Neutrinos – THIS IS PART 2 OF 4

To reduce the size of this section's PostScript file, we have divided it into four PostScript files. We present the following index:

(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 → $\mathbf{<1 \times 10^{-7}}$	90	[69] 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	[70] 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	[71] SHROCK	81	THEO	m_{ν_j}=10 MeV
$<5 \times 10^{-6}$	68	[71] SHROCK	81	THEO	m_{ν_j}=60 MeV
$<1 \times 10^{-5}$	68	[72] SHROCK	80	THEO	m_{ν_j}=80 MeV
$<3 \times 10^{-6}$	68	[72] SHROCK	80	THEO	m_{ν_j}=160 MeV

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

[70] 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).

[71] 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.

[72] 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. • • •						
$< 1 \times 10^{-2}$	95	1	^{3}H	SPEC	[73] HIDDEMANN	95
$< 6 \times 10^{-3}$	95	2	^{3}H	SPEC	[73] HIDDEMANN	95
$< 2 \times 10^{-3}$	95	3	^{3}H	SPEC	[73] HIDDEMANN	95
$< 2 \times 10^{-3}$	95	4	^{3}H	SPEC	[73] HIDDEMANN	95
$0.3 \pm 1.5 \pm 0.8$		17	^{35}S	Mag spect	[74] BERMAN	93
$<$ 2.8	99	17	^{3}H	Prop chamber	[75] KALBFLEISCH	93
$<$ 1	99	14.4–15.2	^{3}H	Prop chamber	[75] KALBFLEISCH	93
$<$ 0.7	99	16.3–16.6	^{3}H	Prop chamber	[75] KALBFLEISCH	93
$<$ 2	95	13–40	^{35}S	Si(Li)	[76] MORTARA	93
$<$ 0.73	95	17	^{63}Ni	Mag spect	OHSHIMA	93
$<$ 1.5	95	10.5–25.0	^{63}Ni	Mag spect	[77] OHSHIMA	93
$<$ 6	95	5–25	^{55}Fe	IBEC in Ge	[78] WIETFELDT	93
$<$ 2	90	17	^{35}S	Mag spect.	[79] CHEN	92
$<$ 0.95	95	17	^{63}Ni	Mag spect	[80] KAWAKAMI	92
$<$ 1.0	95	10–24	^{63}Ni	Mag spect	KAWAKAMI	92
$<$ 10	90	16–35	^{125}I	IBEC; γ det	[81] BORGE	86
$<$ 7.5	99	5–50	^{35}S	Mag spect	ALTZITZOG...	85
$<$ 8	90	80	^{35}S	Mag spect	[82] 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	[83] SCHRECK...	83
$<$ 4	90	140	^{64}Cu	Mag spect	[83] SCHRECK...	83
$<$ 8	90	440	^{64}Cu	Mag spect	[83] SCHRECK...	83
$<$ 1	95	0.1			[84] SIMPSON	81B
$<$ 4	95$\times$ 1010^3				[84] SIMPSON	81B
$<$100	90	0.1–3000		THEO	[85] SHROCK	80
$<$ 0.1	68	80		THEO	[86] SHROCK	80

[73] 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

[74] 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.

[75] KALBFLEISCH 93 extends the 17 keV neutrino search of BAHRAN 92, using an improved proportional chamber to which a small amount of ^{3}H is added. Systematics are significantly reduced, allowing for an improved upper limit. The authors give a 99% confidence limit on $|U_{1j}|^2$ as a function of m_{ν_j} in the range from 13.5 keV to 17.5 keV. Typical upper limits are listed above. They report that this experiment in combination with BAHRAN 92 gives an upper limit of 2.4×10^{-3} at the 99% CL. See also the related papers BAHRAN 93, BAHRAN 93B, and BAHRAN 95 on theoretical aspects of beta spectra and fitting methods for heavy neutrinos.

[76] 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."

[77] 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.

[78] WIETFELDT 93 is an extension of the NORMAN 91 experiment. However, whereas NORMAN 91 reported indications for the emission of a neutrino with mass $m_{\nu_j} = 21 \pm 2$ 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 particlular, 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."

[79] 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 $m_{\nu_j} = 17$ 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.

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

[81] 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.

[82] 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%.

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

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

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

[86] 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. • • •					
1.8×10^{-3}	90	[87] HAGNER	95	MWPC	m_{ν_h} = 1.5 MeV
2.5×10^{-4}	90	[87] HAGNER	95	MWPC	m_{ν_h} = 4 MeV
4.2×10^{-3}	90	[87] HAGNER	95	MWPC	m_{ν_h} = 9 MeV
$<1 \times 10^{-5}$	90	[88] BARANOV	93		m_{ν_j}= 100 MeV
$<1 \times 10^{-6}$	90	[88] BARANOV	93		m_{ν_j}= 200 MeV
$<3 \times 10^{-7}$	90	[88] BARANOV	93		m_{ν_j}= 300 MeV
$<2 \times 10^{-7}$	90	[88] 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	[89] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[89] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[89] 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	[90] OBERAUER	87		m_{ν_j}=1.5 MeV
$<8 \times 10^{-4}$	68	[90] 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	[91] COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<8 \times 10^{-8}$	90	[91] COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV
$<1 \times 10^{-2}$	90	[92] BERGSMA	83B	CNTR	m_{ν_j}=10 MeV
$<1 \times 10^{-5}$	90	[92] BERGSMA	83B	CNTR	m_{ν_j}=110 MeV
$<6 \times 10^{-7}$	90	[92] 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

[87] 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.

[88] 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.

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

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

[91] 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.

[92] 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. • • •					
$< 1–10 \times 10^{-4}$		[93] BRYMAN	96	CNTR	m_{ν_x} = 30–33.91 MeV
$>10^{-16}$		[94] ARMBRUSTER	95	KARM	m_{ν_x} = 33.9 MeV
$< 4 \times 10^{-7}$	95	[95] BILGER	95	LEPS	$m_{\overline{\nu}_x}$ = 33.9 MeV
$< 7 \times 10^{-8}$	95	[95] BILGER	95	LEPS	m_{ν_x} = 33.9 MeV
$< 2.6 \times 10^{-8}$	95	[95] 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_{ν_j} < 19.5 MeV
$< 3 \times 10^{-2}$	90	[96] MINEHART	84		m_{ν_j}=2 MeV

$<1 \times 10^{-3}$	90	[96] MINEHART	84		m_{ν_j}=4 MeV
$<3 \times 10^{-4}$	90	[96] MINEHART	84		m_{ν_j}=10 MeV
$<5 \times 10^{-6}$	90	[97] HAYANO	82		m_{ν_j}=330 MeV
$<1 \times 10^{-4}$	90	[97] HAYANO	82		m_{ν_j}=70 MeV
$<9 \times 10^{-7}$	90	[97] HAYANO	82		m_{ν_j}=250 MeV
$<1 \times 10^{-1}$	90	[96] ABELA	81		m_{ν_j}=4 MeV
$<7 \times 10^{-5}$	90	[96] ABELA	81		m_{ν_j}=10.5 MeV
$<2 \times 10^{-4}$	90	[96] ABELA	81		m_{ν_j}=11.5 MeV
$<2 \times 10^{-5}$	90	[96] ABELA	81		m_{ν_j}=16–30 MeV
$<2 \times 10^{-5}$	95	[97] ASANO	81		m_{ν_j}=170 MeV
$<3 \times 10^{-6}$	95	[97] ASANO	81		m_{ν_j}=210 MeV
$<3 \times 10^{-6}$	95	[97] ASANO	81		m_{ν_j}=230 MeV
$<6 \times 10^{-6}$	95	[98] ASANO	81		m_{ν_j}=240 MeV
$<5 \times 10^{-7}$	95	[98] ASANO	81		m_{ν_j}=280 MeV
$<6 \times 10^{-6}$	95	[98] ASANO	81		m_{ν_j}=300 MeV
$<1 \times 10^{-2}$	95	[96] CALAPRICE	81		m_{ν_j}=7 MeV
$<3 \times 10^{-3}$	95	[96] CALAPRICE	81		m_{ν_j}=33 MeV
$<1 \times 10^{-4}$	68	[99] SHROCK	81	THEO	m_{ν_j}=13 MeV
$<3 \times 10^{-5}$	68	[99] SHROCK	81	THEO	m_{ν_j}=33 MeV
$<6 \times 10^{-3}$	68	[100] SHROCK	81	THEO	m_{ν_j}=80 MeV
$<5 \times 10^{-3}$	68	[100] SHROCK	81	THEO	m_{ν_j}=120 MeV

[93] 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, $< 4\text{–}6 \times 10^{-5}$ (90%CL). They interpret the result as an upper limit for the admixture of a heavy sterile or otherwise unconventional neutrino.

[94] ARMBRUSTER 95 study the reactions ^{12}C(ν_e,e^-)^{12}N and ^{12}C(ν,ν')^{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 $\approx$ 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.

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

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

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

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

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

[100] 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. • • •					
$<3 \times 10^{-6}$	90	GALLAS	95	CNTR	m_{ν_j} = 1 GeV
$<3 \times 10^{-5}$	90	[101] VILAIN	95C	CHM2	m_{ν_j} = 2 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	[102] BURCHAT	90	MRK2	m_{ν_j} < 19.6 GeV
$<1 \times 10^{-10}$	95	[102] BURCHAT	90	MRK2	m_{ν_j} = 22 GeV
$<1 \times 10^{-11}$	95	[102] BURCHAT	90	MRK2	m_{ν_j} = 41 GeV
all values ruled out	95	DECAMP	90F	ALEP	m_{ν_j}= 25.0–42.7 GeV
$<1 \times 10^{-13}$	95	DECAMP	90F	ALEP	m_{ν_j}= 42.7–45.7 GeV
$<5 \times 10^{-4}$	90	[103] 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	[104] MISHRA	87	CNTR	m_{ν_j}=1.5 GeV
$<4 \times 10^{-3}$	90	[104] MISHRA	87	CNTR	m_{ν_j}=2.5 GeV
$<0.9 \times 10^{-2}$	90	[104] MISHRA	87	CNTR	m_{ν_j}=5 GeV
<0.1	90	[104] 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	[105] COOPER-...	85	HLBC	m_{ν_j}=0.4 GeV
$<1.0 \times 10^{-7}$	90	[105] COOPER-...	85	HLBC	m_{ν_j}=1.5 GeV

[101] 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.

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

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

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

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

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.2 \times 10^{-8}$	95	ADEVA	90S	L3	$m_{\nu_j} = 20$ GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S	L3	$m_{\nu_j} = 40$ GeV
all values ruled out	95	[106] BURCHAT	90	MRK2	$m_{\nu_j} < 19.6$ GeV
$<1 \times 10^{-10}$	95	[106] BURCHAT	90	MRK2	$m_{\nu_j} = 22$ GeV
$<1 \times 10^{-11}$	95	[106] BURCHAT	90	MRK2	$m_{\nu_j} = 41$ 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

[106] 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 $\left|U_{1j} \times U_{2j}\right|$ 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	[107] BARANOV	93		m_{ν_j}= 80 MeV
$<3 \times 10^{-6}$	90	[107] BARANOV	93		m_{ν_j}= 160 MeV
$<6 \times 10^{-7}$	90	[107] BARANOV	93		m_{ν_j}= 240 MeV
$<2 \times 10^{-7}$	90	[107] 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

[107] 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.