rvert^2$=0.01–0.001
>24.5	95	[15] BARTEL	83	JADE	e^0_P or e^0_O, $V+A$
>22.5	95	[15] BARTEL	83	JADE	e^0_P or e^0_O, $V-A$
none 1–9	90	[16] CLARK	81	SPEC	μ^0_P
> 1.2		MEYER	77	MRK1	Neutral

[2] ADRIANI 92I is a search for isosinglet heavy lepton N_ℓ which might be produced from $Z \rightarrow \nu_\ell N_\ell$, then decay via a number of different channels. Limits are weaker for decay lengths longer than about 1 m.

[3] ADEVA 90S limits for the heavy neutrino apply if the mixing with the charged leptons satisfies $\lvert U_{1j}\rvert^2 + \lvert U_{2j}\rvert^2 + \lvert U_{3j}\rvert^2 > 6.2\times10^{-8}$ at $m_{L^0} = 20$ GeV and $> 5.1\times10^{-10}$ for $m_{L^0} = 40$ GeV.

[4] AKRAWY 90L limits valid if coupling strength is greater than a mass-dependent value, e.g., 4.9×10^{-7} at $m_{L^0} = 20$ GeV, 3.5×10^{-8} at 30 GeV, 4×10^{-9} at 40 GeV.

[5] Limits apply for $\ell = e$, μ, or τ and for $V-A$ decays of Dirac neutrinos.

[6] BURCHAT 90 searched for Z decay to unstable L^0 pairs at SLC. It includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.

[7] For $25 < m_{L^0} < 42.7$ GeV, DECAMP 90F exclude an L^0 for all values of $\lvert U_{\ell j}\rvert^2$.

[8] ABREU 92B limit is for mixing matrix element ≈ 1 for coupling to e or μ. Reduced somewhat for coupling to τ, increased somewhat for smaller mixing matrix element. Replaces ABREU 91F.

[9] SHAW 89 also excludes the mass region from 8.0 to 27.2 GeV for Dirac L^0 and from 8.1 to 23.6 GeV for Majorana L^0 with equal full-strength couplings to e and μ. SHAW 89 also gives correlated bounds on lepton mixing.

[10] AKERLOF 88 is PEP e^+e^- experiment at $E_{\rm cm} = 29$ GeV. The L^0 is assumed to decay via $V-A$ to e or μ or τ plus a virtual W.

[11] The first bound of BEHREND 88C applies for a general L^0. The second and third have their assumptions indicated.

[12] MISHRA 87 is Fermilab neutrino experiment looking for either dimuon or double vertex events (hence long-lived).

[13] WENDT 87 is MARK-II search at PEP for heavy ν with decay length 1–20 cm (hence long-lived).

[14] BADIER 86 is a search for a long-lived penetrating sequential lepton produced in π^- – nucleon collisions with lifetimes in the range from $5. \times 10^{-7}$–$5. \times 10^{-11}$ s and decaying into at least two charged particles. U_{ej} and U_{mj} are mixing angles to ν_e and ν_μ. See also the BADIER 86 entry in the section "Searches for Massive Neutrinos and Lepton Mixing".

[15] BARTEL 83 is PETRA e^+e^- experiment with average $W_{\rm cm} = 34.2$ GeV. First (second) limit is for $V+A(V-A)$ type $W^- e_P e$ coupling.

[16] CLARK 81 is FNAL experiment with 209 GeV muons. Bounds apply to para-muon which couples with full weak strength to muon. See also section on "Neutral Heavy Lepton Production Cross Section (μ Nucleon)" below.

Astrophysical Limits on Neutrino MASS for $m_\nu > 1$ MeV

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 26–4700		[17] BECK	94	COSM	Dirac
none 60–115		[18] KONOPLICH	94	ASTR	Dirac
none 6 – hundreds		[19,20] MORI	92B	KAM2	Dirac neutrino
none 24 – hundreds		[19,20] MORI	92B	KAM2	Majorana neutrino
none 10–2400	90	[21] REUSSER	91	CNTR	HPGe search
none 3–100	90	SATO	91	KAM2	Kamiokande II
		[22] ENQVIST	89	COSM	
none 12–1400		[17] CALDWELL	88	COSM	Dirac ν
none 4–16	90	[17,19] OLIVE	88	COSM	Dirac ν
none 4–35	90	OLIVE	88	COSM	Majorana ν
>4.2 to 4.7		SREDNICKI	88	COSM	Dirac ν
>5.3 to 7.4		SREDNICKI	88	COSM	Majorana ν
none 20–1000	95	[17] AHLEN	87	COSM	Dirac ν
>4.1		GRIEST	87	COSM	Dirac ν

[17] These results assume that neutrinos make up dark matter in the galactic halo.
[18] KONOPLICH 94 bound is sensitive to assumed ν concentration in the Galaxy.
[19] Limits based on annihilations in the sun and are due to an absence of high energy neutrinos detected in underground experiments.
[20] MORI 92B results assume that neutrinos make up dark matter in the galactic halo. Limits based on annihilations in earth are also given.
[21] REUSSER 91 uses existing $\beta\beta$ detector (see FISHER 89) to search for CDM Dirac neutrinos.
[22] ENQVIST 89 argue that there is no cosmological upper bound on heavy neutrinos.

Neutral Heavy Lepton Production Cross Section (μN)

VALUE (cm^2)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<4. \times 10^{-38}$	0	[23] CLARK	81	SPEC	0	μ^0_P
$<1.22 \times 10^{-34}$		[24] LEBRITTON	80	SPEC	0	$M^0 \to \mu^+ \mu^- \nu$

[23] CLARK 81 is FNAL experiment with 209 GeV muon. Looked for μ^+ nucleon $\to \overline{\mu}^0_P$ X, $\overline{\mu}^0_P \to \mu^+ \mu^- \overline{\nu}_\mu$ and $\mu^+ n \to \mu^{++}_P$ X, $\mu^{++}_P \to 2\mu^+ \nu_\mu$. Above limits are for $\sigma\times$BR taken from their mass-dependence plot figure 2.
[24] LEBRITTON 80 is BNL experiment with 10.5 GeV muons. Trimuons are consistent with QED trident and diffractively produced ρ decay.

Neutral Heavy Lepton Production Cross Section

σ × B($\tau \to$ new neutral lepton) × B(neutral lepton $\to e\pi$ or $\mu\pi$)

VALUE (10^{-5} nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<450	90	[25] MEYER	77	MRK1	For m_L=0.5 GeV
<250	90	[25] MEYER	77	MRK1	For m_L=1.5 GeV

[25] MEYER 77 experiment looks for narrow neutral resonance in $e^-\pi$ and $\mu^-\pi$ channels. See "Heavy Lepton MASS LIMITS" section above.

$\sigma(L\overline{L})$ × [B($L \to e\nu X$) + B($\overline{L} \to e\nu X$)]

VALUE (10^{-5} nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 8	90	[26] ERREDE	84	HRS	For m_L=1 GeV
<18	90	[26] ERREDE	84	HRS	For m_L=2 GeV
<20	90	[26] ERREDE	84	HRS	For m_L=3 GeV
<11	90	[26] ERREDE	84	HRS	For m_L=4 or 5 GeV
<13	90	[26] ERREDE	84	HRS	For m_L=6 GeV
<17	90	[26] ERREDE	84	HRS	For m_L=7 GeV

[26] Assuming X = μ. If X = meson, limits are 20% higher. ERREDE 84 say these limits are comparable to those expected from naive theory. e^+e^-, E_{cm} = 29 GeV. See also GRONAU 84, RIZZO 84.

$\sigma(L_1 + L_2)$ × B($L_1 \to$ only light neutrinos)

VALUE (10^{-5} nb)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.7	90	[27] AKERLOF	85	HRS	For m_L=2 GeV
<18.	90	[27] AKERLOF	85	HRS	For m_L=10 GeV

[27] AKERLOF 85 observe no monojets above background. They use standard couplings to Z to find $\sigma(L_1 + L_2)$ = 0.36 pb. Above data then imply B($L_1 \to$ light neutrinos) <13–50% for m_L = 2–10 GeV.

$\sigma(L\overline{L})$ × BR$_1$ × BR$_2$ / σ(standard via virtual Z)

where BR$_1$ and BR$_2$ are branching ratios leading to events with two or four charged particles, and σ(standard) = $0.35(\beta(3+\beta^2)/4)$ pb with β = velocity/c of L.

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 0.1–0.2	90	0	[28] PERL	85	MRK2	For m_L <1 GeV

[28] PERL 85 examine a variety of models and processes. They search up to m_L = 14 GeV but are most sensitive for m_L <1 GeV. They require lepton lifetime $<m_L 10^{-11}$ s [m_L in GeV] which limits their ability to constrain the mixing of a 4th conventional generation.

(B) Sum of Neutrino Masses

MINIREVIEW GOES HERE

Limit on Total ν MASS, m_{tot}

(Defined in the above note), of effectively stable neutrinos (i.e., those with mean lives greater than or equal to the age of the universe). These papers assumed Dirac neutrinos. When necessary, we have generalized the results reported so they apply to m_{tot}. For other limits, see SZALAY 76, VYSOTSKY 77, BERNSTEIN 81, FREESE 84, SCHRAMM 84, and COWSIK 85.

VALUE (eV)	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
<180	SZALAY	74	COSM
<132	COWSIK	72	COSM
<280	MARX	72	COSM
<400	GERSHTEIN	66	COSM

Astrophysical and Cosmological Limits on ν MASSES

If neutrinos are present as dark matter in galactic halos, limits on neutrino masses have been computed based on neutrino degeneracy and Fermi statistics. The results depend strongly on assumptions. See the references.

VALUE (eV)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	SPERGEL	88B	COSM	
	KAWASAKI	86	COSM	
	KAWASAKI	86B	COSM	
	TAKAHARA	86	COSM	supernovae
	MADSEN	85	COSM	Some anisotropy
	MADSEN	84	COSM	Assume isotropy
	SARKAR	84	COSM	Decaying neutrinos
	FREESE	83	COSM	Degenerate ν
	LIN	83	COSM	
	PRIMACK	83	COSM	
	BOND	81	COSM	Adiabatic
	DAVIS	81	COSM	Adiabatic+decaying ν's
	SCHRAMM	81	COSM	Isothermal
	TREMAINE	79	COSM	Isothermal

Limits on MASSES of Light Stable Right-Handed ν (with necessarily suppressed interaction strengths)

VALUE (eV)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<100–200	[29] OLIVE	82	COSM	Dirac ν
<200–2000	[29] OLIVE	82	COSM	Majorana ν

[29] Depending on interaction strength g_R where $g_R < G_F$.

Limits on MASSES of Heavy Stable Right-Handed ν (with necessarily suppressed interaction strengths)

VALUE (GeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
> 10	[30] OLIVE	82	COSM	g_R/G_F <0.1
>100	[30] OLIVE	82	COSM	g_R/G_F <0.01

[30] These results apply to heavy Majorana neutrinos and are summarized by the equation: m_ν >1.2 GeV (G_F/g_R).

(C) Searches for Neutrinoless Double β Decay

MINIREVIEW GOES HERE

Half-life Measurements and Limits for Double β Decay

In all cases of double beta decay, (Z,A) $\rightarrow$ (Z+2,A) $+ 2\beta^- +$ (0 or 2)$\overline{\nu}_e$.

$t_{1/2}(10^{21}$ yr)	*CL%*	*ISOTOPE*		*TRANSITION*	*METHOD*	*DOCUMENT ID*	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 18	90	^{130}Te	0ν	$0^+ \rightarrow 0^+$	Bolometer	[31] ALESSAND...	94
> 0.041	90	^{96}ZR		$0^+ \rightarrow 2^+_1$		ARPESELLA	94
> 0.033	90	^{96}ZR		$0^+ \rightarrow 0^+_1$		ARPESELLA	94
> 0.024	90	^{96}ZR		$0^+ \rightarrow 2^+_2$		ARPESELLA	94
> 0.031	90	^{96}ZR		$0^+ \rightarrow 2^+_3$		ARPESELLA	94

>2.37	90	^{116}Cd	0ν	$0^+ \rightarrow 2^+$	γ in HP Ge	[32] PIEPKE	94
>2.05	90	^{116}Cd	0ν	$0^+ \rightarrow 0^+_1$	γ in HP Ge	[32] PIEPKE	94
>2.05	90	^{116}Cd	0ν	$0^+ \rightarrow 0^+_2$	γ in HP Ge	[32] PIEPKE	94
>44	68	^{100}Mo	0ν	$0^+ \rightarrow 0^+$	Si(Li)	ALSTON-...	93
>340	90	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	TPC	[33,34] VUILLEUMIER	93
>260	90	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	TPC	[34,35] VUILLEUMIER	93
>0.21	90	^{136}Xe	2ν	$0^+ \rightarrow 0^+$	TPC	[34] VUILLEUMIER	93
>2.5	90	^{130}Te	0ν	$0^+ \rightarrow 0^+$	Bolometer	ALESSAND...	92
>0.093	90	^{136}Xe	2ν	$0^+ \rightarrow 0^+$	Drift chamber	ARTEMJEV	92
>1400	90	^{76}Ge	0ν	$0^+ \rightarrow 0^+$	Enriched HPGe	BALYSH	92
>430	90	^{76}Ge	0ν	$0^+ \rightarrow 2^+$	Enriched HPGe	BALYSH	92
2.7 ± 0.1		^{130}Te			Geochem	BERNATOW...	92
7200 ± 400		^{128}Te			Geochem	[36] BERNATOW...	92
>0.5	90	^{100}Mo	2ν	$0^+ \rightarrow 2^+_1$	HPGe	[37] BLUM	92
>0.9	90	^{100}Mo	2ν	$0^+ \rightarrow 0^+_1$	HPGe	[37] BLUM	92
>0.6	90	^{100}Mo	2ν	$0^+ \rightarrow 2^+_2$	HPGe	[37] BLUM	92
>27	68	^{82}Se	0ν	$0^+ \rightarrow 0^+$	TPC	ELLIOTT	92
$0.108^{+0.026}_{-0.006}$		^{82}Se	2ν	$0^+ \rightarrow 0^+$	TPC	ELLIOTT	92
>0.15	68	^{100}Mo	2ν	$0^+ \rightarrow 2^+_1$	Spect	[38] KUDOMI	92
>1.1	68	^{100}Mo	0ν	$0^+ \rightarrow 2^+_1$	Spect	[38] KUDOMI	92
>0.08	68	^{100}Mo	2ν	$0^+ \rightarrow 0^+_1$	Spect	[38] KUDOMI	92
>0.56	68	^{100}Mo	0ν	$0^+ \rightarrow 0^+_1$	Spect	[38] KUDOMI	92
>0.051	68	^{100}Mo	2ν	$0^+ \rightarrow 4^+_1$	Spect	[38] KUDOMI	92
>0.63	68	^{100}Mo	0ν	$0^+ \rightarrow 4^+_1$	Spect	[38] KUDOMI	92
>0.065	68	^{100}Mo	2ν	$0^+ \rightarrow 2^+_2$	Spect	[38] KUDOMI	92
>0.12	68	^{100}Mo	0ν	$0^+ \rightarrow 2^+_2$	Spect	[38] KUDOMI	92
>330	90	^{76}Ge	0ν	$0^+ \rightarrow 0^+$	HPGe	[39] REUSSER	92
>65	90	^{76}Ge	0ν	$0^+ \rightarrow 2^+$	HPGe	[39] REUSSER	92
$0.92^{+0.07}_{-0.04}$		^{76}Ge	2ν	$0^+ \rightarrow 0^+$	Enriched HPGe	[40] AVIGNONE	91
>12	95	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	Prop cntr	[33,41] BELLOTTI	91
>10	95	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	Prop cntr	[35,41] BELLOTTI	91
>3.3	95	^{136}Xe	0ν	$0^+ \rightarrow 2^+$	Prop cntr	[41] BELLOTTI	91
>0.16	95	^{136}Xe	2ν		Prop cntr	BELLOTTI	91
>4.7	68	^{100}Mo	0ν		Spect	EJIRI	91
$0.0115^{+0.0030}_{-0.0020}$		^{100}Mo	2ν		Spect	EJIRI	91
					Mass spect	[42] HYKAWY	91
2.0 ± 0.6		^{238}U			Geochem	[43] TURKEVICH	91
>9.5	76	^{48}Ca	0ν		CaF_2 scint.	YOU	91
>0.14	68	^{100}Mo	$0\nu+2\nu$	$0^+ \rightarrow 2^+$	γ in HPGe	BARABASH	90
>0.042	68	^{100}Mo	$0\nu+2\nu$	$0^+ \rightarrow 0^+_1$	γ in HPGe	BARABASH	90
>0.17	68	^{116}Cd	$0\nu+2\nu$	$0^+ \rightarrow 2^+$	γ in HPGe	BARABASH	90
$1.12^{+0.48}_{-0.26}$		^{76}Ge	2ν	$0^+ \rightarrow 0^+$	HPGe	[44] MILEY	90
>1300	68	^{76}Ge	0ν	$0^+ \rightarrow 0^+$	Enriched Ge(Li)	[45] VASENKO	90
0.9 ± 0.1		^{76}Ge	2ν		Enriched Ge(Li)	VASENKO	90
>4.0	68	^{100}Mo	0ν	$0^+ \rightarrow 0^+$	Si(Li)	ALSTON-...	89
>0.40	68	^{100}Mo	0ν	$0^+ \rightarrow 2^+$	Si(Li)	ALSTON-...	89
>3.3	68	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	Ion chamber	[33] BARABASH	89
>2.9	68	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	Ion chamber	[35] BARABASH	89
>1.5	68	^{136}Xe	0ν	$0^+ \rightarrow 2^+$	Ion chamber	BARABASH	89
>0.084	68	^{136}Xe	2ν	$0^+ \rightarrow 0^+$	Ion chamber	BARABASH	89
>9	90	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	Prop chamber	[33] BELLOTTI	89
>8	90	^{136}Xe	0ν	$0^+ \rightarrow 0^+$	Prop chamber	[35] BELLOTTI	89
>1.3	68	^{116}Cd	0ν		$^{116}CdWO_4$ scint	DANEVICH	89
>60	68	^{76}Ge	0ν	$0^+ \rightarrow 2^+$	HPGe	[46] MORALES	88
>4.7	68	^{128}Te		$0^+ \rightarrow 2^+$	Ge(Li)	[47] BELLOTTI	87
>4.5	68	^{130}Te		$0^+ \rightarrow 2^+$	Ge(Li)	[47] BELLOTTI	87

>500	68	^{76}Ge	0ν	$0^+ \to 0^+$	HPGe	[48] CALDWELL	87
$0.11^{+0.08}_{-0.03}$		^{82}Se	2ν	$0^+ \to 0^+$	TPC	ELLIOTT	87B
>120	68	^{76}Ge	0ν	$0^+ \to 0^+$	HPGe	BELLOTTI	86
>12	68	^{76}Ge	0ν	$0^+ \to 2^+$	HPGe	BELLOTTI	86
>7.0	68	^{82}Se	0ν	$0^+ \to 0^+$	TPC	ELLIOTT	86
>2.3	68	^{76}Ge	0ν		Ge(Li)	[49] HUBERT	85
>120	68	^{76}Ge	0ν	$0^+ \to 0^+$	Ge(Li)	BELLOTTI	84
>17	68	^{76}Ge	0ν		Ge	FORSTER	84
>17	90	^{76}Ge	0ν		Intrinsic Ge	AVIGNONE	83
>20	68	^{76}Ge	0ν	$0^+ \to 0^+$	Ge(Li)	BELLOTTI	83
>800	95	^{128}Te			Geochem	[50] KIRSTEN	83
2.60 ± 0.28		^{130}Te			Geochem	[50] KIRSTEN	83

[31] ALESSANDRELLO 94 state that their present limit excludes a significant contribution from the 0ν channel of ^{130}Te even if the large lifetime obtained in the geochemical experiment of BERNATOWICZ 92 is assumed.

[32] In PIEPKE 94, the studied excited states of ^{116}Sn have energies above the ground state of 1.2935 MeV for the 2^+ state, 1.7568 MeV for the 0_1^+ state, and 2.0273 for the 0_2^+ state.

[33] Limit in the case of a transition induced by a Majorana mass.

[34] VUILLEUMIER 93 supersedes FISHER 89.

[35] Limit for lepton-number violating right-handed current-induced (RHC) decay.

[36] BERNATOWICZ 92 finds ^{128}Te/^{130}Te activity ratio from slope of ^{128}Xe/^{132}Xe vs ^{130}Xe/^{132}Xe ratios during extraction, and normalizes to lead-dated ages for the ^{130}Te lifetime. The authors state that their results imply that "(a) the double beta decay of ^{128}Te has been firmly established and its half-life has been determined ... without any ambiguity due to trapped Xe interferences... (b) Theoretical calculations ... underestimate the [long half-lives of ^{128}Te ^{130}Te] by 1 or 2 orders of magnitude, pointing to a real supression in the 2ν decay rate of these isotopes. (c) Despite [this], most $\beta\beta$-models predict a *ratio* of 2ν decay widths ... in fair agreement with observation." Further details of the experiment are given in BERNATOWICZ 93. Our listed half-life has been revised downward from the published value by the authors, on the basis of reevaluated cosmic-ray ^{128}Xe production corrections.

[37] BLUM 92 reports lifetime limits for the decay of ^{100}Mo to several excited states of ^{100}Ru. Limits for decay to the 0_1^+ state are about 30% higher if decay to the 2^+ states are assumed negligible. Uses 99.5% enriched ^{100}Mo.

[38] KUDOMI 92 reports lifetime limits for 0ν and 2ν decays to four excited states of the daughter ^{100}Ru. The limits were obtained from searches for the two individual electrons in coincidence with photons from the decays of the excited states. The experiment was performed in the Kamioka underground laboratory. See EJIRI 91 for the group's ground-state transition measurement.

[39] REUSSER 92 contains the final results for the search for neutrinoless double beta decay of ^{76}Ge in the Gotthard tunnel underground laboratory. Supersedes FISHER 89.

[40] AVIGNONE 91 reports confirmation of the MILEY 90 and VASENKO 90 observations of $2\nu\beta\beta$ decay of ^{76}Ge. Error is 2σ.

[41] BELLOTTI 91 uses difference between natural and enriched ^{136}Xe runs to obtain $\beta\beta0\nu$ limits, leading to "less stringent, but safer limits."

[42] HYKAWY 91 gives new mass spectrometer determination of the ^{76}Ge–^{76}Se mass difference, which for given input for the nuclear matrix elements gives information on limits on Majorana masses. Application to recent ^{76}Ge decay experiments produces no new evidence for $\beta\beta(0\nu)$ decay.

[43] TURKEVICH 91 observes activity in old U sample. The authors compare their results with theoretical calculations. They state "Using the phase-space factors of Boehm and Vogel (BOEHM 87) leads to matrix element values for the ^{238}U transition in the same range as deduced for ^{130}Te and ^{76}Ge. On the other hand, the latest theoretical estimates (STAUDT 90) give an upper limit that is 10 times lower. This large discrepancy implies either a defect in the calculations or the presence of a faster path than the standard two-neutrino mode in this case." See BOEHM 87 and STAUDT 90.

[44] MILEY 90 claims only "suggestive evidence" for the decay. Error is 2σ.

[45] VASENKO 90 limit based on background statistics. Maximum likelihood solution is >2000.

[46] MORALES 88 notes a 2.5 sigma coincidence rate between electrons with energy 1483.7 ± 0.5 keV in the Ge detector and photons with energy 558 ± 15 keV in the NaI detector, close to the region where neutrinoless $0^+ \to 2^+$ ^{76}Ge decay should be expected. However, a further study reported in MORALES 91 rejects this peak at the 95% CL.

[47] BELLOTTI 87 searches for γ rays for 2^+ state decays in corresponding Xe isotopes. Limit for ^{130}Te case argues for dominant $0^+ \to 0^+$ transition in known decay of this isotope.

[48] CALDWELL 87 supersedes CALDWELL 85 and CALDWELL 86.

[49] HUBERT 85 gives lifetime limits on neutrinoless double β decay of ^{76}Ge to excited states of ^{76}Se.

[50] KIRSTEN 83 reports "2σ" error. References are given to earlier determinations of the ^{130}Te lifetime.

$\langle m_\nu \rangle$, The Effective Weighted Sum of Majorana Neutrino Masses Contributing to Neutrinoless Double β Decay

$\langle m_\nu \rangle = |\Sigma\ U^2_{1j} m_{\nu_j}|$, where the sum goes from 1 to n and where n = number of neutrino generations, and ν_j is a Majorana neutrino. Note that U^2_{1j}, not $|U_{1j}|^2$, occurs in the sum. The possibility of cancellations has been stressed.

VALUE (eV)	CL%	ISOTOPE		TRANSITION	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
$<$ 6.6	68	^{100}Mo	0ν	$0^+ \to 0^+$	Si(Li)	[51] ALSTON-...	93
$<$ 2.8–4.3	90	^{136}Xe	0ν	$0^+ \to 0^+$	TPC	[52] VUILLEUMIER	93
$<$ 1.5	90	^{76}Ge			Enriched HPGe	[53] BALYSH	92
$<$ 1.1–1.5		^{128}Te			Geochem	[54] BERNATOW...	92
$<$ 5	68	^{82}Se			TPC	[55] ELLIOTT	92
$<$ 1.9–6.7	68	^{76}Ge		$0^+ \to 0^+$	HPGe	[56] REUSSER	92
$<$ 11–30	95	^{136}Xe	0ν	$0^+ \to 0^+$	Prop cntr	[57] BELLOTTI	91
$<$ 3.3–5.0		^{136}Xe	0ν	$0^+ \to 0^+$	TPC	[58] WONG	91
$<$ 8.3	76	^{48}Ca	0ν		CaF_2 scint.	YOU	91
$<$ 1.4–8	68	^{76}Ge	0ν	$0^+ \to 0^+$	Enriched Ge(Li)	[59] VASENKO	90
$<$4.3–28		^{136}Xe	0ν	$0^+ \to 0^+$	Prop chamber	[60] BELLOTTI	89
$<$12	68	^{116}Cd	0ν		$^{116}CdWO_4$ scint	[61] DANEVICH	89
$<$3.4–23		^{76}Ge	0ν	$0^+ \to 0^+$	HPGe	[62] FISHER	89
$<$ 1.8		^{76}Ge	0ν	$0^+ \to 0^+$	HPGe	[63] CALDWELL	87
$<$ 2.7	68	^{76}Ge	0ν	$0^+ \to 0^+$	HPGe	BELLOTTI	86
$<$ 6	68	^{76}Ge	0ν	$0^+ \to 0^+$	HPGe	[64] CALDWELL	86
$<$ 6	68	^{76}Ge	0ν		HPGe	[65] CALDWELL	85
$<$20	68	^{76}Ge	0ν		Ge(Li)	[66] HUBERT	85
$<$ 3.8	68	^{76}Ge	0ν	$0^+ \to 0^+$	Ge(Li)	[67] BELLOTTI	84
$<$22		^{76}Ge	0ν	$0^+ \to 0^+$	Ge	FORSTER	84
$<$10	90	^{76}Ge	0ν		Intrinsic Ge	AVIGNONE	83
$<$22	68	^{76}Ge	0ν	$0^+ \to 0^+$	Ge(Li)	[68] BELLOTTI	83
$<$ 8.3	68	^{76}Ge	0ν	$0^+ \to 0^+$	Ge(Li)	[68] BELLOTTI	83
$<$ 5.6	95	^{128}Te			Geochem	KIRSTEN	83

[51] ALSTON-GARNJOST 93 use the "conservative matrix elements of Engel *et al.* (ENGEL 88).

[52] VUILLEUMIER 93 mass range from parameter range in the Caltech calculations (ENGEL 88). On the basis of these calculations, the BALYSH 92 mass range would be $<$ 2.2–4.4 eV.

[53] BALYSH 92 uses the MUTO 89 matrix elements.

[54] BERNATOWICZ 92 finds these majoron mass limits assuming that the measured geochemical decay width is a limit on the 0ν decay width. The range is the range found using matrix elements from HAXTON 84, TOMODA 87, and SUHONEN 91. Further details of the experiment are given in BERNATOWICZ 93.

[55] ELLIOTT 92 uses the matrix elements of HAXTON 84.

[56] REUSSER 92 contains the final results for the search for neutrinoless double beta decay of ^{76}Ge in the Gotthard tunnel underground laboratory. Range comes from range of nuclear matrix elements used to relate neutrino mass to lifetime limit (ENGEL 88, HAXTON 84, and MUTO 89).

[57] BELLOTTI 91 range of limits comes from range of theoretical calculations considered. Analysis uses difference between natural and enriched ^{136}Xe runs to obtain the $\beta\beta 0\nu$ limits, leading to "less stringent, but safer limits."

[58] WONG 91 uses the quasiparticle random phase approximation of ENGEL 88 to extract the above limit for the case of a transition caused by a Majorana neutrino mass.

[59] VASENKO 90 range comes from range of nuclear matrix elements of HAXTON 84, ENGEL 88. On the basis of the MUTO 89 matrix element, the limit will be $<$ 1.3 eV.

[60] BELLOTTI 89 gives model-dependent upper bounds on Majorana neutrino masses and on the admixture of right-handed lepton-number-violating currents.

[61] DANEVICH 89 uses calculations of GROTZ 86.

[62] FISHER 89 model-dependent bounds are for Majorana neutrino masses.

[63] CALDWELL 87 least stringent limit (using HAXTON 84) is listed. Limits given using other nuclear matrix element calculations are 1.5 eV and 0.7 eV.

[64] CALDWELL 86 gives several limits depending on which calculation of nuclear matrix elements is used; we quote the most conservative, i.e., least stringent. Other limits are 1.0 eV and 1.9 eV. Authors note that the overall uncertainty due to the serious disagreement between nuclear calculations and both lab and geochemical measurements for regular 2-neutrino double β decay is also present in these limits.

[65] CALDWELL 85 uses results of HAXTON 81, HAXTON 82. Authors state that limit could be "two or three times larger."

[66] HUBERT 85 limit is obtained from analysis of data using theoretical calculations by HAXTON 81, HAXTON 82.

[67] See Table 1 of BELLOTTI 84 for their assessment of previous bounds.

[68] BELLOTTI 83 limits are obtained from analysis of data using theoretical calculations by DOI 83 and ROSEN 81.

Limits on Lepton-Number Violating ($V+A$) Current Admixture

For reasons given in the discussion at the beginning of this section, we list only results from 1989 and later.

η_{RR} (10^{-6})	CL%	η_{LR} (10^{-8})	CL%	ISOTOPE	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<2.3	90	<1.5	90	^{76}Ge	Enriched HPGe	[69] BALYSH	92
		<5.3		^{128}Te	Geochem	[70] BERNATOW...	92
<3.6	68	<2.2	68	^{76}Ge	HPGe	[71] REUSSER	92
<9	68	<8	68	^{76}Ge	Ion chamber	BELLOTTI	89

[69] BALYSH 92 uses the MUTO 89 matrix elements.
[70] BERNATOWICZ 92 takes the measured geochemical decay width as a limit on the 0ν width, and uses the SUHONEN 91 coefficients to obtain the least restrictive limit on η. Further details of the experiment are given in BERNATOWICZ 93.
[71] REUSSER 92 uses the MUTO 89 matrix elements for this reduction.

(D) Other Bounds from Nuclear Decays

Limits on $|U_{1j}|^2$ as Function of m_{ν_j}

New Experiments to Apply Peak and Kink Search Tests

Limits on $|U_{1j}|^2$ as function of m_{ν_j}

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1 × 10^{-7}	90	[72] BRITTON	92B	CNTR	50 MeV < m_{ν_j} < 130 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<5 × 10^{-6}	90	DELEENER-...	91		m_{ν_j} = 20 MeV
<5 × 10^{-7}	90	DELEENER-...	91		m_{ν_j} = 40 MeV
<3 × 10^{-7}	90	DELEENER-...	91		m_{ν_j} = 60 MeV
<1 × 10^{-6}	90	DELEENER-...	91		m_{ν_j} = 80 MeV
<1 × 10^{-6}	90	DELEENER-...	91		m_{ν_j} = 100 MeV
<5 × 10^{-7}	90	AZUELOS	86	CNTR	m_{ν_j}=60 MeV
<2 × 10^{-7}	90	AZUELOS	86	CNTR	m_{ν_j}=80 MeV
<3 × 10^{-7}	90	AZUELOS	86	CNTR	m_{ν_j}=100 MeV
<1 × 10^{-6}	90	AZUELOS	86	CNTR	m_{ν_j}=120 MeV
<2 × 10^{-7}	90	AZUELOS	86	CNTR	m_{ν_j}=130 MeV
<8 × 10^{-6}		DELEENER-...	86	CNTR	m_{ν_j}=20 MeV
<4 × 10^{-7}		DELEENER-...	86	CNTR	m_{ν_j}=60 MeV
<2 × 10^{-6}		DELEENER-...	86	CNTR	m_{ν_j}=100 MeV
<7 × 10^{-6}		DELEENER-...	86	CNTR	m_{ν_j}=120 MeV
<1 × 10^{-4}	90	[73] BRYMAN	83B	CNTR	m_{ν_j}=5 MeV
<1.5 × 10^{-6}	90	BRYMAN	83B	CNTR	m_{ν_j}=53 MeV
<1 × 10^{-5}	90	BRYMAN	83B	CNTR	m_{ν_j}=70 MeV
<1 × 10^{-4}	90	BRYMAN	83B	CNTR	m_{ν_j}=130 MeV
<1 × 10^{-4}	68	[74] SHROCK	81	THEO	m_{ν_j}=10 MeV
<5 × 10^{-6}	68	[74] SHROCK	81	THEO	m_{ν_j}=60 MeV
<1	95	[75] SIMPSON	81B		m_{ν_j}=0.1 keV
<4 × 10^{-3}	95	[75] SIMPSON	81B		m_{ν_j}=10 keV
<0.1	68	[76] SHROCK	80	THEO	m_{ν_j}=0.1–3 MeV
<1 × 10^{-5}	68	[77] SHROCK	80	THEO	m_{ν_j}=80 MeV
<3 × 10^{-6}	68	[77] SHROCK	80	THEO	m_{ν_j}=160 MeV

[72] BRITTON 92B is from a search for additional peaks in the e^+ spectrum from $\pi^+ \rightarrow e^+\nu_e$ decay at TRIUMF. See also BRITTON 92.
[73] BRYMAN 83B obtain upper limits from both direct peak search and analysis of B($\pi \rightarrow e\nu$)/B($\pi \rightarrow \mu\nu$). Latter limits are not listed, except for this entry (i.e. — we list the most stringent limits for given mass).
[74] Analysis of $(\pi^+ \rightarrow e^+\nu_e)/(\pi^+ \rightarrow \mu^+\nu_\mu)$ and $(K^+ \rightarrow e^+\nu_e)/(K^+ \rightarrow \mu^+\nu_\mu)$ decay ratios.
[75] Application of kink search test to tritium β decay Kurie plot.
[76] Application of test to search for kinks in β decay Kurie plots.
[77] Analysis of $(K^+ \rightarrow e^+\nu_e)$ spectrum.

Kink Search in Nuclear β Decay

The claims by Simpson, Hime, and others for the emission, via lepton mixing, of a neutrino with mass 17 keV in nuclear beta decay were strongly refuted by a number of high-sensitivity experiments. Accordingly, we no longer list the experiments by these authors and some others which made positive claims of 17 keV neutrino emission. Complete listings are given in the 1994 edition (Physical Review **D50** 1173 (1994)).

VALUE (units 10^{-3})	*CL%*	m_{ν_j} (keV)	*ISOTOPE*	*METHOD*	*DOCUMENT ID*	
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.3 $\pm$1.5$\pm$0.8		17	^{35}S	Mag spect	[78] BERMAN	93
< 2.8	99	17	^{3}H	Prop chamber	[79] KALBFLEISCH	93
< 1	99	14.4–15.2	^{3}H	Prop chamber	[79] KALBFLEISCH	93
< 0.7	99	16.3–16.6	^{3}H	Prop chamber	[79] KALBFLEISCH	93
< 2	95	13–40	^{35}S	Si(Li)	[80] MORTARA	93
< 0.73	95	17	^{63}Ni	Mag spect	OHSHIMA	93
< 1.5	95	10.5–25.0	^{63}Ni	Mag spect	[81] OHSHIMA	93
< 6	95	5–25	^{55}Fe	IBEC in Ge	[82] WIETFELDT	93
< 2	90	17	^{35}S	Mag spect.	[83] CHEN	92
< 0.95	95	17	^{63}Ni	Mag spect	[84] KAWAKAMI	92
< 1.0	95	10–24	^{63}Ni	Mag spect	KAWAKAMI	92
< 10	90	16–35	^{125}I	IBEC; γ det	[85] BORGE	86
< 7.5	99	5–50	^{35}S	Mag spect	ALTZITZOG...	85
< 8	90	80	^{35}S	Mag spect	[86] APALIKOV	85
< 1.5	90	60	^{35}S	Mag spect	APALIKOV	85
< 8	90	30	^{35}S	Mag spect	APALIKOV	85
< 3	90	17	^{35}S	Mag spect	APALIKOV	85
< 45	90	4	^{35}S	Mag spect	APALIKOV	85
< 10	90	5–30	^{35}S	Si(Li)	DATAR	85
< 3.0	90	5–50		Mag spect	MARKEY	85
< 0.62	90	48	^{35}S	Si(Li)	OHI	85
< 0.90	90	30	^{35}S	Si(Li)	OHI	85
< 1.30	90	20	^{35}S	Si(Li)	OHI	85
< 1.50	90	17	^{35}S	Si(Li)	OHI	85
< 3.30	90	10	^{35}S	Si(Li)	OHI	85
< 25	90	30	^{64}Cu	Mag spect	[87] SCHRECK...	83
< 4	90	140	^{64}Cu	Mag spect	[87] SCHRECK...	83
< 8	90	440	^{64}Cu	Mag spect	[87] SCHRECK...	83
<100	90	0.1–3000		THEO	[88] SHROCK	80

[78] BERMAN 93 uses an iron-free intermediate-image magnetic spectrometer to measure ^{35}S β decay over a large portion of the spectrum. Paper reports (0.01 $\pm$ 0.15)%; above result revised by author on basis of analysis refinements.

[79] KALBFLEISCH 93 extends the 17 keV neutrino search of BAHRAN 92, using an improved proportional chamber to which a small amount of ^{3}H is added. Systematics are significantly reduced, allowing for an improved upper limit. The authors give a 99% confidence limit on $|U_{1j}|^2$ as a function of m_{ν_j} in the range from 13.5 keV to 17.5 keV. Typical upper limits are listed above. They report that this experiment in combination with BAHRAN 92 gives an upper limit of 2.4×10^{-3} at the 99% CL. See also the related papers BAHRAN 93 and BAHRAN 93B, on theoretical aspects of beta spectra and fitting methods for heavy neutrinos.

[80] MORTARA 93 limit is from study using a high-resolution solid-state detector with a superconducting solenoid. The authors note that "The sensitivity to neutrino mass is verified by measurement with a mixed source of ^{35}S and ^{14}C, which artificially produces a distortion in the beta spectrum similar to that expected from the massive neutrino."

[81] OHSHIMA 93 is the full data analysis from this experiment. The above limit on the mixing strength for a 17 keV neutrino is obtained from the measurement $|U_{1j}|^2$ = $(-0.11 \pm 0.33 \pm 0.30) \times 10^{-3}$ by taking zero as the best estimate and ignoring physical boundaries; see discussion in HOLZSCHUH 92B for a comparison of methods. An earlier report of this experiment was given in KAWAKAMI 92.

[82] WIETFELDT 93 is an extension of the NORMAN 91 experiment. However, whereas NORMAN 91 reported indications for the emission of a neutrino with mass m_{ν_j} = 21 $\pm$ 2 keV and coupling strength = 0.0085 $\pm$ 0.0045, the present experiment states that "We find no evidence for emission of a neutrino in the mass range 5–25 keV. In particular, a 17 keV neutrino with $\sin^2\theta$ ($|U_{1j}|^2$ in our notation) = 0.008 is excluded at the 7σ level." The listed limits can be obtained from the paper's Fig. 4. The authors acknowledge that this conclusion contradicts the one reported in NORMAN 91, based on a smaller data sample.

[83] CHEN 92 is a continuation and improvement of the Boehm *et al.* Caltech iron-free magnetic spectrometer experiment searching for emission of massive neutrinos in ^{35}S

decay (MARKEY 85). The upper limit on $|U_{1j}|^2$ for m_{ν_j} = 17 keV comes from the measurement $|U_{1j}|^2 = (-0.5 \pm 1.4) \times 10^{-3}$. The authors state that their results "rule out, at the 6σ level, a 17 keV neutrino admixed at 0.85% (*i.e.* with $|U_{1j}|^2 = 0.85 \times 10^{-2}$," the level claimed by Hime and Jelly in HIME 91. They also state that "our data show no evidence for a heavy neutrino with a mass between 12 and 22 keV" with substantial admixture in the weak admixture in the weak eigenstate ν_e; see their Fig. 4 for a graphical set of measured values of $|U_{1j}|^2$ for various hypothetical values of m_{ν_j} in this range.

[84] KAWAKAMI 92 experiment final results are given in OHSHIMA 93. The upper limit is improved to 0.73×10^{-3}, based on $|U_{1j}|^2 = (-0.11 \pm 0.33 \pm 0.30) \times 10^{-3}$. Ohshima notes that the result is 22σ away from the value $|U_{1j}|^2 = 1\%$.

[85] BORGE 86 results originally presented as evidence against the SIMPSON 85 claim of a 17 keV antineutrino emitted with $|U_{1j}|^2 = 0.03$ in ^{3}H decay.

[86] This limit was taken from the figure 3 of APALIKOV 85; the text gives a more restrictive limit of 1.7×10^{-3} at CL = 90%.

[87] SCHRECKENBACH 83 is a combined measurement of the β^+ and β^- spectrum.

[88] SHROCK 80 was a retroactive analysis of data on several superallowed β decays to search for kinks in the Kurie plot.

(E) Bounds from Particle Decays

Searches for Decays of Massive ν

Limits on $|U_{1j}|^2$ as function of m_{ν_j}

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1 \times 10^{-5}$	90	[89] BARANOV	93		m_{ν_j}= 100 MeV
$<1 \times 10^{-6}$	90	[89] BARANOV	93		m_{ν_j}= 200 MeV
$<3 \times 10^{-7}$	90	[89] BARANOV	93		m_{ν_j}= 300 MeV
$<2 \times 10^{-7}$	90	[89] BARANOV	93		m_{ν_j}= 400 MeV
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	m_{ν_j} = 20 GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	m_{ν_j} = 40 GeV
all values ruled out	95	[90] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[90] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[90] BURCHAT	90	MRK2	m_{ν_j} = 41 GeV
all values ruled out	95	DECAMP	90F	ALEP	m_{ν_j}= 25.0–42.7 GeV
$<1 \times 10^{-13}$	95	DECAMP	90F	ALEP	m_{ν_j}= 42.7–45.7 GeV
$<5 \times 10^{-3}$	90	AKERLOF	88	HRS	m_{ν_j}=1.8 GeV
$<2 \times 10^{-5}$	90	AKERLOF	88	HRS	m_{ν_j}=4 GeV
$<3 \times 10^{-6}$	90	AKERLOF	88	HRS	m_{ν_j}=6 GeV
$<1.2 \times 10^{-7}$	90	BERNARDI	88	CNTR	m_{μ_j}=100 MeV
$<1 \times 10^{-8}$	90	BERNARDI	88	CNTR	m_{μ_j}=200 MeV
$<2.4 \times 10^{-9}$	90	BERNARDI	88	CNTR	m_{μ_j}=300 MeV
$<2.1 \times 10^{-9}$	90	BERNARDI	88	CNTR	m_{μ_j}=400 MeV
$<2 \times 10^{-2}$	68	[91] OBERAUER	87		m_{ν_j}=1.5 MeV
$<8 \times 10^{-4}$	68	[91] OBERAUER	87		m_{ν_j}=4.0 MeV
$<8 \times 10^{-3}$	90	BADIER	86	CNTR	m_{ν_j}=400 MeV
$<8 \times 10^{-5}$	90	BADIER	86	CNTR	m_{ν_j}=1.7 GeV
$<8 \times 10^{-8}$	90	BERNARDI	86	CNTR	m_{ν_j}=100 MeV
$<4 \times 10^{-8}$	90	BERNARDI	86	CNTR	m_{ν_j}=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	m_{ν_j}=400 MeV
$<3 \times 10^{-5}$	90	DORENBOS...	86	CNTR	m_{ν_j}=150 MeV

$<1 \times 10^{-6}$	90	DORENBOS...	86	CNTR	m_{ν_j}=500 MeV
$<1 \times 10^{-7}$	90	DORENBOS...	86	CNTR	m_{ν_j}=1.6 GeV
$<7 \times 10^{-7}$	90	[92] COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<8 \times 10^{-8}$	90	[92] COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV
$<1 \times 10^{-2}$	90	[93] BERGSMA	83B	CNTR	m_{ν_j}=10 MeV
$<1 \times 10^{-5}$	90	[93] BERGSMA	83B	CNTR	m_{ν_j}=110 MeV
$<6 \times 10^{-7}$	90	[93] BERGSMA	83B	CNTR	m_{ν_j}=410 MeV
$<1 \times 10^{-5}$	90	GRONAU	83		m_{ν_j}=160 MeV
$<1 \times 10^{-6}$	90	GRONAU	83		m_{ν_j}=480 MeV

[89] BARANOV 93 is a search for neutrino decays into $e^+ e^- \nu_e$ using a beam dump experiment at the 70 GeV Serpukhov proton synchrotron. The limits are not as good as those achieved earlier by BERGSMA 83 and BERNARDI 86, BERNARDI 88.

[90] BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.

[91] OBERAUER 87 bounds from search for $\nu \rightarrow \nu' e e$ decay mode using reactor (anti)neutrinos.

[92] COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_τ flux. We do not list these. Note that for this bound to be nontrivial, j is not equal to 3, i.e. ν_j cannot be the dominant mass eigenstate in ν_τ since $m_{\nu_3} < 70$ MeV (ALBRECHT 85I). Also, of course, j is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

[93] BERGSMA 83B also quote limits on $|U_{13}|^2$ where the index 3 refers to the mass eigenstate dominantly coupled to the τ. Those limits were based on assumptions about the D_s mass and $D_s \rightarrow \tau \nu_\tau$ branching ratio which are no longer valid. See COOPER-SARKAR 85.

Limits on $|U_{2j}|^2$ as Function of m_{ν_j}

Application of Peak Search Test to Existing Data

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6 \times 10^{-6}$	95	[94] ASANO	81		m_{ν_j}=240 MeV
$<5 \times 10^{-7}$	95	[94] ASANO	81		m_{ν_j}=280 MeV
$<6 \times 10^{-6}$	95	[94] ASANO	81		m_{ν_j}=300 MeV
$<3 \times 10^{-2}$	95	[95] SHROCK	81	THEO	m_{ν_j}=7 MeV
$<1 \times 10^{-2}$	95	[95] SHROCK	81	THEO	m_{ν_j}=13 MeV
$<1 \times 10^{-4}$	68	[95] SHROCK	81	THEO	m_{ν_j}=13 MeV
$<3 \times 10^{-5}$	68	[95] SHROCK	81	THEO	m_{ν_j}=33 MeV
$<6 \times 10^{-3}$	68	[96] SHROCK	81	THEO	m_{ν_j}=80 MeV
$<5 \times 10^{-3}$	68	[96] SHROCK	81	THEO	m_{ν_j}=120 MeV
$<5 \times 10^{-2}$	95	[95] SHROCK	80	THEO	m_{ν_j}=4–6 MeV

[94] Analysis of experiment on $K^+ \rightarrow \mu^+ \nu_\mu \nu_x \overline{\nu}_x$ decay.

[95] Analysis of magnetic spectrometer experiment, bubble chamber experiment, and emulsion experiment on $\pi^+ \rightarrow \mu^+ \nu_\mu$ decay.

[96] Analysis of magnetic spectrometer experiment on $K \rightarrow \mu, \nu_\mu$ decay.

Application of Peak Search Test to New Experiments

Limits on $|U_{2j}|^2$ as function of m_{ν_j}

VALUE	CL%	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<2 \times 10^{-2}$	90	DAUM	87	m_{ν_j}=1 MeV
$<1 \times 10^{-3}$	90	DAUM	87	m_{ν_j}=2 MeV
$<6 \times 10^{-5}$	90	DAUM	87	3 MeV $< m_{\nu_j} <$ 19.5 MeV
$<3 \times 10^{-2}$	90	[97] MINEHART	84	m_{ν_j}=2 MeV
$<1 \times 10^{-3}$	90	[97] MINEHART	84	m_{ν_j}=4 MeV
$<3 \times 10^{-4}$	90	[97] MINEHART	84	m_{ν_j}=10 MeV
$<5 \times 10^{-6}$	90	[98] HAYANO	82	m_{ν_j}=330 MeV
$<1 \times 10^{-4}$	90	[98] HAYANO	82	m_{ν_j}=70 MeV
$<9 \times 10^{-7}$	90	[98] HAYANO	82	m_{ν_j}=250 MeV

$<1 \times 10^{-1}$	90	[97] ABELA	81	m_{ν_j}=4 MeV
$<7 \times 10^{-5}$	90	[97] ABELA	81	m_{ν_j}=10.5 MeV
$<2 \times 10^{-4}$	90	[97] ABELA	81	m_{ν_j}=11.5 MeV
$<2 \times 10^{-5}$	90	[97] ABELA	81	m_{ν_j}=16–30 MeV
$<2 \times 10^{-5}$	95	[98] ASANO	81	m_{ν_j}=170 MeV
$<3 \times 10^{-6}$	95	[98] ASANO	81	m_{ν_j}=210 MeV
$<3 \times 10^{-6}$	95	[98] ASANO	81	m_{ν_j}=230 MeV
$<1 \times 10^{-2}$	95	[97] CALAPRICE	81	m_{ν_j}=7 MeV
$<3 \times 10^{-3}$	95	[97] CALAPRICE	81	m_{ν_j}=33 MeV

[97] $\pi^+ \rightarrow \mu^+ \nu_\mu$ peak search experiment.
[98] $K^+ \rightarrow \mu^+ \nu_\mu$ peak search experiment.

Peak Search in Muon Capture

Limits on $|U_{2j}|^2$ as function of m_{ν_j}

VALUE	*DOCUMENT ID*		*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$<1 \times 10^{-1}$	DEUTSCH	83	m_{ν_j}=45 MeV
$<7 \times 10^{-3}$	DEUTSCH	83	m_{ν_j}=70 MeV
$<1 \times 10^{-1}$	DEUTSCH	83	m_{ν_j}=85 MeV

Searches for Decays of Massive ν

Limits on $|U_{2j}|^2$ as function of m_{ν_j}

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	m_{ν_j} = 20 GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	m_{ν_j} = 40 GeV
all values ruled out	95	[99] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[99] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[99] BURCHAT	90	MRK2	m_{ν_j} = 41 GeV
all values ruled out	95	DECAMP	90F	ALEP	m_{ν_j}= 25.0–42.7 GeV
$<1 \times 10^{-13}$	95	DECAMP	90F	ALEP	m_{ν_j}= 42.7–45.7 GeV
$<5 \times 10^{-4}$	90	[100] KOPEIKIN	90	CNTR	m_{ν_j} = 5.2 MeV
$<5 \times 10^{-3}$	90	AKERLOF	88	HRS	m_{ν_j}=1.8 GeV
$<2 \times 10^{-5}$	90	AKERLOF	88	HRS	m_{ν_j}=4 GeV
$<3 \times 10^{-6}$	90	AKERLOF	88	HRS	m_{ν_j}=6 GeV
$<1 \times 10^{-7}$	90	BERNARDI	88	CNTR	m_{μ_j}=200 MeV
$<3 \times 10^{-9}$	90	BERNARDI	88	CNTR	m_{μ_j}=300 MeV
$<4 \times 10^{-4}$	90	[101] MISHRA	87	CNTR	m_{ν_j}=1.5 GeV
$<4 \times 10^{-3}$	90	[101] MISHRA	87	CNTR	m_{ν_j}=2.5 GeV
$<0.9 \times 10^{-2}$	90	[101] MISHRA	87	CNTR	m_{ν_j}=5 GeV
<0.1	90	[101] MISHRA	87	CNTR	m_{ν_j}=10 GeV
$<8 \times 10^{-4}$	90	BADIER	86	CNTR	m_{ν_j}=600 MeV
$<1.2 \times 10^{-5}$	90	BADIER	86	CNTR	m_{ν_j}=1.7 GeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR	m_{ν_j}=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	m_{ν_j}=350 MeV
$<1 \times 10^{-6}$	90	DORENBOS...	86	CNTR	m_{ν_j}=500 MeV
$<1 \times 10^{-7}$	90	DORENBOS...	86	CNTR	m_{ν_j}=1600 MeV
$<0.8 \times 10^{-5}$	90	[102] COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<1.0 \times 10^{-7}$	90	[102] COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV

[99] BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.
[100] KOPEIKIN 90 find no m_{ν_j} in the interval 1–6.3 MeV at 90%CL for maximal mixing.
[101] See also limits on $|U_{3j}|$ from WENDT 87.

[102] COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_τ flux. We do not list these. Note that for this bound to be nontrivial, j is not equal to 3, i.e. ν_j cannot be the dominant mass eigenstate in ν_τ since m_{ν_3} <70 MeV (ALBRECHT 85I). Also, of course, j is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

Limits on $|U_{3j}|^2$ as a Function of m_{ν_j}

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	m_{ν_j} = 20 GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	m_{ν_j} = 40 GeV
all values ruled out	95	[103] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[103] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[103] BURCHAT	90	MRK2	m_{ν_j} = 41 GeV
all values ruled out	95	DECAMP	90F	ALEP	m_{ν_j}= 25.0–42.7 GeV
$<1 \times 10^{-13}$	95	DECAMP	90F	ALEP	m_{ν_j}= 42.7–45.7 GeV
$<5 \times 10^{-2}$	80	AKERLOF	88	HRS	m_{ν_j}=2.5 GeV
$<9 \times 10^{-5}$	80	AKERLOF	88	HRS	m_{ν_j}=4.5 GeV

[103] BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.

Limits on $|U_{aj}|^2$

Where a = 1, 2 from ρ parameter in μ decay.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1 \times 10^{-2}$	68	SHROCK	81B	THEO	m_{ν_j}=10 MeV
$<2 \times 10^{-3}$	68	SHROCK	81B	THEO	m_{ν_j}=40 MeV
$<4 \times 10^{-2}$	68	SHROCK	81B	THEO	m_{ν_j}=70 MeV

Limits on $|U_{1j} \times U_{2j}|$ as Function of m_{ν_j}

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<3 \times 10^{-5}$	90	[104] BARANOV	93		m_{ν_j}= 80 MeV
$<3 \times 10^{-6}$	90	[104] BARANOV	93		m_{ν_j}= 160 MeV
$<6 \times 10^{-7}$	90	[104] BARANOV	93		m_{ν_j}= 240 MeV
$<2 \times 10^{-7}$	90	[104] BARANOV	93		m_{ν_j}= 320 MeV
$<9 \times 10^{-5}$	90	BERNARDI	86	CNTR	m_{ν_j}=25 MeV
$<3.6 \times 10^{-7}$	90	BERNARDI	86	CNTR	m_{ν_j}=100 MeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR	m_{ν_j}=200 MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	m_{ν_j}=350 MeV
$<1 \times 10^{-2}$	90	BERGSMA	83B	CNTR	m_{ν_j}=10 MeV
$<1 \times 10^{-5}$	90	BERGSMA	83B	CNTR	m_{ν_j}=140 MeV
$<7 \times 10^{-7}$	90	BERGSMA	83B	CNTR	m_{ν_j}=370 MeV

[104] BARANOV 93 is a search for neutrino decays into $e^+ e^- \nu_e$ using a beam dump experiment at the 70 GeV Serpukhov proton synchrotron.

(F) Bounds from ν Reactions

MINIREVIEW GOES HERE

Solar ν Experiments

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$73^{+18}_{-16}{}^{+5}_{-7}$ SNU		[105] ABDURASHI...	94	SAGE	^{71}Ga $\rightarrow$ ^{71}Ge
79 ± 10 ± 6 SNU		[106] ANSELMANN	94	GALX	^{71}Ga $\rightarrow$ ^{71}Ge
(0.46 ± 0.05 ± 0.06)×SSM		[107] HIRATA	90	KAM2	Water Cerenkov
2.33 ± 0.25 SNU		[108] DAVIS	89	HOME	^{37}CL radiochemical

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

		[109] ACKER	94	THEO	Solar ν decay
		[110] BAHCALL	94	THEO	
$87 \pm 14 \pm 7$ SNU		[111] ANSELMANN	93	GALX	Repl. by ANSELMANN 94
		[112] BAHCALL	93		
		[113] HAMPEL	93	RVUE	
6.4 ± 1.4 SNU		[114] TURCK-CHI...	93B	THEO	^{37}CL radiochemical
$(4.4 \pm 1.1) \times 10^{-6}$ cm^{-2}s^{-1}		[114] TURCK-CHI...	93B	THEO	Water Cerenkov, $E \geq 7.5$ MeV
123 ± 7 SNU		[114] TURCK-CHI...	93B	THEO	$^{71}\text{Ga} \rightarrow {}^{71}\text{Ge}$
$83 \pm 19 \pm 8$ SNU		[115] ANSELMANN	92	GALX	$^{71}\text{Ga} \rightarrow {}^{71}\text{Ge}$
		[116] ANSELMANN	92B		
8.0 ± 3.0 SNU		[117] BAHCALL	92		^{37}Cl prediction
132^{+21}_{-17} SNU		[117] BAHCALL	92		^{71}Ga prediction
$20^{+15}_{-20} \pm 32$ SNU		ABAZOV	91B	SAGE	Repl. by ABDURASHITOV 94
< 79 SNU	90	ABAZOV	91B	SAGE	Repl. by ABDURASHITOV 94
		[118] GARCIA	91	CNTR	Nuclear physics
		[119] HIRATA	91	KAM2	
		[120] FILIPPONE	90	THY	
		[121] HIRATA	90B	KAM2	
7.9 ± 2.6 SNU		[122] BAHCALL	88	THEO	^{37}Cl prediction; total theor. range
132^{+20}_{-17} SNU		[122] BAHCALL	88	THEO	^{71}Ga prediction; total theor. range
5.8 ± 1.3 SNU		TURCK-CHI...	88	THEO	^{37}Cl prediction
125 ± 5 SNU		TURCK-CHI...	88	THEO	^{71}Ga prediction
5.6 SNU		[120] FILIPPONE	83	THEO	^{37}Cl prediction
7.6 ± 3.3 SNU		[123] BAHCALL	82		^{37}Cl prediction
106^{+13}_{-8} SNU		[123] BAHCALL	82		^{71}Ga prediction
7.0 ± 3.0 SNU		FILIPPONE	82	THEO	^{37}Cl prediction
6.9 ± 1.0 SNU		FOWLER	82	THEO	^{37}Cl prediction
7.3 SNU		BAHCALL	80	THEO	^{37}CL prediction

See also the reviews by BAHCALL 92, DAVIS 89, and ACKER 94. The latter rules out neutrino decay as a solution to the solar neutrino problem at better than 98% using the existing solar neutrino as of mid-1993.

[105] ABDURASHITOV 94 result is for a total of 15 runs from January 1990 through May 1992, using 30 tons of metallic gallium for the first 7 runs, increased to 57 tons for the rest of 8 runs. The first 5 runs in 1990 yielded $40^{+31}_{-38}{}^{+5}_{-7}$ SNU which updates the ABAZOV 91B result.

[106] ANSELMANN 94 result is for a total of 15 initial runs ("GALLEX I") yielding $87 \pm 14 \pm 7$ SNU (see ANSELMANN 93) and 15 new runs ("GALLEX II") yielding $78 \pm 13 \pm 5$ SNU. ANSELMANN 92 reported the first observation of solar neutrinos from the pp reaction, using the GALLEX solar neutrino detector in the Gran Sasso Underground Laboratory. A typical solar model rate prediction is for 132 SNU, but see the reviews by Bahcall and others.

[107] HIRATA 90 data consists of 1040 days with threshold $E_e > 9.3$ MeV (first 450 days) or $E_e > 7.5$ MeV. "The total data sample is also analyzed for short-term variations; within the statistical error, no significant variation is observed." The flux is scaled by the value relative to the standard solar model (SSM) prediction. A theoretical flux of $(5.8 \pm 2.1) \times 10^6$ cm^{-2} s^{-1} is cited, with the central value corresponding to 7.9 SNU for ^{37}Cl experiment (but see TURCK-CHIEZE 93B and other theoretical calculations.) The analysis is more fully reported in HIRATA 91B. Earlier analyses were reported by HIRATA 91 and HIRATA 90B.

[108] DAVIS 89 is the average from the ^{37}CL experiment at the Homestake Mine (HOME) from 1970–1988. Earlier averages are given in the references therein.

[109] ACKER 94 rules out neutrino decay as a solution to the solar neutrino problem at better than 98% CL, using the existing solar neutrino as of mid-1993.

[110] BAHCALL 94 argues that there are really two solar neutrino problems: (1) incompatibility of the Chlorine (Homestake) and Kamiokande experiments, (2) deficiency of the observed solar neutrino flux in the gallium experiments.

[111] ANSELMANN 93 result is for 21 runs of combined GALLEX I and GALLEX II data from inverse beta decay reactions in an aqueous solution of Ga^{3}Cl (30.3 tons of natural Ga) in the Gran Sasso underground laboratory. The 15 runs of GALLEX I yield $81 \pm 17 \pm 9$, which replaces the preliminary result of ANSELMANN 92. The first 6 runs with GALLEX II yield $97 \pm 23 \pm 7$ SNU. A typical solar model rate prediction is for 132 SNU, but see the reviews by Bahcall and others.

[112] BAHCALL 93 is a study of 1000 solar models in which each input parameter is chosen from a normal distribution with the appropriate mean and error. It is concluded that "Even if one abuses the solar models by artifically imposing consistency with the

Kamiokande experiment, the resulting predictions of all 1000 of the 'fudged' solar models are inconsistent with the result of the chlorine experiment."

[113] HAMPEL 93, by a member of the GALLEX collaboration, is a discussion of possible scenarios to explain the combined solar neutrino experimental data.

[114] TURCK-CHIEZE 93B proposes new results on the solar neutrino predictions and acoustic mode frequencies. See also TURCK-CHIEZE 93 for an extensive review (233 pages, 524 references) concerning the solar interior. Table 17 provides a particularly useful comparison of experiment and theory as of mid-1993.

[115] ANSELMANN 92 reports first observation of solar neutrinos from the pp reaction, using the GALLEX solar neutrino detector in the Gran Sasso Underground Laboratory. The total rate is 2σ below the solar model predictions in the range 124–132 SNU's, but they state that "Our result is consistent with the presence of the full pp neutrino flux expected according the the 'standard solar model' together with a reduced flux of ^{8}B and ^{7}Be neutrinos as observed by the Homestake and Kamiokande experiments."

[116] ANSELMANN 92B discusses implications of the GALLEX observations reported in ANSELMANN 92. They state that "To fit this result together with those of the chlorine and Kamiokande experiments requires severe stretching of the solar models but does not rule out such a procedure, leaving the possibility of massless neutrinos... The Mikheyev-Smirnov-Wolfenstein mechanism provides a good fit, and the GALLEX result fixes the $\Delta(m^2)$ and $\sin^2 2\theta$ parameters in two very confined ranges (around $\Delta(m^2) = 6 \times 10^{-6}$ eV^2 and $\sin^2 2\theta = 7\times10^{-3}$ or $\Delta(m^2) = 8\times10^{-6}$ eV^2 and $\sin^2 2\theta = 0.6$). Explanations of the solar neutrino problem based on the decay or magnetic interactions of neutrinos are disfavored."

[117] BAHCALL 92 is an extensive discussion of theoretical neutrino flux calculations with predicted event rates for various different solar neutrino detectors. "The quoted errors represent the total theoretical range and include the effects on the model predictions of 3σ errors in measured input parameters."

[118] GARCIA 91 reports a new study of ^{37}Caβ decays, with the result that the BAHCALL 88 SSM prediction for ^{37}Cl should be increased from 7.9 to 8.1 SNU.

[119] HIRATA 91 reports a search for day-night and semi-annual variations in the solar neutrino flux observed in the Kamiokande II Detector. The sample is the same 1040 day counting period used for HIRATA 90 and HIRATA 90B. "Within statistical error, no such short-time variations were observed." This result was used to constrain neutrino oscillation parameters, in the framework of oscillations between two mass eigenstates. "A region defined by $\sin^2 2\theta > 0.02$ and 2×10^{-6} eV^2 $< \Delta(m^2) < 1 \times 10^{-5}$ eV^2 is excluded at the 90% CL without any assumptions on the absolute value of the expected solar neutrino flux."

[120] In a later unbiased analysis, FILIPPONE 90 show that the hypothesis of a time-independent ^{37}Cl neutrino capture rate is marginally rejected, having only 2% probability. However, it is disturbing that we are not able to find a simple hypothesis of time variation that would describe the data well. A capture rate anticorrelated with sunspot number, although more probable than the constant rate hypothesis, has a probablity of only 6%. One possible explanation of these results is simply the poor statistics of the ^{37}Cl experiment."

[121] HIRATA 90B gives an analysis of the implications of these data for allowed values of $\Delta(m^2)$ and $\sin^2 2\theta$ describing neutrino mixing between two mass eigenstates, in the model of resonant (MSW) neutrino oscillations. The possibility of regeneration as the neutrinos pass through the earth is neglected. Two limits are given, the first from the measured event rate alone, and the second from the combination of the measured event rate and the recoil electron energy spectrum. The latter "disfavor the region of adiabatic solutions $\Delta(m^2) \sim 1.3 \times 10^{-4}$ eV^2 and $7.2 \times 10^{-4} < \sin^2 2\theta < 6.3 \times 10^{-3}$ at 90%CL." The allowed regions in $\sin^2 2\theta$ vs. $\Delta(m^2)$ are given graphically; see Figs. 2(a) and 2(b) in the paper.

[122] BAHCALL 88 "total theoretical range is calculated by evaluating the 3σ uncertainties for all measured input parameters and using the full spread in calculated values for input quantitites that cannot be measured; the uncertainties from different quantities are combined quadratically." (Quotation from BAHCALL 89, p. 301.)

[123] BAHCALL 82 quotes "effective 3σ errors." First extensive discussion of formal uncertainties in the problem.

(G) Deep Underground Detector Experiments

R(μ/e) = (Measured Ratio μ/e) / (Expected Ratio μ/e)

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.57^{+0.08}_{-0.07}\pm0.07$	[124] FUKUDA	94	KAM2	Water Cerenkov
	[125] BECKER-SZ...	92B	IMB	Water Chernekov
	[126] BERGER	90B	FREJ	Calorimeter

[124] FUKUDA 94 supersedes HIRATA 92 and includes data quoted by HIRATA 88 (next data block). They define the ratio of observed events $R(\mu/e) = (N_{\nu_\mu} + N_{\overline{\nu}_\mu})/(N_{\nu_e} + N_{\overline{\nu}_e})$, because then both experimental and theoretical uncertainties in the fluxes cancel. Energies are in the multi-GeV range. From their results, they infer evidence for neutrino

oscillations. Fits to the data yield ($\Delta(m^2)$, $\sin^2 2\theta$) of 1.8×10^{-2} eV^2, 1.0 for $\nu_\mu \rightarrow \nu_e$ and 1.6×10^{-2} eV^2, 1.0 for $\nu_\mu \rightarrow \nu_\tau$.

[125] BECKER-SZENDY 92B reports the fraction of nonshowering events (mostly muons from atomospheric neutrinos) as $0.36 \pm 0.02 \pm 0.02$, as compared with expected fraction $0.51 \pm 0.01 \pm 0.05$. After cutting the energy range to the KAM2 limits, BEIER 92 finds $R(\mu/e)$ very close to the KAM2 value.

[126] BERGER 90B reports e/μ = 0.53–0.57 $\pm$ 0.09 (data) and 0.56–0.61 $\pm$ 0.08 (Monte Carlo), where the range is from different analysis methods. There is thus no significant departure from expectation. See also BEIER 92.

R(ν_μ) = (Measured Flux of ν_μ) / (Expected Flux of ν_μ)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[127] CASPER	91	IMB	Water Cherenkov
	[128] AGLIETTA	89	NUSX	
0.59 ± 0.07	[129] HIRATA	88	KAM2	Water Chernekov
0.95 ± 0.22	[130] BOLIEV	81		Baksan
0.62 ± 0.17	CROUCH	78		Case Western/UCI

[127] CASPER 91 correlates showering/nonshowering signature of single-ring events with parent atmospheric-neutrino flavor. They find nonshowering ($\approx \nu_\mu$ induced) fraction is $0.41 \pm 0.03 \pm 0.02$, as compared with expected 0.51 ± 0.05 (syst).

[128] AGLIETTA 89 finds no evidence for any anomaly in the neutrino flux. They define ρ = (measured number of ν_e's)/(measured number of ν_μ's). They report $\rho(\text{measured}) = \rho(\text{expected}) = 0.96^{+0.32}_{-0.28}$.

[129] HIRATA 88 error is statistical.

[130] From this data BOLIEV 81 obtain the limit $\Delta(m^2) \leq 6 \times 10^{-3}$ eV^2 for maximal mixing, $\nu_\mu \not\rightarrow \nu_\mu$ type oscillation.

$\sin^2(2\theta)$ for Given $\Delta(m^2)$ ($\nu_e \leftrightarrow \nu_\mu$)

For a review see BAHCALL 89.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.33	90	[131] HIRATA	92	KAM2	$\Delta(m^2) > 0.004$ eV^2
<0.47	90	[132] BERGER	90B	FREJ	$\Delta(m^2) > 1$ eV^2
<0.14	90	LOSECCO	87	IMB	$\Delta(m^2) = 0.00011$ eV^2

[131] HIRATA 92 states that the allowed region for $\nu_e \leftrightarrow \nu_\mu$ conflicts with the constraints from the solar neutrino data (HIRATA 90B).

[132] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_e \leftrightarrow \nu_\mu$)

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<150	90	[133] BERGER	90B	FREJ

[133] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\sin^2(2\theta)$ for Given $\Delta(m^2)$ ($\overline{\nu}_e \leftrightarrow \overline{\nu}_\mu$)

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.9	99	[134] SMIRNOV	94	THEO	$\Delta(m^2) > 3 \times 10^{-4}$ eV^2
<0.7	99	[134] SMIRNOV	94	THEO	$\Delta(m^2) > 10^{-11}$ eV^2

[134] SMIRNOV 94 analyzed the data from SN 1987A using stellar-collapse models. They also give less stringent upper limits on $\sin^2 2\theta$ for $10^{-11} < \Delta(m^2) < 10^{-6}$ ev^2 and $10^{-5} < \Delta(m^2) < 3 \times 10^{-4}$ ev^2. The same results apply to $\overline{\nu}_e \leftrightarrow \overline{\nu}_\tau$, ν_μ, and ν_τ.

$\sin^2(2\theta)$ for Given $\Delta(m^2)$ ($\nu_\mu \leftrightarrow \nu_\tau$)

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>0.5	90	[135] BECKER-SZ...	92	IMB	$\Delta(m^2) = 1$–2×10^{-4} eV^2
>0.42	90	HIRATA	92	KAM2	$\Delta(m^2) > 0.001$ eV^2
<0.6	90	[136] BERGER	90B	FREJ	$\Delta(m^2) > 1$ eV^2

[135] BECKER-SZENDY 92 uses upward-going muons to search for atomospheric ν_μ oscillations. The fraction of muons which stop in the detector is used to search for deviations in the expected spectrum. No evidence for oscillations is found.

[136] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_\mu \leftrightarrow \nu_\tau$)

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<350	90	[137] BERGER	90B	FREJ

[137] BERGER 90B uses the Frejus detector to search for oscillations of atmospheric neutrinos. Bounds are for both neutrino and antinuetrino oscillations.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ ($\nu_\mu \rightarrow \nu_s$)

ν_s means ν_τ or any sterile (noninteracting) ν.

VALUE (10^{-5} eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3000 (or <550)	90	[138] OYAMA	89		Kamiokande II
< 4.2 or > 54.	90	BIONTA	88	IMB	Flux has ν_μ, $\overline{\nu}_\mu$, ν_e, and $\overline{\nu}_e$

[138] OYAMA 89 gives a range of limits, depending on assumptions in their analysis. They argue that the region $\Delta(m^2) = (100–1000) \times 10^{-5}$ eV^2 is not ruled out by any data for large mixing.

(H) Reactor $\overline{\nu}$ Experiments

Events (Observed/Expected) from Reactor $\overline{\nu}_e$ Experiments

VALUE	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1.05 ±0.02 ±0.05	VUILLEUMIER	82	$\overline{\nu}_e p \rightarrow e^+ n$
0.955±0.035±0.110	[139] KWON	81	$\overline{\nu}_e p \rightarrow e^+ n$
0.89 ±0.15	[139] BOEHM	80	$\overline{\nu}_e p \rightarrow e^+ n$
0.38 ±0.21	[140,141] REINES	80	
0.40 ±0.22	[140,141] REINES	80	

[139] KWON 81 represents an analysis of a larger set of data from the same experiment as BOEHM 80.

[140] REINES 80 involves comparison of neutral- and charged-current reactions $\overline{\nu}_e d \rightarrow np\overline{\nu}_e$ and $\overline{\nu}_e d \rightarrow nne^+$ respectively. Combined analysis of reactor $\overline{\nu}_e$ experiments was performed by SILVERMAN 81.

[141] The two REINES 80 values correspond to the calculated $\overline{\nu}_e$ fluxes of AVIGNONE 80 and DAVIS 79 respectively.

$\overline{\nu}_e \not\rightarrow \overline{\nu}_e$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.0075	90	[142] VIDYAKIN	94		$\overline{\nu}_e p \rightarrow e^+ n$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[143] KETOV	92		
<0.0083	90	[142] VIDYAKIN	90		$\overline{\nu}_e p \rightarrow e^+ n$
<0.04	90	[144] AFONIN	88	CNTR	$\overline{\nu}_e p \rightarrow e^+ n$
<0.014	68	[145] VIDYAKIN	87		$\overline{\nu}_e p \rightarrow e^+ n$
<0.019	90	[146] ZACEK	86		$\overline{\nu}_e p \rightarrow e^+ n$
<0.02	90	[147] ZACEK	85		$\overline{\nu}_e p \rightarrow e^+ n$
<0.016	90	[148] GABATHULER	84		$\overline{\nu}_e p \rightarrow e^+ n$

[142] This bound is for L=57.0 m, 57.6 m, and 231.4 m at three reactions in the Krasnoyark Reactor complex. VIDYAKIN 94 supersedes VIDYAKIN 90.

[143] KETOV 92 is a limit from search for $\overline{\nu}_e$ oscillations using the reaction $\overline{\nu}_e p \rightarrow e^+ n$ with the $\overline{\nu}_e$ flux from the Rovno power reactor. They obtain the ratio $R = 0.976 \pm 0.02 \pm 0.015$ for the corrected flux ratios at 12 m and 18 m from the reactor core, and thus report no evidence for neutrino oscillations over distances of order 10 m. Virtually no experimental details are given.

[144] AFONIN 86 and AFONIN 87 also give limits on $\sin^2(2\theta)$ for intermediate values of $\Delta(m^2)$. From the Rovno reaction (see also KETOV 92). Supersedes AFONIN 87, AFONIN 86, AFONIN 85, AFONIN 83, and BELENKII 83.

[145] VIDYAKIN 87 bound is for L = 32.8 and 92.3 m distance from two reactors.

[146] This bound is from data for L=37.9 m, 45.9 m, and 64.7 m distance from Gösgen reactor.

[147] See the comment for ZACEK 85 in the section on $\sin^2(2\theta)$ below.

[148] This bound comes from a combination of the VUILLEUMIER 82 data at distance 37.9 m from Gösgen reactor and new data at 45.9 m.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.15	90	[149] VIDYAKIN	94		For $\Delta(m^2) > 5.0\times10^{-2}$ eV^2
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.2	90	[150] AFONIN	88	CNTR	$\overline{\nu}_e p \to e^+ n$
<0.14	68	[151] VIDYAKIN	87		$\overline{\nu}_e p \to e^+ n$
<0.21	90	[152] ZACEK	86		$\overline{\nu}_e p \to e^+ n$
<0.19	90	[153] ZACEK	85		$\overline{\nu}_e p \to e^+ n$
<0.16	90	[154] GABATHULER	84		$\overline{\nu}_e p \to e^+ n$

[149] This bound is for $\Delta(m^2) > 5.0 \times 10^{-2}$ eV^2 and L=57.0 m, 57.6 m, and 231.4 m at three reactions in the Krasnoyark Reactor complex.
[150] Several different methods of data analysis are used in AFONIN 88. We quote the most stringent limits. Different upper limits on $\sin^2 2\theta$ apply at intermediate values of $\Delta(m^2)$. Supersedes AFONIN 87, AFONIN 85, and BELENKII 83.
[151] VIDYAKIN 87 bound is for L = 32.8 and 92.3 m distance from two reactors.
[152] This bound is from data for L=37.9 m, 45.9 m, and 64.7 m distance from Gosgen reactor.
[153] ZACEK 85 (Gosgen reactor) gives two sets of bounds depending on what assumptions are used in the data analysis. The bounds in figure 3(a) of ZACEK 85 are progressively poorer for large $\Delta(m^2)$ whereas those of figure 3(b) approach a constant. We list the latter. Both sets of bounds use combination of data from 37.9, 45.9, and 64.7m distance from reactor. ZACEK 85 states "Our experiment excludes this area (the oscillation parameter region allowed by the Bugey data, CAVAIGNAC 84) almost completely, thus disproving the indications of neutrino oscillations of CAVAIGNAC 84 with a high degree of confidence."
[154] This bound comes from a combination of the VUILLEUMIER 82 data at distance 37.9m from Gosgen reactor and new data at 45.9m.

$\Delta(m^2)$ for Given $\sin^2(2\theta)$

VALUE (eV^2)	DOCUMENT ID		COMMENT
0.2 ±0.1	[155] CAVAIGNAC	84	$\overline{\nu}_e p \to e^+ n$

[155] $\sin^2(2\theta) = 0.25 \pm 0.1$. These are from best fit to data; see CAVAIGNAC 84 for plot of allowed regions in these variables. These data from Bugey reactor.

(I) Accelerator Experiments

(i) Appearance experiments

$\nu_e \to \nu_\tau$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
< 9	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<44	90	TALEBZADEH	87	HLBC	BEBC

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.12	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.36	90	TALEBZADEH	87	HLBC	BEBC

$\overline{\nu}_e \to \overline{\nu}_\tau$

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.7	90	[156] FRITZE	80	HYBR	BEBC CERN SPS

[156] Authors give P($\nu_e \to \nu_\tau$) <0.35, equivalent to above limit.

$\nu_\mu \to \nu_e$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.09	90	ANGELINI	86	HLBC	BEBC CERN PS

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

		[157] ASTIER	90		
		[158] ASTIER	89	CNTR	BNL AGS
<0.1	90	BLUMENFELD	89	CNTR	
<1.3	90	AMMOSOV	88	HLBC	SKAT at Serpukhov
<0.19	90	BERGSMA	88	CHRM	
		[159] LOVERRE	88	RVUE	
<2.4	90	AHRENS	87	CNTR	BNL AGS
<1.8	90	BOFILL	87	CNTR	FNAL
<2.2	90	[160] BRUCKER	86	HLBC	15-ft FNAL
<0.43	90	AHRENS	85	CNTR	BNL AGS E734
<0.20	90	BERGSMA	84	CHRM	
<1.7	90	ARMENISE	81	HLBC	GGM CERN PS
<0.6	90	BAKER	81	HLBC	15-ft FNAL
<1.7	90	ERRIQUEZ	81	HLBC	BEBC CERN PS
<1.2	95	BLIETSCHAU	78	HLBC	GGM CERN PS
<1.2	95	BELLOTTI	76	HLBC	GGM CERN PS

[157] ASTIER 90 again finds an excess of electrons, as was reported in earlier papers by this collaboration. However, the authors concede that systematic effects weaken the statistical arguments and the consequent claim (in the earlier papers) of neutrino oscillations. An interpretation of these results in terms of neutrino oscillations seems to be already excluded by the BNL E734 (AHRENS 85) and the Los Alamos E645 (DURKIN 88) experiments.

[158] ASTIER 89 reports a a positive effect with ν_e(observed)/ν_e(expected) = 2.2 ± 0.6 and $\overline{\nu}_e$(observed)/$\overline{\nu}_e$(expected) = 1.6 ± 0.9.

[159] LOVERRE 88 reports a less stringent, indirect limit based on theoretical analysis of neutral to charged current ratios.

[160] 15ft bubble chamber at FNAL.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE (units 10^{-3})	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 2.5	90	AMMOSOV	88	HLBC	SKAT at Serpukhov
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[161] ASTIER	89	CNTR	BNL AGS
< 16	90	BLUMENFELD	89	CNTR	
< 8	90	BERGSMA	88	CHRM	$\Delta(m^2) \geq$ 30 eV^2
		[162] LOVERRE	88	RVUE	
< 10	90	AHRENS	87	CNTR	BNL AGS
< 15	90	BOFILL	87	CNTR	FNAL
< 20	90	[163] ANGELINI	86	HLBC	BEBC CERN PS
20 to 40		[164] BERNARDI	86B	CNTR	$\Delta(m^2)$=5–10
< 11	90	[165] BRUCKER	86	HLBC	15-ft FNAL
< 3.4	90	AHRENS	85	CNTR	BNL AGS E734
<240	90	BERGSMA	84	CHRM	
< 10	90	ARMENISE	81	HLBC	GGM CERN PS
< 6	90	BAKER	81	HLBC	15-ft FNAL
< 10	90	ERRIQUEZ	81	HLBC	BEBC CERN PS
< 4	95	BLIETSCHAU	78	HLBC	GGM CERN PS
< 10	95	BELLOTTI	76	HLBC	GGM CERN PS

[161] ASTIER 89 reports a a positive effect with ν_e(observed)/ν_e(expected) = 2.2 ± 0.6 and $\overline{\nu}_e$(observed)/$\overline{\nu}_e$(expected) = 1.6 ± 0.9.

[162] LOVERRE 88 reports a less stringent, indirect limit based on theoretical analysis of neutral to charged current ratios.

[163] ANGELINI 86 limit reaches 13×10^{-3} at $\Delta(m^2) \approx 2$ eV^2.

[164] BERNARDI 86B is a typical fit to the data, assuming mixing between two species. As the authors state, this result is in conflict with earlier upper bounds on this type of neutrino oscillations.

[165] 15ft bubble chamber at FNAL.

$\overline{\nu}_\mu \to \overline{\nu}_e$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<0.14	90	[166] FREEDMAN	93	CNTR	LAMPF

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

<0.11	90	[167] DURKIN	88	CNTR	Repl. by FREEDMAN 93
<3.1	90	BOFILL	87	CNTR	FNAL
<2.4	90	TAYLOR	83	HLBC	15-ft FNAL
<0.91	90	[167] NEMETHY	81B	CNTR	LAMPF
<1	95	BLIETSCHAU	78	HLBC	GGM CERN PS

[166] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \rightarrow e^+ n$.

[167] In reaction $\overline{\nu}_e p \rightarrow e^+ n$.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.004	95	BLIETSCHAU	78	HLBC	GGM CERN PS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.024	90	[168] FREEDMAN	93	CNTR	LAMPF
<0.014	90	[169] DURKIN	88	CNTR	Repl. by FREEDMAN 93
<0.04	90	BOFILL	87	CNTR	FNAL
<0.013	90	TAYLOR	83	HLBC	15-ft FNAL
<0.2	90	[169] NEMETHY	81B	CNTR	LAMPF

[168] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \rightarrow e^+ n$.

[169] In reaction $\overline{\nu}_e p \rightarrow e^+ n$.

$\nu_\mu(\overline{\nu}_\mu) \rightarrow \nu_e(\overline{\nu}_e)$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.075	90	BORODOV...	92	CNTR	BNL E776

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<3	90	BORODOV...	92	CNTR	BNL E776

$\nu_\mu \rightarrow \nu_\tau$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
< 0.9	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 4.5	90	BATUSOV	90B	EMUL	FNAL
<10.2	90	BOFILL	87	CNTR	FNAL
< 6.3	90	BRUCKER	86	HLBC	15-ft FNAL
< 4.6	90	ARMENISE	81	HLBC	GGM CERN SPS
< 3	90	BAKER	81	HLBC	15-ft FNAL
< 6	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
< 3	90	USHIDA	81	EMUL	FNAL

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.004	90	USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.06	90	BATUSOV	90B	EMUL	FNAL
<0.34	90	BOFILL	87	CNTR	FNAL
<0.088	90	BRUCKER	86	HLBC	15-ft FNAL
<0.11	90	BALLAGH	84	HLBC	15-ft FNAL
<0.017	90	ARMENISE	81	HLBC	GGM CERN SPS
<0.06	90	BAKER	81	HLBC	15-ft FNAL
<0.05	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
<0.013	90	USHIDA	81	EMUL	FNAL

$\overline{\nu}_\mu \rightarrow \overline{\nu}_\tau$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<2.2	90	ASRATYAN	81	HLBC	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<6.5	90	BOFILL	87	CNTR	FNAL
<7.4	90	TAYLOR	83	HLBC	15-ft FNAL

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<4.4 $\times 10^{-2}$	90	ASRATYAN	81	HLBC	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.15	90	BOFILL	87	CNTR	FNAL
<8.8 $\times 10^{-2}$	90	TAYLOR	83	HLBC	15-ft FNAL

$\nu_\mu(\overline{\nu}_\mu) \rightarrow \nu_\tau(\overline{\nu}_\tau)$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<1.5	90	[170] GRUWE	93	CHM2	CERN SPS

[170] GRUWE 93 is a search using the CHARM II detector in the CERN SPS wide-band neutrino beam for $\nu_\mu \rightarrow \nu_\tau$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_\tau$ oscillations signalled by quasi-elastic ν_τ and $\overline{\nu}_\tau$ interactions followed by the decay $\tau \rightarrow \nu_\tau \pi$. The maximum sensitivity in $\sin^2 2\theta$ ($< 6.4 \times 10^{-3}$ at the 90% CL) is reached for $\Delta(m^2) \simeq 50$ eV^2.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<8	90	[171] GRUWE	93	CHM2	CERN SPS

[171] GRUWE 93 is a search using the CHARM II detector in the CERN SPS wide-band neutrino beam for $\nu_\mu \rightarrow \nu_\tau$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_\tau$ oscillations signalled by quasi-elastic ν_τ and $\overline{\nu}_\tau$ interactions followed by the decay $\tau \rightarrow \nu_\tau \pi$. The maximum sensitivity in $\sin^2 2\theta$ ($< 6.4 \times 10^{-3}$ at the 90% CL) is reached for $\Delta(m^2) \simeq 50$ eV^2.

$\nu_e \rightarrow (\overline{\nu}_e)_L$

This is a limit on lepton family-number violation and total lepton-number violation. $(\overline{\nu}_e)_L$ denotes a hypothetical left-handed $\overline{\nu}_e$. The bound is quoted in terms of $\Delta\ (m^2)$, $\sin(2\theta)$, and α, where α denotes the fractional admixture of $(V{+}A)$ charged current.

$\alpha\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.14	90	[172] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<7	90	[173] COOPER	82	HLBC	BEBC CERN SPS

[172] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \rightarrow e^+ n$.

[173] COOPER 82 states that existing bounds on V+A currents require α to be small.

$\alpha^2\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.032	90	[174] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.05	90	[175] COOPER	82	HLBC	BEBC CERN SPS

[174] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \rightarrow e^+ n$.

[175] COOPER 82 states that existing bounds on V+A currents require α to be small.

$\nu_\mu \to (\overline{\nu}_e)_L$

See note above for $\nu_e \to (\overline{\nu}_e)_L$ limit

$\alpha\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.16	90	[176] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.7	90	[177] COOPER	82	HLBC	BEBC CERN SPS

[176] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \to e^+ n$. The limit on $\Delta(m^2)$ is better than the CERN BEBC experiment, but the limit on $\sin^2\theta$ is almost a factor of 100 less sensitive.

[177] COOPER 82 states that existing bounds on V+A currents require α to be small.

$\alpha^2\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.001	90	[178] COOPER	82	HLBC	BEBC CERN SPS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.07	90	[179] FREEDMAN	93	CNTR	LAMPF

[178] COOPER 82 states that existing bounds on V+A currents require α to be small.

[179] FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types ν_μ, $\overline{\nu}_\mu$, and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{\nu}_e p \to e^+ n$. The limit on $\Delta(m^2)$ is better than the CERN BEBC experiment, but the limit on $\sin^2\theta$

(ii) Disappearance experiments

$\nu_e \not\to \nu_e$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<2.3 OUR LIMIT					
< 8	90	BAKER	81	HLBC	15-ft FNAL
<2.3 OR >8	90	NEMETHY	81B	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<14.9	90	BRUCKER	86	HLBC	15-ft FNAL
<56	90	DEDEN	81	HLBC	BEBC CERN SPS
<10	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<7 $\times 10^{-2}$	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.54	90	BRUCKER	86	HLBC	15-ft FNAL
<0.6	90	BAKER	81	HLBC	15-ft FNAL
<0.3	90	DEDEN	81	HLBC	BEBC CERN SPS

$\nu_\mu \not\to \nu_\mu$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

These experiments also allow sufficiently large $\Delta(m^2)$.

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.23 OR >1500 OUR LIMIT					
<0.23 OR >100	90	DYDAK	84	CNTR	
<13 OR >1500	90	STOCKDALE	84	CNTR	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.29 OR >22	90	BERGSMA	88	CHRM	
<7	90	BELIKOV	85	CNTR	Serpukhov
<8.0 OR >1250	90	STOCKDALE	85	CNTR	
<0.29 OR >22	90	BERGSMA	84	CHRM	
<8.0	90	BELIKOV	83	CNTR	

$\sin^2(2\theta)$ for $\Delta(m^2) = 100\text{eV}^2$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[180] STOCKDALE	85	CNTR	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.17	90	[181] BERGSMA	88	CHRM	
<0.07	90	[182] BELIKOV	85	CNTR	Serpukhov
<0.27	90	[181] BERGSMA	84	CHRM	CERN PS
<0.1	90	[183] DYDAK	84	CNTR	CERN PS
<0.02	90	[184] STOCKDALE	84	CNTR	FNAL
<0.1	90	[185] BELIKOV	83	CNTR	Serpukhov

[180] This bound applies for $\Delta(m^2) = 100$ eV^2. Less stringent bounds apply for other $\Delta(m^2)$; these are nontrivial for $8 < \Delta(m^2) < 1250$ eV^2.
[181] This bound applies for $\Delta(m^2) = 0.7$–$9.$ eV^2. Less stringent bounds apply for other $\Delta(m^2)$; these are nontrivial for $0.28 < \Delta(m^2) < 22$ eV^2.
[182] This bound applies for a wide range of $\Delta(m^2) > 7$ eV^2. For some values of $\Delta(m^2)$, the value is less stringent; the least restrictive, nontrivial bound occurs approximately at $\Delta(m^2) = 300$ eV^2 where $\sin^2(2\theta) < 0.13$ at CL = 90%.
[183] This bound applies for $\Delta(m^2) = 1.$–$10.$ eV^2. Less stringent bounds apply for other $\Delta(m^2)$; these are nontrivial for $0.23 < \Delta(m^2) < 90$ eV^2.
[184] This bound applies for $\Delta(m^2) = 110$ eV^2. Less stringent bounds apply for other $\Delta(m^2)$; these are nontrivial for $13 < \Delta(m^2) < 1500$ eV^2.
[185] Bound holds for $\Delta(m^2) = 20$–1000 eV^2.

$\overline{\nu}_\mu \not\to \overline{\nu}_\mu$

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$

VALUE (eV^2)	CL%	DOCUMENT ID		TECN
<7 OR >1200 OUR LIMIT				
<7 OR >1200	90	STOCKDALE	85	CNTR

$\sin^2(2\theta)$ for 190 eV^2 $< \Delta(m^2) <$ 320 eV^2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[186] STOCKDALE	85	CNTR	FNAL

[186] This bound applies for $\Delta(m^2)$ between 190 and 320 or = 530 eV^2. Less stringent bounds apply for other $\Delta(m^2)$; these are nontrivial for $7 < \Delta(m^2) < 1200$ eV^2.

REFERENCES FOR Searches for Massive Neutrinos and Lepton Mixing

ABDURASHI... 94 PL B328 234 Abdurashitov, Faizov, Gavrin, Gusev+ (SAGE Collab.)
ACKER 94 PL B320 320 +Pakvasa (HAWA)
ALESSAND... 94 PL B335 519 Alessandrello, Brofferio, ..., Fiorini+ (MILA)
ANSELMANN 94 PL B327 377 +Hampel, Heusser, Kiko, Kirsten+ (GALLEX Collab.)
ARPESELLA 94 EPL 27 29 +Barabash, Bellotti+ (SASSO, ITEP, MOSU, MILA, LEBD)
BAHCALL 94 PL B338 276 (IAS)
BECK 94 PL B336 141 + (MPIH, KIAE, SASSO)
FUKUDA 94 PL B335 237 + (Kamiokande Collab.)
KONOPLICH 94 PAN 57 425 +Khlopov (MPEI)
PDG 94 PR D50 1173 Montanet+ (CERN, LBL, BOST, IFIC+)
PIEPKE 94 NP A577 493 +..., Klapdor-Kleingrothaus+ (MPIH, ITEP)
SMIRNOV 94 PR D49 1389 +Spergel, Bahcall (IAS, ICTP, INRM, PRIN)
VIDYAKIN 94 JETPL 59 390 +Vyrodov, Kozlov+ (KIAE)
Translated from ZETFP 59 364.
ALSTON-... 93 PRL 71 831 Alston-Garnjost+ (LBL, MTHO, UNM, INEL)
ANSELMANN 93 PL B314 445 +Hampel, Heusser, Kiko, Kirsten+ (GALLEX Collab.)
BAHCALL 93 PR D47 1298 +Bethe (IAS, CORN)
BAHRAN 93 PR D47 R754 +Kalbfleisch (OKLA)
BAHRAN 93B PR D47 R759 +Kalbfleisch (OKLA)
BARANOV 93 PL B302 336 +Batusov, Bunyatov, Klimov+ (JINR, SERP, BUDA)
BERMAN 93 PR C48 R1 +Pitt, Calaprice, Lowry (PRIN)
BERNATOW... 93 PR C47 806 Bernatowicz, Brazzle, Cowsik+ (WUSL, TATA)
FREEDMAN 93 PR D47 811 +Fujikawa, Napolitano, Nelson+ (LAMPF E645 Collab.)
GRUWE 93 PL B309 463 +Mommaert, Vilain, Wilquet+ (CHARM II Collab.)
HAMPEL 93 JPG 19 S209 (MPIH)
KALBFLEISCH 93 PL B303 355 +Bahran (OKLA)
MORTARA 93 PRL 70 394 +Ahmad, Coulter, Freedman+ (ANL, LBL, UCB)
OHSHIMA 93 PR D47 4840 + (KEK, TUAT, RIKEN, SCUC, ROCH, TSUK, INUS)
TURCK-CHI... 93 PRPL 230 57 Turck-Chieze+ (SACLD, USC, NICEA, NICEO, MEUD)
TURCK-CHI... 93B APJ 408 347 Turck-Chieze, Lopez (SACLD)
VUILLEUMIER 93 PR D48 1009 +Busto, Farine, Jorgens+ (NEUC, CIT, VILL)
WIETFELDT 93 PRL 70 1759 +Chan, da Cruz, Garcia+ (LBL, UCB, SPAUL)
ABREU 92B PL B274 230 +Adams, Adami, Adye+ (DELPHI Collab.)
ADRIANI 92I PL B295 371 +Aguilar-Benitez, Ahlen, Akbari, Alcaraz+ (L3 Collab.)
ALESSAND... 92 PL B285 176 Alessandrello, Camin, Cremonesi, Fiorini+ (MILA, SASSO)
ANSELMANN 92 PL B285 376 +Hampel, Heusser+ (GALLEX Collab.)
ANSELMANN 92B PL B285 390 +Hampel, Heusser+ (GALLEX Collab.)
ARTEMJEV 92 PL B280 159 +Brakchman, Ivanovsky, Karelin+ (ITEP)
BAHCALL 92 RMP 64 885 +Pinsonneault (IAS, YALE)
BAHRAN 92 PL B291 336 +Kalbfleisch (OKLA)
BALYSH 92 PL B283 32 +Belyaev, Bockholt, Demehin+ (MPIH, KIAE, SASSO)
BECKER-SZ... 92 PRL 69 1010 Becker-Szendy, Bratton, Casper, Dye+ (IMB Collab.)

BECKER-SZ...	92B	PR D46 3720	Becker-Szendy, Bratton, Casper, Dye+	(IMB Collab.)
BEIER	92	PL B283 446	+Frank, Frati, Kim, Mann+	(KAM2 Collab.)
Also	94	PTRSL A346 63	Beier, Frank	(PENN)
BERNATOW...	92	PRL 69 2341	Bernatowicz, Brannon, Brazzle, Cowsik+	(WUSL, TATA)
BLUM	92	PL B275 506	+Busto, Campagne, Dassie, Hubert+	(NEMO Collab.)
BORODOV...	92	PRL 68 274	Borodovsky, Chi, Ho, Kondakis, Lee+	(COLU, JHU, ILL)
BRITTON	92	PRL 68 3000	+Ahmad, Bryman, Burnham+	(TRIU, CARL)
Also	94	PR D49 28	Britton, Ahmad, Bryman+	(TRIU, CARL)
BRITTON	92B	PR D46 R885	+Ahmad, Bryman+	(TRIU, CARL)
CHEN	92	PRL 69 3151	+Imel, Radcliffe, Henrickson, Boehm	(CIT)
ELLIOTT	92	PR C46 1535	+Hahn, Moe+	(UCI)
HIRATA	92	PL B280 146	+Inoue, Ishida+	(Kamiokande II Collab.)
HOLZSCHUH	92B	PL B287 381	+Fritschi, Kuendig	(ZURI)
KAWAKAMI	92	PL B287 45	+	(INUS, KEK, SCUC, TUAT, RIKEN, ROCH, TSUK)
KETOV	92	JETPL 55 564	+Machulin, Mikaelyan+	(KIAE)
		Translated from ZETFP 55 544.		
KUDOMI	92	PR C46 R2132	+Ejiri, Nagata, Okada, Shibata+	(OSAK, INUS)
MORI	92B	PL B289 463	+Hikasa, Nojiri, Oyama+	(KAM2 Collab.)
REUSSER	92	PR D45 2548	Reussser, Treichel, Boehm+	(CIT, NEUC, VILL)
ABAZOV	91B	PRL 67 3332	+Anosov, Faizov+	(SAGE Collab.)
ABREU	91F	NP B367 511	+Adam, Adami, Adye, Akesson+	(DELPHI Collab.)
ALEXANDER	91F	ZPHY C52 175	+Allison, Allport, Anderson, Arcelli+	(OPAL Collab.)
AVIGNONE	91	PL B256 559	+Brodzinski, Guerard+	(SCUC, PNL, ITEP, YERE)
BELLOTTI	91	PL B266 193	+Cremonesi, Fiorini, Gervasio+	(MILA, INFN)
CASPER	91	PRL 66 2561	+Becker-Szendy, Bratton, Cady+	(IMB Collab.)
DELEENER-...	91	PR D43 3611	De Leener-Rosier, Deutsch+	(LVLN, ZURI, LAUS)
EJIRI	91	PL B258 17	+Fushimi, Kamada, Kinoshita+	(OSAK)
GARCIA	91	PRL 67 3654	+Adelberger, Magnus, Swanson+	(WASH, CERN, LBL)
HIME	91	PL B257 441	+Jelley	(OXF)
HIRATA	91	PRL 66 9	+Inoue, Kajita, Kihara+	(Kamiokande II Collab.)
HIRATA	91B	PR D44 2241		
HYKAWY	91	PRL 67 1708	+Nxumalo, Unger, Lander+	(MANI)
MORALES	91	NC 104A 1581	+Morales, Nunez-Lagos, Puimedon+	(ZARA)
NORMAN	91	JPG 17 S291	+Sur, Lesko+	(LBL)
REUSSER	91	PL B255 143	+Treichel, Boehm, Broggini+	(NEUC, CIT, VILL)
SATO	91	PR D44 2220	+Hirata, Kajita, Kifune, Kihara+	(Kamioka Collab.)
SUHONEN	91	NP A535 509	+Khadkikar, Faessler	(JYV, AHMED, TUBIN)
TURKEVICH	91	PRL 67 3211	+Economou, Cowan	(CHIC, LANL)
WONG	91	PRL 67 1218	+Boehm, Fisher, Gabathuler+	(CIT, VILL, NEUC)
YOU	91	PL B265 53	+Zhu, Lu+	(BHEP, CAST+)
ADEVA	90S	PL B251 321	+Adriani, Aguilar-Benitez, Akbari+	(L3 Collab.)
AKRAWY	90L	PL B247 448	+Alexander, Allison, Allport+	(OPAL Collab.)
ASTIER	90	NP B335 517	+Bernardi+	(BOST, BNL, CERN, CURIN, PARIN)
BARABASH	90	PL B249 186	+Kopylov, Cherehovsky	(ITEP, INRM)
BATUSOV	90B	ZPHY C48 209	+Bunyatov, Kuznetsov, Pozharova+	(JINR, ITEP, SERP)
BERGER	90B	PL B245 305	+Froehlich, Moench, Nisius+	(FREJUS Collab.)
BURCHAT	90	PR D41 3542	+King, Abrams, Adolphsen+	(Mark II Collab.)
DECAMP	90F	PL B236 511	+Deschizeaux, Lees, Minard+	(ALEPH Collab.)
FILIPPONE	90	PL B246 546	+Vogel	(CIT)
HIRATA	90	PRL 65 1297	+Inoue, Kajita+	(Kamiokande II Collab.)
HIRATA	90B	PRL 65 1301	+Inoue, Kajita+	(Kamiokande II Collab.)
JUNG	90	PRL 64 1091	+Van Kooten, Abrams, Adolphsen+	(Mark II Collab.)
KOPEIKIN	90	JETPL 51 86	+Mikazlyan, Fayans	(KIAE)
		Translated from ZETFP 51 75.		
MILEY	90	PRL 65 3092	+Avignone, Brodzinski, Collar, Reeves	(SCUC, PNL)
STAUDT	90	EPL 13 31	+Muto, Klapdor-Kleingrothaus	(MPIH)
VASENKO	90	MPL A5 1299	+Kirpichnikov, Kuznetsov, Starostin	(ITEP, YERE)
VIDYAKIN	90	JETP 71 424	+Vyrodov, Gurevich, Koslov+	(KIAE)
		Translated from ZETF 98 764.		
ABRAMS	89C	PRL 63 2447	+Adolphsen, Averill, Ballam+	(Mark II Collab.)
AGLIETTA	89	EPL 8 611	+Battistoni, Bellotti+	(FREJUS Collab.)
ALSTON-...	89	PRL 63 1671	Alston-Garnjost, Dougherty+	(LBL, MTHO, UNM, INEL)
ASTIER	89	PL B220 646	+Bernardi, Carugno+	(CURIN, PARIN, BOST, CERN, BNL)
BAHCALL	89	Neutrino Astrophysics, Cambridge Univ. Press		(IAS)
BARABASH	89	PL B223 273	+Kuzminov, Lobashev, Novikov+	(ITEP, INRM)
BELLOTTI	89	PL B221 209	+Cremonesi, Fiorini, Gervasio+	(MILA)
BLUMENFELD	89	PRL 62 2237	+Chi, Chichura, Chien+	(COLU, ILL, JHU)
DANEVICH	89	JETPL 49 476	+Zdesenko, Nikolaiko, Tretyak	(UZINR)
		Translated from ZETFP 49 417.		
DAVIS	89	ARNPS 39 467	+Mann, Wolfenstein	(BNL, PENN, CMU)
ENQVIST	89	NP B317 647	+Kainulainen, Maalampi	(HELS)
FISHER	89	PL B218 257	+Boehm, Bovet, Egger+	(CIT, NEUC, PSI)
MUTO	89	ZPHY A334 187	+Bender, Klapdor	(TINT, MPIH)
OYAMA	89	PR D39 1481	+Hirata, Kajita, Kifune+	(Kamiokande II Collab.)
SHAW	89	PRL 63 1342	+Blanis, Bodek, Budd+	(AMY Collab.)
AFONIN	88	JETP 67 213	+Ketov, Kopeikin, Mikaelyan+	(KIAE)
		Translated from ZETF 94 1, issue 2.		
AKERLOF	88	PR D37 577	+Chapman, Errede, Ken+	(HRS Collab.)
AMMOSOV	88	ZPHY C40 487	+Belikov+	(SKAT Collab.)
BAHCALL	88	RMP 60 297	+Ulrich	(IAS, UCLA)
BEHREND	88C	ZPHY C41 7	+Buerger, Criegee, Dainton+	(CELLO Collab.)
BERGSMA	88	ZPHY C40 171	+Dorenbosch, Nieuwenhuis+	(CHARM Collab.)
BERNARDI	88	PL B203 332	+Carugno, Chauveau+	(PARIN, CERN, INFN, ATEN)
BIONTA	88	PR D38 768	+Blewitt, Bratton, Casper+	(IMB Collab.)
CALDWELL	88	PRL 61 510	+Eisberg, Grumm, Witherell+	(UCSB, UCB, LBL)
DURKIN	88	PRL 61 1811	+Harper, Ling+	(OSU, ANL, CIT, LBL, LSU, LANL)
ENGEL	88	PR C37 731	+Vogel, Zimbene	
GAN	88	IJMP A3 531	+Perl	(SLAC)
HIRATA	88	PL B205 416	+Kajita, Koshiba+	(Kamiokande II Collab.)
LOVERRE	88	PL B206 711		(INFN)
MORALES	88	NC 100A 525	+Morales, Nunez-Lagos, Puimedon+	(ZARA)
OLIVE	88	PL B205 553	+Srednicki	(MINN, UCSB)
SPERGEL	88B	PR D38 2014	+Weinberg, Gott	(PRIN)
SREDNICKI	88	NP B310 693	+Watkins, Olive	(MINN, UCSB)
TURCK-CHI...	88	APJ 335 415	Turck-Chieze, Cahen, Casse, Doom	(SACL, BRUX)
AFONIN	87	JETPL 45 257	+Bogatov, Vershinskii+	(KIAE)
		Translated from ZETFP 45 201.		

*CITATION: L. Montanet et al., Physical Review D50, 1173 (1994) and 1995 off-year partial update for the 1996 edition (URL: http://pdg.lbl.gov/)

AHLEN	87	PL B195 603	+Avignone, Brodzinski+	(BOST, SCUC, HARV, CHIC)
AHRENS	87	PR D36 702	+ (BNL, BROW, UCI, HIRO, KEK, OSAK, PENN, STON)	
BELLOTTI	87	EPL 3 889	+Cattadori, Cremonesi, Fiorini+	(MILA)
BOEHM	87	Massive Neutrinos	+Vogel	(CIT)
Cambridge Univ.		Press, Cambridge		
BOFILL	87	PR D36 3309	+Busza, Eldridge+	(MIT, FNAL, MSU)
CALDWELL	87	PRL 59 419	+Eisberg, Grumm, Witherell+	(UCSB, LBL)
DAUM	87	PR D36 2624	+Kettle, Jost+	(SIN, VIRG)
ELLIOTT	87B	PRL 59 2020	+Hahn, Moe	(UCI)
GRIEST	87	NP B283 681	+Seckel	(UCSC, CERN)
Also	88	NP B296 1034 erratum	Griest, Seckel	(UCSC, CERN)
LOSECCO	87	PL B184 305	+Bionta, Blewitt, Bratton+	(IMB Collab.)
MISHRA	87	PRL 59 1397	+Auchincloss+	(COLU, CIT, FNAL, CHIC, ROCH)
OBERAUER	87	PL B198 113	+von Feilitzsch, Mossbauer	(MUNT)
TALEBZADEH	87	NP B291 503	+Guy, Venus+	(BEBC WA66 Collab.)
TOMODA	87	PL B199 475	+Faessler	(TUBIN)
VIDYAKIN	87	JETP 66 243	+Vyrodov, Gurevich, Kozlov+	(KIAE)
		Translated from ZETF 93 424.		
WENDT	87	PRL 58 1810	+Abrams, Amidei, Baden+	(Mark II Collab.)
AFONIN	86	JETPL 44 142	+Bogatov, Borovoi, Vershinskii+	(KIAE)
		Translated from ZETFP 44 111.		
ANGELINI	86	PL B179 307	+Apostolakis, Baldini+	(PISA, ATHU, PADO, WISC)
AZUELOS	86	PRL 56 2241	+Britton, Bryman+	(TRIU, CNRC)
BADIER	86	ZPHY C31 21	+Bemporad, Boucrot, Callot+	(NA3 Collab.)
BELLOTTI	86	NC 95A 1	+Cremonesi, Fiorini, Liguori+	(MILA)
BERNARDI	86	PL 166B 479	+Carugno+	(CURIN, INFN, CDEF, ATEN, CERN)
BERNARDI	86B	PL B181 173	+Carugno+	(CURIN, INFN, CDEF, ATEN, CERN)
BORGE	86	PS 34 591	+DeRujula, Hansen, Jonson+	(ISOLDE Collab.)
BRUCKER	86	PR D34 2183	+Jacques, Kalelkar, Koller+	(RUTG, BNL, COLU)
CALDWELL	86	PR D33 2737	+Eisberg, Grumm, Hale, Witherell+	(UCSB, LBL)
DELEENER-...	86	PL B177 228	DeLeener-Rosier, Deutsch+	(LVLN, ZURI, LAUS)
DORENBOS...	86	PL 166B 473	Dorenbosch, Allaby, Amaldi+	(CHARM Collab.)
ELLIOTT	86	PRL 56 2582	+Hahn, Moe	(UCI)
GROTZ	86	NC C9 535	+Klapdor	(MPIH)
KAWASAKI	86	PL B178 71	+Terasawa, Sato	(TOKY)
KAWASAKI	86B	PL 169B 280	+Sato	(TOKY)
TAKAHARA	86	PL B174 373	+Sato	(TOKY)
USHIDA	86C	PRL 57 2897	+Kondo, Tasaka, Park, Song+	(FNAL E531 Collab.)
ZACEK	86	PR D34 2621	+Feilitzsch+	(CIT-SIN-TUM Collab.)
AFONIN	85	JETPL 41 435	+Borovoi, Dobrynin+	(KIAE)
		Translated from ZETFP 41 355.		
Also	85B	JETPL 42 285	Afonin, Bogatov, Borovoi, Dobrynin+	(KIAE)
		Translated from ZETFP 42 230.		
AHRENS	85	PR D31 2732	+Aronson+	(BNL, BROW, KEK, OSAK, PENN+)
AKERLOF	85	PL 156B 271	+Bonvicini, Chapman, Errede+	(HRS Collab.)
ALBRECHT	85I	PL 163B 404	+Binder, Drescher, Schubert+	(ARGUS Collab.)
ALTZITZOG...	85	PRL 55 799	Altzitzoglou, Calaprice, Dewey+	(PRIN)
APALIKOV	85	JETPL 42 289	+Boris, Golutvin, Laptin, Lubimov+	(ITEP)
		Translated from ZETFP 42 233.		
BELIKOV	85	SJNP 41 589	+Volkov, Kochetkov, Mukhin+	(SERP)
		Translated from YAF 41 919.		
CALDWELL	85	PRL 54 281	+Eisberg, Grumm, Hale, Witherell+	(UCSB, LBL)
COOPER-...	85	PL 160B 207	Cooper-Sarkar+	(CERN, LOIC, OXF, SACL+)
COWSIK	85	PL 151B 62		(TATA)
DATAR	85	Nature 318 547	+Baba, Bhattacherjee, Bhuinya, Roy	(BHAB, TATA)
HUBERT	85	NC 85A 19	+Leccia, Dassie, Mennrath+	(BCEN, ZARA)
MADSEN	85	PRL 54 2720	+Epstein	(AARH, LANL)
MARKEY	85	PR C32 2215	+Boehm	(CIT)
OHI	85	PL 160B 322	+Nakajima, Tamura+	(TOKY, INUS, KEK)
PERL	85	PR D32 2859	+Barklow, Boyarski+	(Mark II Collab.)
SIMPSON	85	PRL 54 1891		(GUEL)
STOCKDALE	85	ZPHY C27 53	+Bodek+	(ROCH, CHIC, COLU, FNAL)
ZACEK	85	PL 164B 193	+Zacek, Boehm+	(MUNI, CIT, SIN)
BALLAGH	84	PR D30 2271	+Bingham+	(UCB, LBL, FNAL, HAWA, WASH, WISC)
BELLOTTI	84	PL 146B 450	+Cremonesi, Fiorini, Liguori, Pullia+	(MILA)
BERGSMA	84	PL 142B 103	+Dorenbosch, Allaby, Abt+	(CHARM Collab.)
CAVAIGNAC	84	PL 148B 387	+Hoummada, Koang+	(ISNG, LAPP)
DYDAK	84	PL 134B 281	+Feldman+	(CERN, DORT, HEIDH, SACL, WARS)
ERREDE	84	PL 149B 519	+Akerlof, Chapman, Harnew+	(HRS Collab.)
FORSTER	84	PL 138B 301	+Kwon, Markey, Boehm, Henrikson	(CIT)
FREESE	84	NP B233 167	+Schramm	(CHIC, FNAL)
GABATHULER	84	PL 138B 449	+Boehm+	(CIT, SIN, MUNI)
GRONAU	84	PR D29 2539	+Leung, Rosner	(SYRA, FNAL, CHIC)
HAXTON	84	PPNP 12 409	+Stevenson	
MADSEN	84	APJ 282 11	+Epstein	(AARH, LANL)
MINEHART	84	PRL 52 804	+Ziock, Marshall, Stephens, Daum+	(VIRG, SIN)
RIZZO	84	PL 136B 251		(ISU)
SARKAR	84	PL 148B 347	+Cooper	(OXF, CERN)
SCHRAMM	84	PL 141B 337	+Steigman	(FNAL, BART)
STOCKDALE	84	PRL 52 1384	+Bodek+	(ROCH, CHIC, COLU, FNAL)
AFONIN	83	JETPL 38 436	+Bogatov, Borovoi, Vershinskii+	(KIAE)
		Translated from ZETFP 38 361.		
AVIGNONE	83	PRL 50 721	+Brodzinski, Brown, Evans, Hensley+	(SCUC, PNL)
BARTEL	83	PL 123B 353	+Cords, Dietrich, Eichler+	(JADE Collab.)
BELENKII	83	JETPL 38 493	+Dobrynin, Zemlyakov, Mikaelyan+	(KIAE)
		Translated from ZETFP 38 406.		
BELIKOV	83	JETPL 38 661	+Volkov, Kochetkov, Mukhin, Sviridov+	(SERP)
		Translated from ZETFP 38 547.		

BELLOTTI	83	PL 121B 72	+Fiorini, Ligurori, Pullia, Sarracino+ (MILA)
BERGSMA	83	PL 122B 465	+Dorenbosch, Jonker+ (CHARM Collab.)
BERGSMA	83B	PL 128B 361	+Dorenbosch+ (CHARM Collab.)
BRYMAN	83B	PRL 50 1546	+Dubois, Numao, Olaniya, Olin+ (TRIU, CNRC)
Also	83	PRL 50 7	Bryman, Dubois, Numao, Olaniya+ (TRIU, CNRC)
DEUTSCH	83	PR D27 1644	+Lebrun, Prieels (LVLN)
DOI	83	PTP 69 602	+Kotani, Nishiura, Takasugi (OSAK, KYOTY)
FILIPPONE	83	PRL 50 412	+Elwyn, Davids+ (ANL, CHIC, VALP)
FREESE	83	PR D27 1689	+Kolb, Turner (CHIC, LANL)
GRONAU	83	PR D28 2762	(HAIF)
KIRSTEN	83	PRL 50 474	+Richter, Jessberger (MPIH)
Also	83B	ZPHY 16 189	Kirsten, Richter, Jessberger (MPIH)
LIN	83	APJ 266 L21	+Faber (UCSC)
PRIMACK	83	Phil. 4th Workshop on Grand Unification	(UCSC)
SCHRECK...	83	PL 129B 265	Schreckenbach, Colvin+ (ISNG, ILLG)
TAYLOR	83	PR D28 2705	+Cence, Harris, Jones+ (HAWA, LBL, FNAL)
BAHCALL	82	RMP 54 767	+Huebner, Lubow+ (IAS, LANL, HPC, YALE, UCLA)
COOPER	82	PL 112B 97	+Guy, Michette, Tyndel, Venus (RL)
FILIPPONE	82	APJ 253 393	+Schramm (ANL, EFI)
FOWLER	82	A.I.P. 96 80	(CIT)
HAXTON	82	PR D25 2360	+Stephenson, Strottman (LANL, PURD)
HAYANO	82	PRL 49 1305	+Taniguchi, Yamanaka+ (TOKY, KEK, TSUK)
OLIVE	82	PR D25 213	+Turner (CHIC, UCSB)
VUILLEUMIER	82	PL 114B 298	+Boehm, Egger+ (CIT, SIN, MUNI)
ABELA	81	PL 105B 263	+Daum, Eaton, Frosch, Jost, Kettle, Steiner (SIN)
ARMENISE	81	PL 100B 182	+Fogli-Muciaccia+ (BARI, CERN, MILA, LALO)
ASANO	81	PL 104B 84	+Hayano, Kikutani, Kurokawa+(KEK, TOKY, INUS, OSAK)
Also	81	PR D24 1232	Shrock (STON)
ASRATYAN	81	PL 105B 301	+Efremenko, Fedotov+ (ITEP, FNAL, SERP, MICH)
BAKER	81	PRL 47 1576	+Connolly, Kahn, Kirk, Murtagh+ (BNL, COLU)
Also	78	PRL 40 144	Cnops, Connolly, Kahn, Kirk+ (BNL, COLU)
BERNSTEIN	81	PL 101B 39	+Feinberg (STEV, COLU)
BOLIEV	81	SJNP 34 787	+Butkevich, Zakidyshev, Makoev+ (INRM)
		Translated from YAF 34 1418.	
BOND	81	Nu Conf. Hawaii	+Szalay (UCB, CHIC)
CALAPRICE	81	PL 106B 175	+Schreiber, Schneider+ (PRIN, IND)
CLARK	81	PRL 46 299	+Johnson, Kerth, Loken+ (UCB, LBL, FNAL, PRIN)
DAVIS	81	APJ 250 423	+Lecar, Pryor, Witten (HARV, PRIN)
DEDEN	81	PL 98B 310	+Grassler, Boeckmann, Mermikides+ (BEBC Collab.)
ERRIQUEZ	81	PL 102B 73	+Natali+ (BARI, BIRM, BRUX, EPOL, RHEL, SACL+)
HAXTON	81	PRL 47 153	+Stephenson, Strottman (PURD, LASL)
KWON	81	PR D24 1097	+Boehm, Hahn, Henrikson+ (CIT, ISNG, MUNI)
NEMETHY	81B	PR D23 262	+ (YALE, LBL, LASL, MIT, SACL, SIN, CNRC, BERN)
ROSEN	81	Nu Conf. Hawaii	(PURD)
Also	78	RMP 50 11	Bryman, Picciotto (TRIU, VICT)
SCHRAMM	81	APJ 243 1	+Steigman (CHIC, BART)
SHROCK	81	PR D24 1232	(STON)
SHROCK	81B	PR D24 1275	(STON)
SILVERMAN	81	PRL 46 467	+Soni (UCI, UCLA)
SIMPSON	81B	PR D24 2971	(GUEL)
USHIDA	81	PRL 47 1694	+ (AICH, FNAL, KOBE, SEOU, MCGI, NAGO, OSU+)
AVIGNONE	80	PR C22 594	+Greenwood (SCUC)
BAHCALL	80	PRL 45 945	+Lubow, Huebner+ (IAS, LASL, YALE, LLL, UCLA)
Also	76	Science 191 264	Bahcall, Davis (IAS, BNL)
BOEHM	80	PL 97B 310	+Cavaignac, Feilitzsch+ (ILLG, CIT, ISNG, MUNI)
FRITZE	80	PL 96B 427	(AACH3, BONN, CERN, LOIC, OXF, SACL)
LEBRITTON	80	PL 89B 271	+McCal, Melissinos+ (ROCH, BNL, NSF)
REINES	80	PRL 45 1307	+Sobel, Pasierb (UCI)
Also	59	PR 113 273	Reines, Cowan (LASL)
Also	66	PR 142 852	Nezrick, Reines (CASE)
Also	76	PRL 37 315	Reines, Gurr, Sobel (UCI)
SHROCK	80	PL 96B 159	(STON)
DAVIS	79	PR C19 2259	+Vogel, Mann, Schenter (CIT)
TREMAINE	79	PRL 42 407	+Gunn (CIT, CAMB, CAIW)
BLIETSCHAU	78	NP B133 205	+Deden, Hasert, Krenz+ (Gargamelle Collab.)
CROUCH	78	PR D18 2239	+Landecker, Lathrop, Reines+ (CASE, UCI, WITW)
MEYER	77	PL 70B 469	+Nguyen, Abrams+ (SLAC, LBL, NWES, HAWA)
VYSOTSKY	77	JETPL 26 188	+Dolgov, Zeldovich (ITEP)
		Translated from ZETFP 26 200.	
BELLOTTI	76	LNC 17 553	+Cavalli, Fiorini, Rollier (MILA)
SZALAY	76	AA 49 437	+Marx (EOTV)
SZALAY	74	APAH 35 8	+Marx (EOTV)
COWSIK	72	PRL 29 669	+McClelland (UCB)
MARX	72	Nu Conf. Budapest	+Szalay (EOTV)
GERSHTEIN	66	JETPL 4 120	+Zeldovich (KIAM)
		Translated from ZETFP 4 189.	