Massive Neutrinos and Lepton Mixing, Searches for

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(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 $|U_{1j}|^2 + |U_{2j}|^2 + |U_{3j}|^2 >$ 6.2×10^{-8} at m_{L^0} = 20 GeV and $>$ 5.1×10^{-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.

See the "Quark and Lepton Compositeness, Searches for" Listings for limits on radiatively decaying excited neutral leptons, *i.e.* $\nu^* \rightarrow \nu\gamma$.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>69.8	95	[2] ACKERSTAFF	98C	OPAL	Majorana, coupling to e
>79.1	95	[2] ACKERSTAFF	98C	OPAL	Dirac, coupling to e
>68.7	95	[2] ACKERSTAFF	98C	OPAL	Majorana, coupling to μ
>78.5	95	[2] ACKERSTAFF	98C	OPAL	Dirac, coupling to μ
>54.4	95	[2] ACKERSTAFF	98C	OPAL	Majorana, coupling to τ
>69.0	95	[2] ACKERSTAFF	98C	OPAL	Dirac, coupling to τ
>78.0	95	[2] ACCIARRI	97P	L3	Dirac coupling to e
>66.7	95	[2] ACCIARRI	97P	L3	Majorana coupling to e
>78.0	95	[2] ACCIARRI	97P	L3	Dirac coupling to μ
>66.7	95	[2] ACCIARRI	97P	L3	Majorana coupling to μ
>72.2	95	[2] ACCIARRI	97P	L3	Dirac coupling to τ
>58.2	95	[2] ACCIARRI	97P	L3	Majorana coupling to τ
>63	95	[3,4] BUSKULIC	96S	ALEP	Dirac
>54.3	95	[3,5] BUSKULIC	96S	ALEP	Majorana

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

>59.3	95	ACCIARRI	96G	L3	Dirac coupling to e
>57.9	95	ACCIARRI	96G	L3	Dirac coupling to μ
>48.6	95	ACCIARRI	96G	L3	Majorana coupling to e
>47.2	95	ACCIARRI	96G	L3	Majorana coupling to μ
>62.5	95	ALEXANDER	96P	OPAL	Dirac coupling to e
>63.0	95	ALEXANDER	96P	OPAL	Dirac coupling to μ
>57.4	95	ALEXANDER	96P	OPAL	Dirac coupling to τ
>51.4	95	ALEXANDER	96P	OPAL	Majorana coupling to e
>52.2	95	ALEXANDER	96P	OPAL	Majorana coupling to μ
>44.2	95	ALEXANDER	96P	OPAL	Majorana coupling to τ
>44.5	95	[6] ABREU	92B	DLPH	Dirac
>39.0	95	[6] ABREU	92B	DLPH	Majorana
none 2.5–50	95	[7] ADRIANI	92I	L3	$\lvert U_{\tau \text{ or } \mu}\rvert^2 < 3\times10^{-4}$
none 4–50	95	[7] ADRIANI	92I	L3	$\lvert U_{\tau}\rvert^2 < 3\times10^{-4}$
>46.4	95	[8] ADEVA	90S	L3	Dirac
>45.1	95	[8] ADEVA	90S	L3	Majorana
>46.5	95	[9] AKRAWY	90L	OPAL	Coupling to e or μ
>45.7	95	[9] AKRAWY	90L	OPAL	Coupling to τ
>41	95	[10,11] BURCHAT	90	MRK2	Dirac, $\lvert U_{\ell j}\rvert^2 > 10^{-10}$
>19.6	95	[10,11] BURCHAT	90	MRK2	Dirac, all $\lvert U_{\ell j}\rvert^2$
none 25–45.7	95	[10,12] DECAMP	90F	ALEP	Dirac $\lvert U_{\ell j}\rvert^2 > 10^{-13}$
none 8.2–26.5	95	[13] SHAW	89	AMY	Dirac L^0, $\lvert U_{e j}\rvert^2 > 10^{-6}$
none 8.3–22.4	95	[13] SHAW	89	AMY	Majorana L^0, $\lvert U_{e j}\rvert^2 > 10^{-6}$
none 8.1–24.9	95	[13] SHAW	89	AMY	Majorana L^0, $\lvert U_{\mu j}\rvert^2 > 10^{-6}$
none 1.8–6.7	90	[14] AKERLOF	88	HRS	$\lvert U_{e j}\rvert^2=1$
none 1.8–6.4	90	[14] AKERLOF	88	HRS	$\lvert U_{\mu j}\rvert^2=1$
none 2.5–6.3	80	[14] AKERLOF	88	HRS	$\lvert U_{\tau j}\rvert^2=1$
none 0.25–14	90	[15] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2=1.$
none 0.25–10	90	[15] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2=0.1$
none 0.25–7.7	90	[15] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2=0.03$
none 1.–2.	90	[16] WENDT	87	MRK2	$\lvert U_{e \text{ or } \mu j}\rvert^2=0.1$
none 2.2–4.	90	[16] WENDT	87	MRK2	$\lvert U_{e \text{ or } \mu j}\rvert^2=0.001$
none 2.3–3.	90	[16] WENDT	87	MRK2	$\lvert U_{\tau j}\rvert^2=0.1$
none 3.2–4.8	90	[16] WENDT	87	MRK2	$\lvert U_{\tau j}\rvert^2=0.001$
none 0.3–0.9	90	[17] BADIER	86	CNTR	$\lvert U_{e j}\rvert^2=0.8$
none 0.33–2.0	90	[17] BADIER	86	CNTR	$\lvert U_{e j}\rvert^2=0.03$
none 0.6–0.7	90	[17] BADIER	86	CNTR	$\lvert U_{\mu j}\rvert^2=0.8$
none 0.6–2.0	90	[17] BADIER	86	CNTR	$\lvert U_{\mu j}\rvert^2=0.01$–$0.001$
> 1.2		MEYER	77	MRK1	Neutral

[2] The decay length of the heavy lepton is assumed to be < 1 cm, limiting the square of the mixing angle $\lvert U_{\ell j}\rvert^2$ to 10^{-12}.

[3] BUSKULIC 96S requires the decay length of the heavy lepton to be < 1 cm, limiting the square of the mixing angle $|U_{\ell j}|^2$ to 10^{-10}.

[4] BUSKULIC 96S limit for mixing with τ. Mass is > 63.6 GeV for mixing with e or μ.

[5] BUSKULIC 96S limit for mixing with τ. Mass is > 55.2 GeV for mixing with e or μ.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

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

[11] 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.

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

[13] 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.

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

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

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

[17] 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 $U_{m,j}$ 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".

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 60–115		[18] FARGION	95	ASTR	Dirac
none 9.2–2000		[19] GARCIA	95	COSM	Nucleosynthesis
none 26–4700		[19] BECK	94	COSM	Dirac
none 6 – hundreds		[20,21] MORI	92B	KAM2	Dirac neutrino
none 24 – hundreds		[20,21] MORI	92B	KAM2	Majorana neutrino
none 10–2400	90	[22] REUSSER	91	CNTR	HPGe search
none 3–100	90	SATO	91	KAM2	Kamiokande II
		[23] ENQVIST	89	COSM	

none 12–1400		[19] CALDWELL	88	COSM	Dirac ν
none 4–16	90	[19,20] 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	[19] AHLEN	87	COSM	Dirac ν
>4.1		GRIEST	87	COSM	Dirac ν

[18] FARGION 95 bound is sensitive to assumed ν concentration in the Galaxy. See also KONOPLICH 94.

[19] These results assume that neutrinos make up dark matter in the galactic halo.

[20] Limits based on annihilations in the sun and are due to an absence of high energy neutrinos detected in underground experiments.

[21] MORI 92B results assume that neutrinos make up dark matter in the galactic halo. Limits based on annihilations in earth are also given.

[22] REUSSER 91 uses existing $\beta\beta$ detector (see FISHER 89) to search for CDM Dirac neutrinos.

[23] ENQVIST 89 argue that there is no cosmological upper bound on heavy neutrinos.

(B) Sum of neutrino masses

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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

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	[24] OLIVE	82	COSM	Dirac ν
<200–2000	[24] OLIVE	82	COSM	Majorana ν

[24] 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	[25] OLIVE	82	COSM	$G_R/G_F < 0.1$
>100	[25] OLIVE	82	COSM	$G_R/G_F < 0.01$

[25] These results apply to heavy Majorana neutrinos and are summarized by the equation: $m_\nu > 1.2$ GeV (G_F/G_R). The bound saturates, and if G_R is too small no mass range is allowed.

(C) Searches for neutrinoless double-β decay

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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)$\overline{\nu}_e$. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

$t_{1/2}(10^{21}$ yr)	CL%	ISOTOPE		TRANSITION	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
> 56	90	^{130}Te	0ν		Cryog. det.	[26] ALESSAND...	98
> 16	90	^{130}Te	0ν	$0^+ \rightarrow 2^+$	Cryog. det.	[26] ALESSAND...	98
> 17	90	^{128}Te	0ν		Cryog. det.	[26] ALESSAND...	98
> 440	90	^{136}Xe	0ν		Xe TPC	[27] LUESCHER	98
> 0.36	90	^{136}Xe	2ν		Xe TPC	[28] LUESCHER	98
$(7.6^{+2.2}_{-1.4})$E18		^{100}Mo	2ν		Si(Li)	[29] ALSTON-...	97
> 0.19	90	^{92}Mo	$0\nu+2\nu$	$0^+ \rightarrow 0^+$	γ in HPGe	[30] BARABASH	97
> 0.81	90	^{92}Mo	$0\nu+2\nu$	$0^+ \rightarrow 0^+_1$	γ in HPGe	[30] BARABASH	97
> 0.89	90	^{92}Mo	$0\nu+2\nu$	$0^+ \rightarrow 2^+_1$	γ in HPGe	[30] BARABASH	97
>11000	90	^{76}Ge	0ν	$0^+ \rightarrow 0^+$	Enriched HPGe	[31] BAUDIS	97
$(6.82^{+0.38}_{-0.53} \pm 0.68)$E18		^{100}Mo	2ν		TPC	[32] DESILVA	97
$(6.75^{+0.37}_{-0.42} \pm 0.68)$E18		^{150}Nd	2ν		TPC	[33] DESILVA	97
> 1.2	90	^{150}Nd	0ν		TPC	[34] DESILVA	97
$1.77 \pm 0.01^{+0.13}_{-0.11}$		^{76}Ge	2ν		Enriched HPGe	[35] GUENTHER	97
$(3.75 \pm 0.35 \pm 0.21)$E19		^{116}Cd	2ν	$0^+ \rightarrow 0^+$	NEMO 2	[36] ARNOLD	96
$0.043^{+0.024}_{-0.011} \pm 0.014$		^{48}Ca	2ν		TPC	[37] BALYSH	96
> 52	68	^{100}Mo	$0\nu,\langle m_\nu\rangle$	$0^+ \rightarrow 0^+$	ELEGANT V	[38] EJIRI	96
> 39	68	^{100}Mo	$0\nu,\langle\lambda\rangle$	$0^+ \rightarrow 0^+$	ELEGANT V	[38] EJIRI	96
> 51	68	^{100}Mo	$0\nu,\langle\eta\rangle$	$0^+ \rightarrow 0^+$	ELEGANT V	[38] EJIRI	96
0.79 ± 0.10		^{130}Te	$0\nu+2\nu$		Geochem	[39] TAKAOKA	96
$0.61^{+0.18}_{-0.11}$		^{100}Mo	$0\nu+2\nu$	$0^+ \rightarrow 0^+_1$	γ in HPGe	[40] BARABASH	95
> 0.00013	99	^{160}Gd	2ν	$0^+ \rightarrow 0^+$	Gd_2SiO_5:Ce scint	[41] BURACHAS	95
> 0.00012	99	^{160}Gd	2ν	$0^+ \rightarrow 2^+$	Gd_2SiO_5:Ce scint	[41] BURACHAS	95
> 0.014	90	^{160}Gd	0ν	$0^+ \rightarrow 0^+$	Gd_2SiO_5:Ce scint	[41] BURACHAS	95
> 0.013	90	^{160}Gd	0ν	$0^+ \rightarrow 2^+$	Gd_2SiO_5:Ce scint	[41] BURACHAS	95
$(9.5 \pm 0.4 \pm 0.9)$E18		^{100}Mo	2ν		NEMO 2	DASSIE	95
> 0.6	90	^{100}Mo	0ν	$0^+ \rightarrow 0^+_1$	NEMO 2	DASSIE	95
$0.026^{+0.009}_{-0.005}$		^{116}Cd	2ν	$0^+ \rightarrow 0^+$	ELEGANT IV	EJIRI	95
> 29	90	^{116}Cd	0ν	$0^+ \rightarrow 0^+$	$^{116}CdWO_4$ scint	[42] GEORGADZE	95
> 0.3	68	^{160}Gd	0ν		Gd_2SiO_5: Ce scint	KOBAYASHI	95
> 2.37	90	^{116}Cd	$0\nu+2\nu$	$0^+ \rightarrow 2^+$	γ in HPGe	[43] PIEPKE	94
> 2.05	90	^{116}Cd	$0\nu+2\nu$	$0^+ \rightarrow 0^+_1$	γ in HPGe	[43] PIEPKE	94
> 2.05	90	^{116}Cd	$0\nu+2\nu$	$0^+ \rightarrow 0^+_2$	γ in HPGe	[43] PIEPKE	94

$0.017^{+0.010}_{-0.005} \pm 0.0035$		^{150}Nd	2ν	$0^+ \to 0^+$	TPC	ARTEMEV	93
0.039 ± 0.009		^{96}Mo	0ν+2ν		Geochem	KAWASHIMA	93
$>$ 430	90	^{76}Ge	0ν	$0^+ \to 2^+$	Enriched HPGe	BALYSH	92
2.7 ± 0.1		^{130}Te			Geochem	BERNATOW...	92
7200 ± 400		^{128}Te			Geochem	[44] BERNATOW...	92
$>$ 27	68	^{82}Se	0ν	$0^+ \to 0^+$	TPC	ELLIOTT	92
$0.108^{+0.026}_{-0.006}$		^{82}Se	2ν	$0^+ \to 0^+$	TPC	ELLIOTT	92
$0.92^{+0.07}_{-0.04}$		^{76}Ge	2ν	$0^+ \to 0^+$	Enriched HPGe	[45] AVIGNONE	91
$>$ 3.3	95	^{136}Xe	0ν	$0^+ \to 2^+$	Prop cntr	[46] BELLOTTI	91
$>$ 0.16	95	^{136}Xe	2ν		Prop cntr	BELLOTTI	91
2.0 ± 0.6		^{238}U			Radiochem	[47] TURKEVICH	91
$>$ 9.5	76	^{48}Ca	0ν		CaF_2 scint.	YOU	91
$1.12^{+0.48}_{-0.26}$		^{76}Ge	2ν	$0^+ \to 0^+$	HPGe	[48] MILEY	90
0.9 ± 0.1		^{76}Ge	2ν		Enriched Ge(Li)	VASENKO	90
$>$ 4.7	68	^{128}Te		$0^+ \to 2^+$	Ge(Li)	[41] BELLOTTI	87
$>$ 4.5	68	^{130}Te		$0^+ \to 2^+$	Ge(Li)	[41] BELLOTTI	87
$>$ 800	95	^{128}Te			Geochem	[49] KIRSTEN	83
2.60 ± 0.28		^{130}Te			Geochem	[49] KIRSTEN	83

[26] ALESSANDRELLO 98 report limits using an array of 20 cryogenic detectors of 340 grams of TeO_2 each. Supersedes ALESSANDRELLO 96B.

[27] LUESCHER 98 report a limit for the 0ν decay of ^{136}Xe TPC. Supersedes VUILLEUMIER 93.

[28] LUESCHER 98 report a limit for the 2ν decay of ^{136}Xe using Xe TPC. Supersedes VUILLEUMIER 93.

[29] ALSTON-GARNJOST 97 report evidence for 2ν decay of ^{100}Mo. This decay has been also observed by EJIRI 91, DASSIE 95, and DESILVA 97.

[30] BARABASH 97 measure limits for β^+, EC, and ECEC decay of ^{92}Mo to the ground and excited states of ^{92}Ru, respectively. Limits are not competive compared to $\beta^-\beta^-$ searches as far as sensitivity to $\langle m_\nu \rangle$ or RHC admixtures is concerned.

[31] BAUDIS 97 limit for 0ν decay of enriched ^{76}Ge using Ge calorimeters supersedes GUENTHER 97.

[32] DESILVA 97 result for 2ν decay of ^{100}Mo is in agreement with ALSTON-GARNJOST 97 and DASSIE 95. This measurement has the smallest errors.

[33] DESILVA 97 result for 2ν decay of ^{150}Nd is in marginal agreement with ARTEMEV 93. It has smaller errors.

[34] DESILVA 97 do not explain whether their efficiency for 0ν decay of ^{150}Nd was calculated under the assumption of a $\langle m_\nu \rangle$, $\langle \lambda \rangle$, or $\langle \eta \rangle$ driven decay.

[35] GUENTHER 97 half-life for the 2ν decay of ^{76}Ge is not in good agreement with the previous measurements of BALYSH 94, AVIGNONE 91, and MILEY 90.

[36] ARNOLD 96 measure the 2ν decay of ^{116}Cd. This result is in agreement with EJIRI 95, but has smaller errors. Supersedes ARNOLD 95.

[37] BALYSH 96 measure the 2ν decay of ^{48}Ca, using a passive source of enriched ^{48}Ca in a TPC.

[38] EJIRI 96 use energy and angular correlations of the 2β-rays in efficiency estimate to give limits for the 0ν decay modes associated with $\langle m_\nu \rangle$, $\langle \lambda \rangle$, and $\langle \eta \rangle$, respectively. Enriched ^{100}Mo source is used in tracking calorimeter. These are the best limits for ^{100}Mo. Limit is more stringent than ALSTON-GARNJOST 97.

[39] TAKAOKA 96 measure the geochemical half-life of ^{130}Te. Their value is in disagreemnt with the quoted values of BERNATOWICZ 92 and KIRSTEN 83; but agrees with several other unquoted determinations, e.g., MANUEL 91.

[40] BARABASH 95 cannot distinguish 0ν and 2ν, but it is inferred indirectly that the 0ν mode accounts for less than 0.026% of their event sample. They also note that their result disagrees with the previous experiment by the NEMO group (BLUM 92).

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

[42] GEORGADZE 95 result for this and other modes are also give in DANEVICH 95. Result for 2ν decay omitted because of authors' caveats.

[43] 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.

[44] 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.

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

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

[47] 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.

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

[49] 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. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

VALUE (eV)	CL%	ISOTOPE		TRANSITION	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
< 2.4–2.7	90	^{136}Xe	0ν		Xe TPC	[50] LUESCHER	98
<9.3	68	^{100}Mo	0ν		Si(Li)	[51] ALSTON-...	97
<0.46	90	^{76}Ge	0ν	$0^+ \to 0^+$	Enriched HPGe	[52] BAUDIS	97
<2.2	68	^{100}Mo	0ν	$0^+ \to 0^+$	ELEGANT V	[53] EJIRI	96
<4.1	90	^{116}Cd	0ν		$^{116}CdWO_4$ scint	[54] DANEVICH	95
< 2.8–4.3	90	^{136}Xe	0ν	$0^+ \to 0^+$	TPC	[55] VUILLEUMIER	93
< 1.1–1.5		^{128}Te			Geochem	[56] BERNATOW...	92
<5	68	^{82}Se			TPC	[57] ELLIOTT	92
<8.3	76	^{48}Ca	0ν		CaF_2 scint.	YOU	91
<5.6	95	^{128}Te			Geochem	KIRSTEN	83

[50] LUESCHER 98 limit for $\langle m_\nu \rangle$ is based on the matrix elements of ENGEL 88.

[51] ALSTON-GARNJOST 97 obtain the limit for $\langle m_\nu \rangle$ using the matrix elements of ENGEL 88. The limit supersedes ALSTON-GARNJOST 93.

[52] BAUDIS 97 limit for $\langle m_\nu \rangle$ is based on the matrix elements of STAUDT 90. This is the most stringent bound on $\langle m_\nu \rangle$. It supersedes the limit of GUENTHER 97.

[53] EJIRI 96 obtain the limit for $\langle m_\nu \rangle$ using the matrix elements of TOMODA 91.

[54] DANEVICH 95 is identical to GEORGADZE 95.

[55] 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.

[56] 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.

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

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. $\langle \lambda \rangle = \lambda \sum U_{1j} V_{1j}$ and $\langle \eta \rangle = \eta \sum U_{1j} V_{1j}$, where the sum is over the number of neutrino generations. This sum vanishes for massless or unmixed neutrinos. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

$\langle \lambda \rangle$ (10^{-6})	CL%	$\langle \eta \rangle$ (10^{-8})	CL%	ISOTOPE	METHOD	DOCUMENT ID	
• • • We do not use the following data for averages, fits, limits, etc. • • •							
<1.1	90	<0.64	90	^{76}Ge	Enriched HPGe	[58] GUENTHER	97
<3.7	68	<2.5	68	^{100}Mo	Elegant V	[59] EJIRI	96
<5.3	90	<5.9	90	^{116}Cd	$^{116}CdWO_4$ scint	[60] DANEVICH	95
<4.4	90	<2.3	90	^{136}Xe	TPC	[61] VUILLEUMIER	93
		<5.3		^{128}Te	Geochem	[62] BERNATOW...	92

[58] GUENTHER 97 limits use the matrix elements of STAUDT 90. Supersedes BALYSH 95 and BALYSH 92.
[59] EJIRI 96 obtain limits for $\langle\lambda\rangle$ and $\langle\eta\rangle$ using the matrix elements of TOMODA 91.
[60] DANEVICH 95 is identical to GEORGADZE 95.
[61] VUILLEUMIER 93 uses the matrix elements of MUTO 89.
[62] 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.

(D) Other bounds from nuclear and particle decays

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

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	[63] BRITTON	92B	CNTR	50 MeV $< m_{\nu_j} <$ 130 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<5 \times 10^{-6}$	90	DELEENER-...	91		m_{ν_j} = 20 MeV
$<5 \times 10^{-7}$	90	DELEENER-...	91		m_{ν_j} = 40 MeV
$<3 \times 10^{-7}$	90	DELEENER-...	91		m_{ν_j} = 60 MeV
$<1 \times 10^{-6}$	90	DELEENER-...	91		m_{ν_j} = 80 MeV
$<1 \times 10^{-6}$	90	DELEENER-...	91		m_{ν_j} = 100 MeV
$<5 \times 10^{-7}$	90	AZUELOS	86	CNTR	m_{ν_j}=60 MeV
$<2 \times 10^{-7}$	90	AZUELOS	86	CNTR	m_{ν_j}=80 MeV
$<3 \times 10^{-7}$	90	AZUELOS	86	CNTR	m_{ν_j}=100 MeV
$<1 \times 10^{-6}$	90	AZUELOS	86	CNTR	m_{ν_j}=120 MeV
$<2 \times 10^{-7}$	90	AZUELOS	86	CNTR	m_{ν_j}=130 MeV
$<8 \times 10^{-6}$		DELEENER-...	86	CNTR	m_{ν_j}=20 MeV
$<4 \times 10^{-7}$		DELEENER-...	86	CNTR	m_{ν_j}=60 MeV
$<2 \times 10^{-6}$		DELEENER-...	86	CNTR	m_{ν_j}=100 MeV
$<7 \times 10^{-6}$		DELEENER-...	86	CNTR	m_{ν_j}=120 MeV
$<1 \times 10^{-4}$	90	[64] BRYMAN	83B	CNTR	m_{ν_j}=5 MeV
$<1.5 \times 10^{-6}$	90	BRYMAN	83B	CNTR	m_{ν_j}=53 MeV
$<1 \times 10^{-5}$	90	BRYMAN	83B	CNTR	m_{ν_j}=70 MeV
$<1 \times 10^{-4}$	90	BRYMAN	83B	CNTR	m_{ν_j}=130 MeV
$<1 \times 10^{-4}$	68	[65] SHROCK	81	THEO	m_{ν_j}=10 MeV
$<5 \times 10^{-6}$	68	[65] SHROCK	81	THEO	m_{ν_j}=60 MeV
$<1 \times 10^{-5}$	68	[66] SHROCK	80	THEO	m_{ν_j}=80 MeV
$<3 \times 10^{-6}$	68	[66] SHROCK	80	THEO	m_{ν_j}=160 MeV

[63] BRITTON 92B is from a search for additional peaks in the e^+ spectrum from $\pi^+ \to e^+\nu_e$ decay at TRIUMF. See also BRITTON 92.

[64] 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).

[65] 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.

[66] Analysis of ($K^+ \rightarrow e^+\nu_e$) spectrum.

Kink search in nuclear β decay

High-sensitivity follow-up experiments show that indications for a neutrino with mass 17 keV (Simpson, Hime, and others) were not valid. 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)). Limits on $|U_{1j}|^2$ as a function of m_{ν_j}. See WIETFELDT 96 for a comprehensive review.

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. • • •						
10–40	90	370–640	^{37}Ar	EC ion recoil	[67] HINDI	98
$<1\times10^{-2}$	95	1	^{3}H	SPEC	[68] HIDDEMANN	95
$<6\times10^{-3}$	95	2	^{3}H	SPEC	[68] HIDDEMANN	95
$<2\times10^{-3}$	95	3	^{3}H	SPEC	[68] HIDDEMANN	95
$<2\times10^{-3}$	95	4	^{3}H	SPEC	[68] HIDDEMANN	95
$0.3 \pm1.5\pm0.8$		17	^{35}S	Mag spect	[69] BERMAN	93
$<$ 2.8	99	17	^{3}H	Prop chamber	[70] KALBFLEISCH	93
$<$ 1	99	14.4–15.2	^{3}H	Prop chamber	[70] KALBFLEISCH	93
$<$ 0.7	99	16.3–16.6	^{3}H	Prop chamber	[70] KALBFLEISCH	93
$<$ 2	95	13–40	^{35}S	Si(Li)	[71] MORTARA	93
$<$ 0.73	95	17	^{63}Ni	Mag spect	OHSHIMA	93
$<$ 1.5	95	10.5–25.0	^{63}Ni	Mag spect	[72] OHSHIMA	93
$<$ 6	95	5–25	^{55}Fe	IBEC in Ge	[73] WIETFELDT	93
$<$ 2	90	17	^{35}S	Mag spect.	[74] CHEN	92
$<$ 0.95	95	17	^{63}Ni	Mag spect	[75] KAWAKAMI	92
$<$ 1.0	95	10–24	^{63}Ni	Mag spect	KAWAKAMI	92
$<$ 10	90	16–35	^{125}I	IBEC; γ det	[76] BORGE	86
$<$ 7.5	99	5–50	^{35}S	Mag spect	ALTZITZOG...	85
$<$ 8	90	80	^{35}S	Mag spect	[77] 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	[78] SCHRECK...	83
$<$ 4	90	140	^{64}Cu	Mag spect	[78] SCHRECK...	83
$<$ 8	90	440	^{64}Cu	Mag spect	[78] SCHRECK...	83
$<$ 1	95	0.1			[79] SIMPSON	81B
$<$4E−3	95	10			[79] SIMPSON	81B
$<$100	90	0.1–3000		THEO	[80] SHROCK	80
$<$ 0.1	68	80		THEO	[81] SHROCK	80

[67] HINDI 98 obtain a limit on heavy neutrino admixture from EC decay of ^{37}Ar by measuring the time-of-flight distribution of the recoiling ions in coincidence with x-rays or Auger electrons. The authors report upper limit for $|U_{1j}|^2$ of $\approx$ 3% for m_{ν_j}=500 keV, 1% for m_{ν_j}=550 keV, 2% for m_{ν_j}=600 keV, and 4% for m_j=650 keV. Their reported limits for $m_{\nu_j} \leq$ 450 keV are inferior to the limits of SCHRECKENBACH 83.

[68] In the beta spectrum from tritium β decay nonvanishing or mixed $m_{\overline{\nu}_1}$ state in the mass region 0.01–4 keV. For m_{ν_j} <1 keV, their upper limit on $|U_{1j}|^2$ becomes less

[69] BERMAN 93 uses an iron-free intermediate-image magnetic spectrometer to measure ^{35}Sβ 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.

[70] 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 $\times$ 10^{-3} at the 99% CL. See also the related papers BAHRAN 93, BAHRAN 93B, and BAHRAN 95 on theoretical aspects of beta spectra and fitting methods for heavy neutrinos.

[71] 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."

[72] 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.

[73] 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. In further tests, WIETFELDT 95 have shown that "the observed distortion was most likely caused by systematic effects... A new measurement with a smaller data sample shows no sign of this distortion."

[74] 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.

[75] 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 $|U_{1j}|^2 = 1\%$.

[76] 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.

[77] 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%.

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

[79] Application of kink search test to tritium β decay Kurie plot.

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

[81] Application of test to search for kinks in β decay Kurie plots.

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. • • •					
$<2 \times 10^{-5}$	95	[82] ABREU	97I	DLPH	m_{ν_j}=6 GeV
$<3 \times 10^{-5}$	95	[82] ABREU	97I	DLPH	m_{ν_j}=50 GeV
$<1.8 \times 10^{-3}$	90	[83] HAGNER	95	MWPC	m_{ν_h} = 1.5 MeV
$<2.5 \times 10^{-4}$	90	[83] HAGNER	95	MWPC	m_{ν_h} = 4 MeV
$<4.2 \times 10^{-3}$	90	[83] HAGNER	95	MWPC	m_{ν_h} = 9 MeV
$<1 \times 10^{-5}$	90	[84] BARANOV	93		m_{ν_j}= 100 MeV
$<1 \times 10^{-6}$	90	[84] BARANOV	93		m_{ν_j}= 200 MeV
$<3 \times 10^{-7}$	90	[84] BARANOV	93		m_{ν_j}= 300 MeV
$<2 \times 10^{-7}$	90	[84] 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	[85] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[85] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[85] 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_{ν_j}=100 MeV
$<1 \times 10^{-8}$	90		BERNARDI	88	CNTR	m_{ν_j}=200 MeV
$<2.4 \times 10^{-9}$	90		BERNARDI	88	CNTR	m_{ν_j}=300 MeV
$<2.1 \times 10^{-9}$	90		BERNARDI	88	CNTR	m_{ν_j}=400 MeV
$<2 \times 10^{-2}$	68	[86]	OBERAUER	87		m_{ν_j}=1.5 MeV
$<8 \times 10^{-4}$	68	[86]	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	[87]	COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<8 \times 10^{-8}$	90	[87]	COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV
$<1 \times 10^{-2}$	90	[88]	BERGSMA	83B	CNTR	m_{ν_j}=10 MeV
$<1 \times 10^{-5}$	90	[88]	BERGSMA	83B	CNTR	m_{ν_j}=110 MeV
$<6 \times 10^{-7}$	90	[88]	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

[82] ABREU 97I long-lived ν_j analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity except at 3.5 GeV, where the limit is the same as at 6 GeV.

[83] HAGNER 95 obtain limits on heavy neutrino admixture from the decay $\nu_h \rightarrow \nu_e e^+ e^-$ at a nuclear reactor for the ν_h mass range 2–9 MeV.

[84] 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.

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

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

[87] 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.

[88] 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}

Peak search test

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. • • •				
0.22	90	[89] ASSAMAGAN 98	SILI	m_{ν_x}= 0.53 MeV
0.029	90	[89] ASSAMAGAN 98	SILI	m_{ν_x}= 0.75 MeV
0.016	90	[89] ASSAMAGAN 98	SILI	m_{ν_x}= 1.0 MeV
$<$ 1–10 $\times 10^{-4}$		[90] BRYMAN 96	CNTR	m_{ν_x} = 30–33.91 MeV
$>10^{-16}$		[91] ARMBRUSTER 95	KARM	m_{ν_x} = 33.9 MeV
$< 4 \times 10^{-7}$	95	[92] BILGER 95	LEPS	$m_{\overline{\nu}_x}$ = 33.9 MeV
$< 7 \times 10^{-8}$	95	[92] BILGER 95	LEPS	m_{ν_x} = 33.9 MeV
$< 2.6 \times 10^{-8}$	95	[92] DAUM 95B	TOF	m_{ν_x} = 33.9 MeV
$< 2 \times 10^{-2}$	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	[93] MINEHART 84		m_{ν_j}=2 MeV
$< 1 \times 10^{-3}$	90	[93] MINEHART 84		m_{ν_j}=4 MeV
$< 3 \times 10^{-4}$	90	[93] MINEHART 84		m_{ν_j}=10 MeV
$< 5 \times 10^{-6}$	90	[94] HAYANO 82		m_{ν_j}=330 MeV
$< 1 \times 10^{-4}$	90	[94] HAYANO 82		m_{ν_j}=70 MeV
$< 9 \times 10^{-7}$	90	[94] HAYANO 82		m_{ν_j}=250 MeV
$< 1 \times 10^{-1}$	90	[93] ABELA 81		m_{ν_j}=4 MeV
$< 7 \times 10^{-5}$	90	[93] ABELA 81		m_{ν_j}=10.5 MeV
$< 2 \times 10^{-4}$	90	[93] ABELA 81		m_{ν_j}=11.5 MeV
$< 2 \times 10^{-5}$	90	[93] ABELA 81		m_{ν_j}=16–30 MeV
$< 2 \times 10^{-5}$	95	[94] ASANO 81		m_{ν_j}=170 MeV
$< 3 \times 10^{-6}$	95	[94] ASANO 81		m_{ν_j}=210 MeV
$< 3 \times 10^{-6}$	95	[94] ASANO 81		m_{ν_j}=230 MeV
$< 6 \times 10^{-6}$	95	[95] ASANO 81		m_{ν_j}=240 MeV
$< 5 \times 10^{-7}$	95	[95] ASANO 81		m_{ν_j}=280 MeV
$< 6 \times 10^{-6}$	95	[95] ASANO 81		m_{ν_j}=300 MeV
$< 1 \times 10^{-2}$	95	[93] CALAPRICE 81		m_{ν_j}=7 MeV
$< 3 \times 10^{-3}$	95	[93] CALAPRICE 81		m_{ν_j}=33 MeV
$< 1 \times 10^{-4}$	68	[96] SHROCK 81	THEO	m_{ν_j}=13 MeV
$< 3 \times 10^{-5}$	68	[96] SHROCK 81	THEO	m_{ν_j}=33 MeV
$< 6 \times 10^{-3}$	68	[97] SHROCK 81	THEO	m_{ν_j}=80 MeV
$< 5 \times 10^{-3}$	68	[97] SHROCK 81	THEO	m_{ν_j}=120 MeV

[89] ASSAMAGAN 98 obtain a limit on heavy neutrino admixture from π^+ decay essentially at rest, by measuring with good resolution the momentum distribution of the muons. However, the search uses an ad hoc shape correction. The authors report upper limit for $|U_{2j}|^2$ of 0.22 for $m_\nu = 0.53$ MeV, 0.029 for $m_\nu = 0.75$ MeV, and 0.016 for $m_\nu = 1.0$ MeV at 90%CL.

[90] BRYMAN 96 search for massive unconventional neutrinos of mass m_{ν_x} in π^+ decay. The reported value is the upper limit for the branching ratio, < 4–6×10^{-5} (90%CL). They interpret the result as an upper limit for the admixture of a heavy sterile or otherwise unconventional neutrino.

[91] ARMBRUSTER 95 study the reactions $^{12}C(\nu_e,e^-)\,^{12}N$ and $^{12}C(\nu,\nu')\,^{12}C^*$ induced by neutrinos from π^+ and μ^+ decay at the ISIS neutron spallation source at the Rutherford-Appleton laboratory. An anomaly in the time distribution can be interpreted as the decay $\pi^+ \rightarrow \mu^+ \nu_x$, where ν_x is a neutral weakly interacting particle with mass ≈ 33.9 MeV and spin 1/2. The lower limit to the branching ratio is a function of the lifetime of the new massive neutral particle, and reaches a minimum of a few $\times 10^{-16}$ for $\tau_x \sim 5$ s.

[92] From experiments of π^+ and π^- decay in flight at PSI, to check the claim of the KARMEN Collaboration quoted above (ARMBRUSTER 95).

[93] $\pi^+ \rightarrow \mu^+ \nu_\mu$ peak search experiment.

[94] $K^+ \rightarrow \mu^+ \nu_\mu$ peak search experiment.

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

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

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

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. • • •					
$<2 \times 10^{-5}$	95	[98] ABREU	97I	DLPH	m_{ν_j}=6 GeV
$<3 \times 10^{-5}$	95	[98] ABREU	97I	DLPH	m_{ν_j}=50 GeV
$<3 \times 10^{-6}$	90	GALLAS	95	CNTR	$m_{\nu_j} = 1$ GeV
$<3 \times 10^{-5}$	90	[99] VILAIN	95C	CHM2	$m_{\nu_j} = 2$ GeV
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	$m_{\nu_j} = 20$ GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	$m_{\nu_j} = 40$ GeV
all values ruled out	95	[100] BURCHAT	90	MRK2	$m_{\nu_j} < 19.6$ GeV
$<1 \times 10^{-10}$	95	[100] BURCHAT	90	MRK2	$m_{\nu_j} = 22$ GeV
$<1 \times 10^{-11}$	95	[100] BURCHAT	90	MRK2	$m_{\nu_j} = 41$ GeV
all values ruled out	95	DECAMP	90F	ALEP	$m_{\nu_j} = 25.0$–42.7 GeV

$<1 \times 10^{-13}$	95		DECAMP	90F	ALEP	m_{ν_j} = 42.7–45.7 GeV
$<5 \times 10^{-4}$	90	[101]	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_{ν_j}=200 MeV
$<3 \times 10^{-9}$	90		BERNARDI	88	CNTR	m_{ν_j}=300 MeV
$<4 \times 10^{-4}$	90	[102]	MISHRA	87	CNTR	m_{ν_j}=1.5 GeV
$<4 \times 10^{-3}$	90	[102]	MISHRA	87	CNTR	m_{ν_j}=2.5 GeV
$<0.9 \times 10^{-2}$	90	[102]	MISHRA	87	CNTR	m_{ν_j}=5 GeV
<0.1	90	[102]	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	[103]	COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<1.0 \times 10^{-7}$	90	[103]	COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV

[98] ABREU 97I long-lived ν_j analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity except at 3.5 GeV, where the limit is the same as at 6 GeV.

[99] VILAIN 95C is a search for the decays of heavy isosinglet neutrinos produced by neutral current neutrino interactions. Limits were quoted for masses in the range from 0.3 to 24 GeV. The best limit is listed above.

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

[101] KOPEIKIN 90 find no m_{ν_j} in the interval 1–6.3 MeV at 90%CL for maximal mixing.

[102] See also limits on $|U_{3j}|$ from WENDT 87.

[103] 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. • • •					
$<2 \times 10^{-5}$	95	[104] ABREU	97I	DLPH	m_{ν_j}=6 GeV
$<3 \times 10^{-5}$	95	[104] ABREU	97I	DLPH	m_{ν_j}=50 GeV
$<6.2 \times 10^{-8}$	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	[105] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[105] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[105] 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

[104] ABREU 97I long-lived ν_j analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity.

[105] 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	[106] BARANOV	93		m_{ν_j}= 80 MeV
$<3 \times 10^{-6}$	90	[106] BARANOV	93		m_{ν_j}= 160 MeV
$<6 \times 10^{-7}$	90	[106] BARANOV	93		m_{ν_j}= 240 MeV
$<2 \times 10^{-7}$	90	[106] 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

[106] 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.

(E) Solar ν Experiments

A REVIEW GOES HERE – Check our WWW List of Reviews

1 SNU (Solar Neutrino Unit) = 10^{-36} captures per atom per second.

VALUE	DOCUMENT ID		TECN	COMMENT
$2.56 \pm 0.16 \pm 0.16$ SNU	[107] CLEVELAND	98	HOME	^{37}Cl radiochem.
$(2.42 \pm 0.06^{+0.10}_{-0.07}) \times 10^6$ cm^{-2} s^{-1}	[108] FUKUDA	98B	SKAM	^{8}B ν flux
$(2.39 \pm 0.09^{+0.10}_{-0.07}) \times 10^6$ cm^{-2} s^{-1}	[108] FUKUDA	98B	SKAM	^{8}B ν flux (day)
$(2.44^{+0.09}_{-0.08}{}^{+0.10}_{-0.07}) \times 10^6$ cm^{-2} s^{-1}	[108] FUKUDA	98B	SKAM	^{8}B ν flux (night)
$(2.80 \pm 0.19 \pm 0.33) \times 10^6$cm^{-2}s^{-1}	[109] FUKUDA	96	KAMI	^{8}Bν flux
$(2.70 \pm 0.27) \times 10^6$cm^{-2}s^{-1}	[109] FUKUDA	96	KAMI	^{8}Bν flux (day)
$(2.87^{+0.27}_{-0.26}) \times 10^6$cm^{-2}s^{-1}	[109] FUKUDA	96	KAMI	^{8}Bν flux (night)
$69.7 \pm 6.7^{+3.9}_{-4.5}$ SNU	[110] HAMPEL	96	GALX	^{71}Ga $\rightarrow$ ^{71}Ge
$73^{+18}_{-16}{}^{+5}_{-7}$ SNU	[111] ABDURASHI...	94	SAGE	^{71}Ga $\rightarrow$ ^{71}Ge

[107] CLEVELAND 98 is a detailed report of the ^{37}Cl experiment at the Homestake Mine. The average solar neutrino-induced ^{37}Ar production rate from 108 runs between 1970 and 1994 updates the DAVIS 89 result.

[108] FUKUDA 98B results are for a total of 297.4 live days with Super-Kamiokande between 31 May 1996 and 23 June 1997, with threshold $E_e > 6.5$ MeV.

[109] FUKUDA 96 results are for a total of 2079 live days with Kamiokande II and III from January 1987 through February 1995, covering the entire solar cycle 22, with threshold $E_e > 9.3$ MeV (first 449 days), > 7.5 MeV (middle 794 days), and > 7.0 MeV (last 836 days). These results update the HIRATA 90 result for the average ^{8}B solar-neutrino flux and HIRATA 91 result for the day-night variation in the ^{8}B solar-neutrino flux. The total data sample was also analyzed for short-term variations: within experimental errors, no strong correlation of the solar-neutrino flux with the sunspot numbers was found.

[110] HAMPEL 96 reports the combined result for GALLEX I+II+III (53 runs in total), which updates the ANSELMANN 95B result. The GALLEX III result (14 runs) is $53.9 \pm 10.6 \pm 3.1$ SNU, which is "15.8 SNU below but statistically compatible with the new combined result." The total run data, covering the period 14 May 1991 through 4 October 1995, are consistent with a ^{71}Ge production rate constant in time, but "the confidence with which some kind of periodic or sporadic variability may be excluded has decreased as a result of the statistical departure of GALLEX III." HAMPEL 96 also reports the second calibration run using a strong ^{51}Cr source. The final result for the two source experiments (ANSELMANN 95 and HAMPEL 96) is reported in HAMPEL 98: the ratio, (measured)/(expected), of Cr-induced ^{71}Ge rates is 0.93 ± 0.08.

[111] 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.

(F) Astrophysical neutrino observations

Neutrinos and antineutrinos produced in the atmosphere induce μ-like and e-like events in underground detectors. The ratio of the numbers of the two kinds of events is defined as μ/e. It has the advantage that that systematic effects, such as flux uncertainty, tend to cancel, for both experimental and theoretical values of the ratio. The "ratio of the ratios" of experimental to theoretical μ/e, $R(\mu/e)$, or that of experimental to theoretical μ/total, $R(\mu/\text{total})$ with total $= \mu + e$, is reported below. If the actual value is not unity, the value obtained in a given experiment may depend on the experimental conditions.

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. • • •				
$0.61 \pm 0.03 \pm 0.05$	[112] FUKUDA	98	SKAM	sub-GeV
$0.66 \pm 0.06 \pm 0.08$	[113] FUKUDA	98E	SKAM	multi-GeV
$0.72 \pm 0.19 {}^{+0.05}_{-0.07}$	[114] ALLISON	97	SOU2	Calorimeter
	[115] FUKUDA	96B	KAMI	Water Cerenkov
$1.00 \pm 0.15 \pm 0.08$	[116] DAUM	95	FREJ	Calorimeter
$0.60 {}^{+0.06}_{-0.05} \pm 0.05$	[117] FUKUDA	94	KAMI	sub-GeV
$0.57 {}^{+0.08}_{-0.07} \pm 0.07$	[118] FUKUDA	94	KAMI	multi-Gev
	[119] BECKER-SZ...	92B	IMB	Water Cerenkov

[112] FUKUDA 98 result is based on an exposure of 25.5 kton yr. The analyzed data sample consists of fully-contained e-like events with $0.1\ \text{GeV}/c < p_e$ and μ-like events with $0.2\ \text{GeV}/c < p_\mu$, both having a visible energy < 1.33 GeV. These criteria match the definition used by FUKUDA 94.

[113] FUKUDA 98E result is based on an exposure of 25.5 kton yr. The analyzed data sample consists of fully-contained single-ring events with visible energy > 1.33 GeV and partially contained events. All partially contained events are classified as μ-like.

[114] ALLISON 97 result is based on an exposure of 1.52 kton yr. ALLISON 97 also studied the background due to interaction of neutrons or photons produced by muon interactions in the rock surrounding the detector. This background is shown not to produce the low values of R(μ/e).

[115] FUKUDA 96B studied neutron background in the atmospheric neutrino sample observed in the Kamiokande detector. No evidence for the background contamination was found.

[116] DAUM 95 results are based on an exposure of 2.0 kton yr which includes the data used by BERGER 90B. This ratio is for the contained and semicontained events. DAUM 95 also report $R(\mu/e) = 0.99 \pm 0.13 \pm 0.08$ for the total neutrino induced data sample which includes upward going stopping muons and horizontal muons in addition to the contained and semicontained events.

[117] FUKUDA 94 result is based on an exposure of 7.7 kton yr and updates the HIRATA 92 result. The analyzed data sample consists of fully-contained e-like events with $0.1 < p_e < 1.33\ \text{GeV}/c$ and fully-contained μ-like events with $0.2 < p_\mu < 1.5\ \text{GeV}/c$.

[118] FUKUDA 94 analyzed the data sample consisting of fully contained events with visible energy > 1.33 GeV and partially contained μ-like events.

[119] 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 Kamiokande limits, BEIER 92 finds $R(\mu/e)$ very close to the Kamiokande value.

$R(\nu_\mu)$ = (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. • • •				
$0.74 \pm 0.036 \pm 0.046$	[120] AMBROSIO	98	MCRO	Streamer tubes
	[121] CASPER	91	IMB	Water Cherenkov
	[122] AGLIETTA	89	NUSX	
0.95 ± 0.22	[123] BOLIEV	81		Baksan
0.62 ± 0.17	CROUCH	78		Case Western/UCI

[120] AMBROSIO 98 result is for all nadir angles and updates AHLEN 95 result. The lower cutoff on the muon energy is 1 GeV. In addition to the statistical and systematic errors, there is a Monte Carlo flux error (theoretical error) of ± 0.13. With a neutrino oscillation hypothesis, the fit either to the flux or zenith distribution independently yields $\sin^2 2\theta = 1.0$ and $\Delta(m^2) \sim$ a few times 10^{-3} eV^2. However, the fit to the observed zenith distribution gives a maximum probability for χ^2 of only 5% for the best oscillation hypothesis.

[121] 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).

[122] 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 $\rho(\text{measured}) = \rho(\text{expected}) = 0.96^{+0.32}_{-0.28}$.

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

$R(\mu/\text{total})$ = (Measured Ratio μ/total) / (Expected Ratio μ/total)

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$1.1^{+0.07}_{-0.12} \pm 0.11$	[124] CLARK	97	IMB	multi-GeV

[124] CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cerenkov detector with visible energy > 0.95 GeV.

$N_{\text{up}}(\mu)/N_{\text{down}}(\mu)$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.52^{+0.07}_{-0.06} \pm 0.01$	[125] FUKUDA	98E	SKAM	multi-GeV

[125] FUKUDA 98E result is based on an exposure of 25.5 kton yr. The analyzed data sample consists of fully-contained single-ring μ-like events with visible energy > 1.33 GeV and partially contained events. All partially contained events are classified as μ-like. Upward-going events are those with $-1 <$ cos (zenith angle) < -0.2 and downward-going events with those with $0.2 <$ cos (zenith angle) < 1. FUKUDA 98E result strongly deviates from an expected value of $0.98 \pm 0.03 \pm 0.02$.

$N_{up}(e)/N_{down}(e)$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$0.84^{+0.14}_{-0.12}\pm0.02$	[126] FUKUDA	98E	SKAM	multi-GeV

[126] FUKUDA 98E result is based on an exposure of 25.5 kton yr. The analyzed data sample consists of fully-contained single-ring e-like events with visible energy $>$ 1.33 GeV. Upward-going events are those with $-1 <\cos$ (zenith angle) < -0.2 and downward-going events are those with $0.2 <\cos$ (zenith angle) < 1. FUKUDA 98E result is conpared to an expected value of $1.01 \pm 0.06 \pm 0.03$.

$\sin^2(2\theta)$ 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. • • •					
<0.6	90	[127] OYAMA	98	KAMI	$\Delta(m^2) > 0.1$ eV^2
<0.5		[128] CLARK	97	IMB	$\Delta(m^2) > 0.1$ eV^2
>0.55	90	[129] FUKUDA	94	KAMI	$\Delta(m^2) = 0.007$–0.08 eV^2
<0.47	90	[130] BERGER	90B	FREJ	$\Delta(m^2) > 1$ eV^2
<0.14	90	LOSECCO	87	IMB	$\Delta(m^2)= 0.00011$ eV^2

[127] OYAMA 98 obtained this result by an analysis of upward-going muons in Kamiokande. The data sample used is essentially the same as that used by HATAKEYAMA 98.

[128] CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cerenkov detector with visible energy $>$ 0.95 GeV.

[129] FUKUDA 94 obtained this result by a combined analysis of sub- and multi-GeV atmospheric neutrino events in Kamiokande.

[130] 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. • • •				
<560	90	[131] OYAMA	98	KAMI
<980		[132] CLARK	97	IMB
$700 < \Delta(m^2) < 7000$	90	[133] FUKUDA	94	KAMI
<150	90	[134] BERGER	90B	FREJ

[131] OYAMA 98 obtained this result by an analysis of upward-going muons in Kamiokande. The data sample used is essentially the same as that used by HATAKEYAMA 98.

[132] CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cerenkov detector with visible energy $>$ 0.95 GeV.

[133] FUKUDA 94 obtained this result by a combined analysis of sub- and multi-GeV atmospheric neutrino events in Kamiokande.

[134] 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	[135] SMIRNOV	94	THEO	$\Delta(m^2) > 3 \times 10^{-4}$ eV^2
<0.7	99	[135] SMIRNOV	94	THEO	$\Delta(m^2) < 10^{-11}$ eV^2

[135] 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 $10^{-11} < \Delta(m^2) < 3 \times 10^{-7}$ 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. • • •					
>0.82	90	[136] AMBROSIO	98	MCRO	$\Delta(m^2) \sim 0.0025$ eV^2
>0.82	90	[137] FUKUDA	98C	SKAM	$\Delta(m^2) = 0.0005$–0.006 eV^2
>0.3	90	[138] HATAKEYAMA	98	KAMI	$\Delta(m^2) = 0.00055$–0.14 eV^2
>0.73	90	[139] HATAKEYAMA	98	KAMI	$\Delta(m^2) = 0.004$–0.025 eV^2
<0.7		[140] CLARK	97	IMB	$\Delta(m^2) > 0.1$ eV^2
>0.65	90	[141] FUKUDA	94	KAMI	$\Delta(m^2) = 0.005$–0.03 eV^2
<0.5	90	[142] BECKER-SZ...	92	IMB	$\Delta(m^2) = 1$–2×10^{-4} eV^2
<0.6	90	[143] BERGER	90B	FREJ	$\Delta(m^2) > 1$ eV^2

[136] AMBROSIO 98 result is only 17% probable at maximum because of relatively low flux for $\cos\theta < -0.8$.

[137] FUKUDA 98C obtained this result by an analysis of 33.0 kton yr atmospheric-neutrino data which include the 25.5 kton yr data used by FUKUDA 98 (sub-GeV) and FUKUDA 98E (multi-GeV). Inside the physical region, the best fit was obtained at $\sin^2 2\theta = 1.0$ and $\Delta(m^2) = 2.2 \times 10^{-3}$ eV^2. In addition, FUKUDA 98C gave the 99% confidence interval, $\sin^2 2\theta > 0.73$ and $3 \times 10^{-4} < \Delta(m^2) < 8.5 \times 10^{-3}$ eV^2. FUKUDA 98C also tested the $\nu_\mu \rightarrow \nu_e$ hypothesis, and concluded that it is not favored.

[138] HATAKEYAMA 98 obtained this result from a total of 2456 live days of upward-going muon data in Kamiokande between December 1985 and May 1995. With a threshold of $E_\mu > 1.6$ GeV, the observed flux of upward through-going muon is $(1.94 \pm 0.10^{+0.07}_{-0.06}) \times 10^{-13}$ cm^{-2} s^{-1} sr^{-1}. This is compared to the expected flux of (2.46 ± 0.54 (theoretical error)) $\times 10^{-13}$ cm^{-2} s^{-1} sr^{-1}. For the $\nu_\mu \rightarrow \nu_\tau$ hypothesis, the best fit inside the physical region was obtained at $\sin^2 2\theta = 1.0$ and $\Delta(m^2) = 3.2 \times 10^{-3}$ eV^2.

[139] HATAKEYAMA 98 obtained this result from a combined analysis of Kamiokande's contained events (FUKUDA 94) and upward-going muon events. The best fit was obtained at $\sin^2 2\theta = 0.95$ and $\Delta(m^2) = 1.3 \times 10^{-2}$ eV^2.

[140] CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cerenkov detector with visible energy > 0.95 GeV.

[141] FUKUDA 94 obtained this result by a combined analysis of sub-and multi-GeV atmospheric neutrino events in Kamiokande.

[142] BECKER-SZENDY 92 uses upward-going muons to search for atmospheric 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.

[143] 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. • • •				
$50< \Delta(m^2) < 600$	90	[144] AMBROSIO	98	MCRO
$50< \Delta(m^2) < 600$	90	[145] FUKUDA	98C	SKAM
$55< \Delta(m^2) < 5000$	90	[146] HATAKEYAMA	98	KAMI
$400< \Delta(m^2) < 2300$	90	[147] HATAKEYAMA	98	KAMI
<1500		[148] CLARK	97	IMB
$500 < \Delta(m^2) < 2500$	90	[149] FUKUDA	94	KAMI
< 350	90	[150] BERGER	90B	FREJ

[144] AMBROSIO 98 result is only 17% probable at maximum because of relatively low flux for $\cos\theta < -0.8$.

[145] FUKUDA 98C obtained this result by an analysis of 33.0 kton yr atmospheric-neutrino data which include the 25.5 kton yr data used by FUKUDA 98 (sub-GeV) and FUKUDA 98E (multi-GeV). Inside the physical region, the best fit was obtained at $\sin^2 2\theta$=1.0 and $\Delta(m^2)$=2.2×10^{-3} eV^2. In addition, FUKUDA 98C gave the 99% confidence interval, $\sin^2 2\theta > 0.73$ and $3\times10^{-4} < \Delta(m^2) < 8.5\times10^{-3}$ eV^2. FUKUDA 98C also tested the $\nu_\mu \rightarrow \nu_e$ hypothesis, and concluded that it is not favored.

[146] HATAKEYAMA 98 obtained this result from a total of 2456 live days of upward-going muon data in Kamiokande between December 1985 and May 1995. With a threshold of $E_\mu > 1.6$ GeV, the observed flux of upward through-going muon is $(1.94 \pm 0.10^{+0.07}_{-0.06}) \times 10^{-13}$ cm^{-2} s^{-1} sr^{-1}. This is compared to the expected flux of (2.46 $\pm$ 0.54 (theoretical error)) $\times 10^{-13}$ cm^{-2} s^{-1} sr^{-1}. For the $\nu_\mu \rightarrow \nu_\tau$ hypothesis, the best fit inside the physical region was obtained at $\sin^2 2\theta$=1.0 and $\Delta(m^2)$=3.2×10^{-3} eV^2.

[147] HATAKEYAMA 98 obtained this result from a combined analysis of Kamiokande's contained events (FUKUDA 94) and upward-going muon events. The best fit was obtained at $\sin^2 2\theta$=0.95 and $\Delta(m^2)$=1.3×10^{-2} eV^2.

[148] CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cerenkov detector with visible energy > 0.95 GeV.

[149] FUKUDA 94 obtained this result by a combined analysis of sub-and multi-GeV atmospheric neutrino events in Kamiokande.

[150] 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	[151] OYAMA	89	KAMI	Water Cerenkov
< 4.2 or > 54.	90	BIONTA	88	IMB	Flux has ν_μ, $\overline{\nu}_\mu$, ν_e, and $\overline{\nu}_e$

[151] 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.

(G) Reactor $\overline{\nu}_e$ disappearance experiments

In most cases, the reaction $\overline{\nu}_e p \rightarrow e^+ n$ is observed at different distances from one or more reactors in a complex.

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

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.98 ±0.04 ±0.04	[152] APOLLONIO	98	CHOZ	Chooz reactors 1.1 km
0.987±0.006±0.037	[153] GREENWOOD	96		Savannah River, 18.2 m
1.055±0.010±0.037	[153] GREENWOOD	96		Savannah River, 23.8 m
0.988±0.004±0.05	ACHKAR	95	CNTR	Bugey reactor, 15 m
0.994±0.010±0.05	ACHKAR	95	CNTR	Bugey reactor, 40 m
0.915±0.132±0.05	ACHKAR	95	CNTR	Bugey reactor, 95 m
0.987±0.014±0.027	[154] DECLAIS	94	CNTR	Bugey reactor, 15 m
0.985±0.018±0.034	KUVSHINN...	91	CNTR	Rovno reactor
1.05 ±0.02 ±0.05	VUILLEUMIER	82		Gösgen reactor
0.955±0.035±0.110	[155] KWON	81		$\overline{\nu}_e p \rightarrow e^+ n$
0.89 ±0.15	[155] BOEHM	80		$\overline{\nu}_e p \rightarrow e^+ n$
0.38 ±0.21	[156,157] REINES	80		
0.40 ±0.22	[156,157] REINES	80		

[152] APOLLONIO 98 search for neutrino oscillations at 1.1 km fixed distance from Chooz reactors. They use $\overline{\nu}_e p \rightarrow e^+ n$ in Gd-loaded scintillator target.

[153] GREENWOOD 96 search for neutrino oscillations at 18 m and 24 m from the reactor at Savannah River.

[154] DECLAIS 94 result based on integral measurement of neutrons only. Result is ratio of measured cross section to that expected in standard V-A theory. Replaced by ACHKAR 95.

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

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

[157] 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
<0.0009	90	[158] APOLLONIO	98	CHOZ	Chooz reactors 1.1 km
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.06	90	[159] GREENWOOD	96		Savannah River
<0.01	90	[160] ACHKAR	95	CNTR	Bugey reactor
<0.0075	90	[161] VIDYAKIN	94		Krasnoyark reactors
<0.0083	90	[161] VIDYAKIN	90		Krasnoyark reactors
<0.04	90	[162] AFONIN	88	CNTR	Rovno reactor
<0.014	68	[163] VIDYAKIN	87		$\overline{\nu}_e p \rightarrow e^+ n$
<0.019	90	[164] ZACEK	86		Gösgen reactor
<0.02	90	[165] ZACEK	85		Gösgen reactor
<0.016	90	[166] GABATHULER	84		Gösgen reactor

[158] APOLLONIO 98 search for neutrino oscillations at 1.1 km fixed distance from Chooz reactors. They use $\overline{\nu}_e p \rightarrow e^+ n$ in Gd-loaded scintillator target. This is the most sensitive search in terms of $\Delta(m^2)$ for $\overline{\nu}_e$ disappearance.

[159] GREENWOOD 96 search for neutrino oscillations at 18 m and 24 m from the reactor at Savannah River by observing $\overline{\nu}_e p \rightarrow e^+ n$ in a Gd loaded scintillator target. Their region of sensitivity in $\Delta(m^2)$ and $\sin^2 2\theta$ is already excluded by ACHKAR 95.

[160] ACHKAR 95 bound is for L=15, 40, and 95 m.

[161] VIDYAKIN 94 bound is for L=57.0 m, 57.6 m, and 231.4 m. Supersedes VIDYAKIN 90.

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

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

[164] This bound is from data for L=37.9 m, 45.9 m, and 64.7 m.

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

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

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[167] ACHKAR	95	CNTR	For $\Delta(m^2) = 0.6$ eV^2
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.18	90	[168] APOLLONIO	98	CHOZ	Chooz reactors 1.1 km
<0.24	90	[169] GREENWOOD	96		
<0.04	90	[169] GREENWOOD	96		For $\Delta(m^2) = 1.0$ eV^2
<0.087	68	[170] VYRODOV	95	CNTR	For $\Delta(m^2)$ >2 eV^2
<0.15	90	[171] VIDYAKIN	94		For $\Delta(m^2) > 5.0\times10^{-2}$ eV^2
<0.2	90	[172] AFONIN	88	CNTR	$\overline{\nu}_e p \rightarrow e^+ n$
<0.14	68	[173] VIDYAKIN	87		$\overline{\nu}_e p \rightarrow e^+ n$
<0.21	90	[174] ZACEK	86		$\overline{\nu}_e p \rightarrow e^+ n$
<0.19	90	[175] ZACEK	85		Gösgen reactor
<0.16	90	[176] GABATHULER	84		$\overline{\nu}_e p \rightarrow e^+ n$

[167] ACHKAR 95 bound is from data for L=15, 40, and 95 m distance from the Bugey reactor.

[168] APOLLONIO 98 search for neutrino oscillations at 1.1 km fixed distance from Chooz reactors. They

[169] GREENWOOD 96 search for neutrino oscillations at 18 m and 24 m from the reactor at Savannah River by observing $\overline{\nu}_e p \rightarrow e^+ n$ in a Gd loaded scintillator target. Their region of sensitivity in $\Delta(m^2)$ and $\sin^2 2\theta$ is already excluded by ACHKAR 95.

[170] The VYRODOV 95 bound is from data for L=15 m distance from the Bugey-5 reactor.

[171] The VIDYAKIN 94 bound is from data for L=57.0 m, 57.6 m, and 231.4 m from three reactors in the Krasnoyark Reactor complex.

[172] 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.

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

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

[175] ZACEK 85 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."

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

(H) Accelerator neutrino appearance experiments

$\nu_e \rightarrow \nu_\tau$

$\Delta(m^2)$ 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
<0.25	90	[177] USHIDA	86C	EMUL	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.36	90	TALEBZADEH	87	HLBC	BEBC

[177] USHIDA 86C published result is $\sin^2 2\theta < 0.12$. The quoted result is corrected for a numerical mistake incurred in calculating the expected number of ν_e CC events, normalized to the total number of neutrino interactions (3886) rather than to the total number of ν_μ CC events (1870).

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

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.7	90	[178] FRITZE	80	HYBR	BEBC CERN SPS

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

$\nu_\mu \rightarrow \nu_e$

$\Delta(m^2)$ 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. • • •					
<0.77	90	[179] ARMBRUSTER	98	KARM	ν_τ channel
0.03 to 0.3	95	[180] ATHANASSO...	98	LSND	$\nu_\mu \rightarrow \nu_e$
<2.3	90	[181] LOVERRE	96		CHARM/CDHS
<0.9	90	VILAIN	94C	CHM2	CERN SPS
<0.1	90	BLUMENFELD	89	CNTR	
<1.3	90	AMMOSOV	88	HLBC	SKAT at Serpukhov
<0.19	90	BERGSMA	88	CHRM	
		[182] LOVERRE	88	RVUE	
<2.4	90	AHRENS	87	CNTR	BNL AGS

<1.8	90		BOFILL	87	CNTR	FNAL
<2.2	90	[183]	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

[179] ARMBRUSTER 98 use KARMEN detector with ν_e from muon decay at rest and observe $^{12}C(\nu_e,e^-)^{12}N_{gs}$ essentially free from this background. The reported limits on the parameters of ν_e disappearance are not competitive. A three-flavor analysis is also presented.

[180] ATHANASSOPOULOS 98 is a search for the $\nu_\mu \to \nu_e$ oscillations using ν_μ from π^+ decay in flight. The 40 observed beam-on electron events are consistent with $\nu_e C \to e^- X$; the expected background is 21.9 ± 2.1. Authors interpret this excess as evidence for an oscillation signal corresponding to oscillations with probability $(0.26 \pm 0.10 \pm 0.05)\%$. Although the significance is only $2.3\,\sigma$, this measurement is an important and consistent cross check of ATHANASSOPOULOS 96 who reported evidence for $\overline{\nu}_\mu \to \overline{\nu}_e$ oscillations from μ^+ decay at rest. See also ATHANASSOPOULOS 98B.

[181] LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.

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

[183] 15ft bubble chamber at FNAL.

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

VALUE (units 10^{-3})	*CL%*		*DOCUMENT ID*		*TECN*	*COMMENT*
< 3.0	90	[184]	LOVERRE	96		CHARM/CDHS
< 2.5	90		AMMOSOV	88	HLBC	SKAT at Serpukhov
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 0.338	90	[185]	ARMBRUSTER	98	KARM	ν_τ channel
0.0005 to 0.03	95	[186]	ATHANASSO...	98	LSND	$\nu_\mu \to \nu_e$
< 9.4	90		VILAIN	94C	CHM2	CERN SPS
< 5.6	90	[187]	VILAIN	94C	CHM2	CERN SPS
< 16	90		BLUMENFELD	89	CNTR	
< 8	90		BERGSMA	88	CHRM	$\Delta(m^2) \geq 30$ eV^2
		[188]	LOVERRE	88	RVUE	
< 10	90		AHRENS	87	CNTR	BNL AGS
< 15	90		BOFILL	87	CNTR	FNAL
< 20	90	[189]	ANGELINI	86	HLBC	BEBC CERN PS
20 to 40		[190]	BERNARDI	86B	CNTR	$\Delta(m^2)$=5–10
< 11	90	[191]	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

[184] LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.

[185] See foonote in preeding table (ARMBRUSTER 98) for further details, and see the paper for a plot showing allowed regions. A three-flavor analysis is also presented here.

[186] ATHANASSOPOULOS 98 report (0.26 $\pm$ 0.10 $\pm$ 0.05)% for the oscillation probability; the value of $\sin^2 2\theta$ for large Δm^2 is deduced from this probability. See footnote in preceding table for further details, and see the paper for a plot showing allowed regions. If effect is due to oscillation, it is most likely to be intermediate $\sin^2 2\theta$ and Δm^2. See also ATHANASSOPOULOS 98B.

[187] VILAIN 94C limit derived by combining the ν_μ and $\overline{\nu}_\mu$ data assuming *CP* conservation.

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

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

[190] 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.

[191] 15ft bubble chamber at FNAL.

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

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

VALUE (eV^2)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<0.14	90	[192] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.05–0.08	90	[193] ATHANASSO...	96	LSND	LAMPF
0.048–0.090	80	[194] ATHANASSO...	95		
<0.07	90	[195] HILL	95		
<0.9	90	VILAIN	94C	CHM2	CERN SPS
<3.1	90	BOFILL	87	CNTR	FNAL
<2.4	90	TAYLOR	83	HLBC	15-ft FNAL
<0.91	90	[196] NEMETHY	81B	CNTR	LAMPF
<1	95	BLIETSCHAU	78	HLBC	GGM CERN PS

[192] 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 $\overline{\nu}_e p \rightarrow e^+ n$. FREEDMAN 93 replaces DURKIN 88.

[193] ATHANASSOPOULOS 96 is a search for $\overline{\nu}_e$ 30 m from LAMPF beam stop. Neutrinos originate mainly from π^+ decay at rest. $\overline{\nu}_e$ could come from either $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ or $\nu_e \rightarrow \overline{\nu}_e$; our entry assumes the first interpretation. They are detected through $\overline{\nu}_e p \rightarrow e^+ n$ (20 MeV $< E_{e^+} <$ 60 MeV) in delayed coincidence with $n p \rightarrow d \gamma$. Authors observe 51 $\pm$ 20 $\pm$ 8 total excess events over an estimated background 12.5 $\pm$ 2.9. ATHANASSOPOULOS 96B is a shorter version of this paper.

[194] ATHANASSOPOULOS 95 error corresponds to the 1.6σ band in the plot. The expected background is 2.7 $\pm$ 0.4 events. Corresponds to an oscillation probability of $(0.34^{+0.20}_{-0.18} \pm 0.07)$%. For a different interpretation, see HILL 95. Replaced by ATHANASSOPOULOS 96.

[195] HILL 95 is a report by one member of the LSND Collaboration, reporting a different conclusion from the analysis of the data of this experiment (see ATHANASSOPOULOS 95). Contrary to the rest of the LSND Collaboration, Hill finds no evidence for the neutrino oscillation $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ and obtains only upper limits.

[196] 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. • • •					
$0.0062 \pm 0.0024 \pm 0.0010$		[197] ATHANASSO...	96	LSND	LAMPF
0.003–0.012	80	[198] ATHANASSO...	95		
<0.006	90	[199] HILL	95		
<4.8	90	VILAIN	94C	CHM2	CERN SPS
<5.6	90	[200] VILAIN	94C	CHM2	CERN SPS
<0.024	90	[201] FREEDMAN	93	CNTR	LAMPF
<0.04	90	BOFILL	87	CNTR	FNAL
<0.013	90	TAYLOR	83	HLBC	15-ft FNAL
<0.2	90	[202] NEMETHY	81B	CNTR	LAMPF

[197] ATHANASSOPOULOS 96 reports $(0.31 \pm 0.12 \pm 0.05)\%$ for the oscillation probability; the value of $\sin^2 2\theta$ for large $\Delta(m^2)$ should be twice this probability. See footnote in preceding table for further details, and see the paper for a plot showing allowed regions.

[198] ATHANASSOPOULOS 95 error corresponds to the 1.6σ band in the plot. The expected background is 2.7 ± 0.4 events. Corresponds to an oscillation probability of $(0.34^{+0.20}_{-0.18} \pm 0.07)\%$. For a different interpretation, see HILL 95. Replaced by ATHANASSOPOULOS 96.

[199] HILL 95 is a report by one member of the LSND Collaboration, reporting a different conclusion from the analysis of the data of this experiment (see ATHANASSOPOULOS 95). Contrary to the rest of the LSND Collaboration, Hill finds no evidence for the neutrino oscillation $\overline{\nu}_\mu \to \overline{\nu}_e$ and obtains only upper limits.

[200] VILAIN 94C limit derived by combining the ν_μ and $\overline{\nu}_\mu$ data assuming *CP* conservation.

[201] 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 $\overline{\nu}_e p \to e^+ n$. FREEDMAN 93 replaces DURKIN 88.

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

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

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

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
<0.075	90	BORODOV...	92	CNTR	BNL E776
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.6	90	[203] ROMOSAN	97	CCFR	FNAL

[203] ROMOSAN 97 uses wideband beam with a 0.5 km decay region.

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

VALUE (units 10^{-3})	CL%	DOCUMENT ID		TECN	COMMENT
<1.8	90	[204] ROMOSAN	97	CCFR	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3.8	90	[205] MCFARLAND	95	CCFR	FNAL
<3	90	BORODOV...	92	CNTR	BNL E776

[204] ROMOSAN 97 uses wideband beam with a 0.5 km decay region.

[205] MCFARLAND 95 state that "This result is the most stringent to date for $250 < \Delta(m^2) < 450$ eV^2 and also excludes at 90%CL much of the high $\Delta(m^2)$ region favored by the recent LSND observation." See ATHANASSOPOULOS 95 and ATHANASSOPOULOS 96.

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

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

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
< 1.1	90	[206] ESKUT	98B	CHRS	CERN SPS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 1.2	90	[207] ASTIER	99	NOMD	CERN SPS
< 1.4	90	[208] ALTEGOER	98B	NOMD	CERN SPS
< 1.5	90	[209] ESKUT	98	CHRS	CERN SPS
< 3.3	90	[210] LOVERRE	96		CHARM/CDHS
< 1.4	90	MCFARLAND	95	CCFR	FNAL
< 4.5	90	BATUSOV	90B	EMUL	FNAL
<10.2	90	BOFILL	87	CNTR	FNAL
< 6.3	90	BRUCKER	86	HLBC	15-ft FNAL
< 0.9	90	USHIDA	86C	EMUL	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

[206] ESKUT 98B search for $\tau^- \rightarrow \mu^- \nu_\tau \overline{\nu}_\mu$ or $h^- \nu_\tau \overline{\nu}_\mu$, where h^- is a negatively charged hadron. The μ^- sample is somewhat larger than in ESKUT 98, which this result supersedes. Bayesian limit.

[207] ASTIER 99 limits are based on data corresponding to $\sim$ 950000 ν_μCC interactions in the 1995, 1996, and (most) 1997 runs. This is a "blind" analysis using the FELDMAN 98 classical CL approach, and other algorithms have also been improved since ALTEGOER 98B.

[208] ALTEGOER 98B is the NOMAD 1995 data sample result, searching for events with $\tau^- \rightarrow e^- \nu_\tau \overline{\nu}_e$, hadron$^-$ ν_τ, or $\pi^- \pi^+ \pi^-$ decay modes using classical CL approach of FELDMAN 98.

[209] ESKUT 98 search for events with one μ^- with indication of a kink from τ^- decay in the nuclear emulsion. No candidates were found in a 31,423 event subsample.

[210] LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0012	90	[211] ASTIER	99	NOMD	CERN SPS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.0042	90	[212] ALTEGOER	98B	NOMD	CERN SPS
<0.0035	90	[213] ESKUT	98	CHRS	CERN SPS
<0.0018	90	[214] ESKUT	98B	CHRS	CERN SPS
<0.006	90	[215] LOVERRE	96		CHARM/CDHS
<0.0081	90	MCFARLAND	95	CCFR	FNAL
<0.06	90	BATUSOV	90B	EMUL	FNAL
<0.34	90	BOFILL	87	CNTR	FNAL
<0.088	90	BRUCKER	86	HLBC	15-ft FNAL
<0.004	90	USHIDA	86C	EMUL	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

211 ASTIER 99 limits are based on data corresponding to $\sim$ 950000 ν_μCC interactions in the 1995, 1996, and (most) 1997 runs. This is a "blind" analysis using the FELDMAN 98 classical CL approach, and other algorithms have also been improved since ALTEGOER 98B.

212 ALTEGOER 98B is the NOMAD 1995 data sample result, searching for events with $\tau^- \rightarrow e^- \nu_\tau \overline{\nu}_e$, hadron$^-$ ν_τ, or $\pi^- \pi^+ \pi^-$ decay modes using classical CL approach of FELDMAN 98.

213 ESKUT 98 search for events with one μ^- with indication of a kink from τ^- decay in the nuclear emulsion. No candidates were found in a 31,423 event subsample.

214 ESKUT 98B search for $\tau^- \rightarrow \mu^- \nu_\tau \overline{\nu}_\mu$ or $h^- \nu_\tau \overline{\nu}_\mu$, where h^- is a negatively charged hadron. The μ^- sample is somewhat larger than in ESKUT 98, which this result supersedes. Bayesian limit.

215 LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.

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

$\Delta(m^2)$ 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. • • •					
<1.4	90	MCFARLAND	95	CCFR	FNAL
<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. • • •					
<0.0081	90	MCFARLAND	95	CCFR	FNAL
<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	[216] GRUWE	93	CHM2	CERN SPS

216 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	[217] GRUWE	93	CHM2	CERN SPS

217 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.

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

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	[218] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<7	90	[219] COOPER	82	HLBC	BEBC CERN SPS

[218] 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 $\overline{\nu}_e\,p \to e^+ n$.

[219] 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	[220] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.05	90	[221] COOPER	82	HLBC	BEBC CERN SPS

[220] 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 $\overline{\nu}_e\,p \to e^+ n$.

[221] 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	[222] FREEDMAN	93	CNTR	LAMPF
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.7	90	[223] COOPER	82	HLBC	BEBC CERN SPS

[222] 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.

[223] 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	[224] COOPER	82	HLBC	BEBC CERN SPS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.07	90	[225] FREEDMAN	93	CNTR	LAMPF

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

[225] 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 $\overline{\nu}_e p \rightarrow e^+ n$. The limit on $\Delta(m^2)$ is better than the CERN BEBC experiment, but the limit on $\sin^2\theta$

(I) Disappearance experiments with accelerator & radioactive source neutrinos

$\nu_e \not\rightarrow \nu_e$

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

VALUE (eV^2)	CL%	DOCUMENT ID		TECN	COMMENT
$<$ 0.18	90	[226] HAMPEL	98	GALX	^{51}Cr source
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<40	90	[227] BORISOV	96	CNTR	IHEP-JINR detector
<14.9	90	BRUCKER	86	HLBC	15-ft FNAL
$<$ 8	90	BAKER	81	HLBC	15-ft FNAL
<56	90	DEDEN	81	HLBC	BEBC CERN SPS
<10	90	ERRIQUEZ	81	HLBC	BEBC CERN SPS
<2.3 OR >8	90	NEMETHY	81B	CNTR	LAMPF

[226] HAMPEL 98 analyzed the GALLEX calibration results with ^{51}Cr neutrino sources and updates the BAHCALL 95 analysis result. They also gave 95% and 99% CL limits of < 0.2 and < 0.22, respectively.

[227] BORISOV 96 exclusion curve extrapolated to obtain this value; however, it does not have the right curvature in this region.

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<7 × 10^{-2}	90	[228] ERRIQUEZ	81	HLBC	BEBC CERN SPS
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.4	90	[229] HAMPEL	98	GALX	^{51}Cr source
<0.115	90	[230] BORISOV	96	CNTR	$\Delta(m^2) = 175$ eV^2
<0.54	90	BRUCKER	86	HLBC	15-ft FNAL
<0.6	90	BAKER	81	HLBC	15-ft FNAL
<0.3	90	[228] DEDEN	81	HLBC	BEBC CERN SPS

[228] Obtained from a Gaussian centered in the unphysical region.

[229] HAMPEL 98 analyzed the GALLEX calibration results with ^{51}Cr neutrino sources and updates the BAHCALL 95 analysis result. They also gave 95% and 99% CL limits of < 0.45 and < 0.56, respectively.

[230] BORISOV 96 sets less stringent limits at large $\Delta(m^2)$, but exclusion curve does not have clear asymptotic behavior.

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

$\Delta(m^2)$ 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 $\Delta(m^2) = 100 eV^2$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[231] STOCKDALE	85	CNTR	FNAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.17	90	[232] BERGSMA	88	CHRM	
<0.07	90	[233] BELIKOV	85	CNTR	Serpukhov
<0.27	90	[232] BERGSMA	84	CHRM	CERN PS
<0.1	90	[234] DYDAK	84	CNTR	CERN PS
<0.02	90	[235] STOCKDALE	84	CNTR	FNAL
<0.1	90	[236] BELIKOV	83	CNTR	Serpukhov

[231] 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.

[232] 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.

[233] 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%.

[234] 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.

[235] 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.

[236] 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	[237] STOCKDALE	85	CNTR	FNAL

[237] 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

ASTIER	99	PL B453 169	P. Astier+	(NOMAD Collab.)
ACKERSTAFF	98C	EPJ C1 45	K. Ackerstaff+	(OPAL Collab.)
ALESSAND...	98	PL B433 156	A. Alessandrello+	
ALTEGOER	98B	PL B431 219	S. Altegoer+	(NOMAD Collab.)
AMBROSIO	98	PL B434 451	M. Ambrosio+	(MACRO Collab.)
APOLLONIO	98	PL B420 397	M. Apollonio+	(CHOOZ Collab.)
ARMBRUSTER	98	PR C57 3414	B. Armbruster+	(KARMEN Collab.)
ASSAMAGAN	98	PL B434 158	K. Assamagan+	
ATHANASSO...	98	PRL 81 1774	C. Athanassopoulos+	(LSND Collab.)
ATHANASSO...	98B	PR C58 2489	C. Athanassopoulos+	(LSND Collab.)
CLEVELAND	98	APJ 496 505	B.T. Cleveland+	(Homestake Collab.)
ESKUT	98	PL B424 202	E. Eskut+	(CHORUS Collab.)
ESKUT	98B	PL B434 205	E. Eskut+	(CHORUS Collab.)
FELDMAN	98	PR D57 3873	G.J. Feldman, R.D. Cousins	
FUKUDA	98	PL B433 9	Y. Fukuda+	(Super-Kamiokande Collab.)
FUKUDA	98B	PRL 81 1158	Y. Fukuda+	(Super-Kamiokande Collab.)
FUKUDA	98C	PRL 81 1562	Y. Fukuda+	(Super-Kamiokande Collab.)
FUKUDA	98E	PL B436 33	Y. Fukuda+	(Super-Kamiokande Collab.)
HAMPEL	98	PL B420 114	W. Hampel+	(GALLEX Collab.)
HATAKEYAMA	98	PRL 81 2016	S. Hatakeyama+	(Kamiokande Collab.)
HINDI	98	PR C58 2512	M.M. Hindi+	
LUESCHER	98	PL B434 407	R. Luescher+	
OYAMA	98	PR D57 R6594	Y. Oyama	
ABREU	97I	ZPHY C74 57	+Adam, Adye, Ajinenko, Alekseev+	(DELPHI Collab.)
Also	97L	ZPHY C75 580 erratum	Abreu, Adam, Adye, Ajinenko+	(DELPHI Collab.)
ACCIARRI	97P	PL B412 189	+Adriani, Aguilar-Benitez, Ahlen+	(L3 Collab.)
ALLISON	97	PL B391 491	+Alner, Ayres, Barrett+	(Soudan 2 Collab.)
ALSTON-...	97	PR C55 474	Alston-Garnjost, Dougherty+	(LBL, MTHO, UNM, INEL)
BARABASH	97	ZPHY A357 351	+Gurriaran, Hubert, Hubert, Umatov	(ITEP, BCEN)
BAUDIS	97	PL B407 219	L. Baudis+	(MPIH, KIAE, SASSO)
CLARK	97	PRL 79 345	+Becker-Szendy, Bratton, Brealt+	(IMB Collab.)
DESILVA	97	PR C56 2451	De Silva, Moe, Nelson, Vient	(UCI)
GUENTHER	97	PR D55 54	+Hellmig+	(MPIH, KIAE, SASSO)
ROMOSAN	97	PRL 78 2912	+Arroyo, de Barbaro, de Barbaro+	(CCFR Collab.)
ACCIARRI	96G	PL B377 304	+Adam, Adriani, Aguilar-Benitez+	(L3 Collab.)
ALESSAND...	96B	NPBPS 48 238	Alessandrello, Brofferio, Bucci+	(MILA, SASSO)
ALEXANDER	96P	PL B385 433	+Allison, Altekamp, Ametewee+	(OPAL Collab.)
ARNOLD	96	ZPHY C72 239	R. Arnold+	(BCEN, CAEN, JINR+)
ATHANASSO...	96	PR C54 2685	Athanassopoulos, Auerbach, Burman+	(LSND Collab.)
ATHANASSO...	96B	PRL 77 3082	Athanassopoulos, Auerbach, Burman+	(LSND Collab.)
BALYSH	96	PRL 77 5186	+De Silva, Lebedev, Lou, Moe+	(KIAE, UCI, CIT)
BORISOV	96	PL B369 39	+Chernichenko, Chukin, Goryachev+	(SERP, JINR)
BRYMAN	96	PR D53 558	+Numao	(TRIU)
BUSKULIC	96S	PL B384 439	+De Bonis, Decamp, Ghez+	(ALEPH Collab.)
EJIRI	96	NP A611 85	H. Ejiri+	(OSAK)
FUKUDA	96	PRL 77 1683	+Hayakawa, Inoue, Ishihara+	(Kamiokande Collab.)
FUKUDA	96B	PL B388 397	+Hayakawa, Inoue, Ishihara+	(Kamiokande Collab.)
GREENWOOD	96	PR D53 6054	+Kropp, Mandelkern, Nakamura+	(UCI, SVR, SCUC)
HAMPEL	96	PL B388 384	+Heusser, Kiko, Kirsten+	(GALLEX Collab.)
LOVERRE	96	PL B370 156	P.F. Loverre	
TAKAOKA	96	PR C53 1557	+Motomura, Nagao	(KYUSH, OKAY)
WIETFELDT	96	PRPL 273 149	+Norman	(LBL)
ACHKAR	95	NP B434 503	+Aleksan+	(SING, SACLD, CPPM, CDEF, LAPP)
AHLEN	95	PL B357 481	+Ambrosio, Antolini, Auriemma+	(MACRO Collab.)
ANSELMANN	95	PL B342 440	+Fockenbrock, Hampel, Heusser+	(GALLEX Collab.)
ANSELMANN	95B	PL B357 237	+Hampel, Heusser, Kike+	(GALLEX Collab.)
ARMBRUSTER	95	PL B348 19	+Blair, Bodmann, Booth+	(KARMEN Collab.)
ARNOLD	95	JETPL 61 170	+Caurier, Guyonnet, Linck+	(NEMO Collab.)
		Translated from ZETFP 61 168.		
ATHANASSO...	95	PRL 75 2650	Athanassopoulos, Auerbach+	(LSND Collab.)
BAHCALL	95	PL B348 121	+Krastev, Lisi	(IAS)
BAHRAN	95	PL B354 481	+Kalbfleisch	(OKLA)
BALYSH	95	PL B356 450	+Beck, Belyaev+	(MPIH, KIAE, SASSO)
BARABASH	95	PL B345 408	+Avignone+	(ITEP, SCUC, PNL, MINN, LEBD)
BILGER	95	PL B363 41	+Clement, Denig, Fohl+	(TUBIN, KARLE, PSI)
BURACHAS	95	PAN 58 153	+Danevich, Zdesenko, Kobychev+	(KIEV)
		Translated from YAF 58 195.		

DANEVICH 95 PL B344 72 +Georgadze, Kobychev, Kropivyansky+ (KIEV)
DASSIE 95 PR D51 2090 +Eschbach, Hubert, Isaac, Isac+ (NEMO Collab.)
DAUM 95 ZPHY C66 417 +Rhode, Bareyre, Barloutaud+ (FREJUS Collab.)
DAUM 95B PL B361 179 +Frosch, Hajdas, Janousch+ (PSI, VIRG)
EJIRI 95 JPSJ 64 339 +Fushmii, Hazama, Kawasaki+ (OSAK, KIEV)
FARGION 95 PR D52 1828 +Khlopov, Konplich, Mignani (ROMA, KIAM, MPEI)
GALLAS 95 PR D52 6 +Abolins, Brock, Cobau+ (MSU, FNAL, MIT, FLOR)
GARCIA 95 PR D51 1458 +Morales, Morales, Sarsa+ (ZARA, SCUC, PNL)
GEORGADZE 95 PAN 58 1093
Translated from YAF 58 1170.
HAGNER 95 PR D52 1343 +Altmann, Feilitzsch, Oberauer+ (MUNT, LAPP, CPPM)
HIDDEMANN 95 JP G21 639 +Daniel, Schwentker (MUNT)
HILL 95 PRL 75 2654 (PENN)
KOBAYASHI 95 NP A586 457 +Kobayashi (KEK, SAGA)
MCFARLAND 95 PRL 75 3993 +Naples, Arroyo, Auchinchloss+ (CCFR Collab.)
VILAIN 95C PL B351 387 +Wilquet, Petrak+ (CHARM II Collab.)
Also 95 PL B343 453 Vilain, Wilquet+ (CHARM II Collab.)
VYRODOV 95 JETPL 61 163 +Kozlov, Martem'yanov, Machulin+ (KIAE, LAPP, CDEF)
Translated from ZETFP 61 161.
WIETFELDT 95 PR C52 1028 +Norman+ (LBL, UCB, SPAUL, IND, TENN)
ABDURASHI... 94 PL B328 234 Abdurashitov, Faizov, Gavrin, Gusev+ (SAGE Collab.)
BALYSH 94 PL B322 176 +Beck, Belyaev, Bensch+ (MPIH, KIAE, SASSO)
BECK 94 PL B336 141 +Bensch, Bockholt+ (MPIH, KIAE, SASSO)
DECLAIS 94 PL B338 383 Y. Declais+
FUKUDA 94 PL B335 237 +Hayakawa, Inoue, Ishida+ (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.
VILAIN 94C ZPHY C64 539 +Wilquet, Beyer+ (CHARM II Collab.)
ALSTON-... 93 PRL 71 831 Alston-Garnjost+ (LBL, MTHO, UNM, INEL)
ARTEMEV 93 JETPL 58 262 +Brakhman, Zeldofich, Karelin+ (ITEP, INRM)
Translated from ZETFP 58 256.
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.)
KALBFLEISCH 93 PL B303 355 +Bahran (OKLA)
KAWASHIMA 93 PR C47 R2452 +Takahashi, Masuda (TOKYC, RIKEN)
MORTARA 93 PRL 70 394 +Ahmad, Coulter, Freedman+ (ANL, LBL, UCB)
OHSHIMA 93 PR D47 4840 + (KEK, TUAT, RIKEN, SCUC, ROCH, TSUK, INUS)
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.)
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.

MORI	92B	PL B289 463	+Hikasa, Nojiri, Oyama+	(KAM2 Collab.)
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+	(LOUV, ZURI, LAUS)
EJIRI	91	PL B258 17	+Fushimi, Kamada, Kinoshita+	(OSAK)
HIME	91	PL B257 441	+Jelley	(OXF)
HIRATA	91	PRL 66 9	+Inoue, Kajita, Kihara+	(Kamiokande II Collab.)
KUVSHINN...	91	JETPL 54 253	A.A. Kuvshinnikov+	(KIAE)
MANUEL	91	JP G17 S221		(MISSR)
NORMAN	91	JPG 17 S291	+Sur, Lesko+	(LBL)
REUSSER	91	PL B255 143	+Treichel, Boehm, Broggini+	(NEUC, CIT, PSI)
SATO	91	PR D44 2220	+Hirata, Kajita, Kifune+	(Kamiokande Collab.)
SUHONEN	91	NP A535 509	+Khadkikar, Faessler	(JYV, AHMED, TUBIN)
TOMODA	91	RPP 54 53	T. Tomoda	
TURKEVICH	91	PRL 67 3211	+Economou, Cowan	(CHIC, LANL)
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.)
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.)
HIRATA	90	PRL 65 1297	+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.)
BAHCALL	89	Neutrino Astrophysics, Cambridge Univ. Press		(IAS)
BLUMENFELD	89	PRL 62 2237	+Chi, Chichura, Chien+	(COLU, ILL, JHU)
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.)
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	
LOVERRE	88	PL B206 711		(INFN)
OLIVE	88	PL B205 553	+Srednicki	(MINN, UCSB)
SREDNICKI	88	NP B310 693	+Watkins, Olive	(MINN, UCSB)
AFONIN	87	JETPL 45 257	+Bogatov, Vershinskii+	(KIAE)
		Translated from ZETFP 45 201.		
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)
DAUM	87	PR D36 2624	+Kettle, Jost+	(SIN, VIRG)
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.)
ABRAMOWICZ	86	PRL 57 298	H. Abramowicz+	(CDHS Collab.)
AFONIN	86	JETPL 44 142	+Bogatov, Borovoi, Vershinskii+	(KIAE)
		Translated from ZETFP 44 111.		
ALLABY	86	PL B177 446	J.V. Allaby+	(CHARM Collab.)
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.)
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)
DELEENER-...	86	PL B177 228	DeLeener-Rosier, Deutsch+	(LOUV, ZURI, LAUS)
DORENBOS...	86	PL 166B 473	Dorenbosch, Allaby, Amaldi+	(CHARM Collab.)
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+)
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.		
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)
MARKEY	85	PR C32 2215	+Boehm	(CIT)
OHI	85	PL 160B 322	+Nakajima, Tamura+	(TOKY, INUS, KEK)
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)
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)
FREESE	84	NP B233 167	+Schramm	(CHIC, FNAL)
GABATHULER	84	PL 138B 449	+Boehm+	(CIT, SIN, MUNI)
HAXTON	84	PPNP 12 409	+Stevenson	
MINEHART	84	PRL 52 804	+Ziock, Marshall, Stephens, Daum+	(VIRG, SIN)
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.		
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.		
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	(LOUV)
GRONAU	83	PR D28 2762		(HAIF)
KIRSTEN	83	PRL 50 474	+Richter, Jessberger	(MPIH)
Also	83B	ZPHY 16 189	Kirsten, Richter, Jessberger	(MPIH)
SCHRECK...	83	PL 129B 265	Schreckenbach, Colvin+	(ISNG, ILLG)
TAYLOR	83	PR D28 2705	+Cence, Harris, Jones+	(HAWA, LBL, FNAL)
COOPER	82	PL 112B 97	+Guy, Michette, Tyndel, Venus	(RL)
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.		
CALAPRICE	81	PL 106B 175	+Schreiber, Schneider+	(PRIN, IND)
DEDEN	81	PL 98B 310	+Grassler, Boeckmann, Mermikides+	(BEBC Collab.)
ERRIQUEZ	81	PL 102B 73	+Natali+	(BARI, BIRM, BRUX, EPOL, RHEL, SACL+)
KWON	81	PR D24 1097	+Boehm, Hahn, Henrikson+	(CIT, ISNG, MUNI)
NEMETHY	81B	PR D23 262	+	(YALE, LBL, LASL, MIT, SACL, SIN, CNRC, BERN)
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)
BOEHM	80	PL 97B 310	+Cavaignac, Feilitzsch+	(ILLG, CIT, ISNG, MUNI)
FRITZE	80	PL 96B 427		(AACH3, BONN, CERN, LOIC, OXF, SACL)
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)
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.		