## (A) Bounds from Particle and Nuclear Decays

### Limits on $|U_{1j}|^2$ as Function of $m_{\nu_j}$

### Application of Kink and Peak Search Test to Existing Data

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| $<1 \times 10^{-4}$ | 68 | [1] SHROCK 81 | THEO | $m_{\nu_j}$=10 MeV |
| $<5 \times 10^{-6}$ | 68 | [1] SHROCK 81 | THEO | $m_{\nu_j}$=60 MeV |
| $<1$ | 95 | [2] SIMPSON 81B | | $m_{\nu_j}$=0.1 keV |
| $<4 \times 10^{-3}$ | 95 | [2] SIMPSON 81B | | $m_{\nu_j}$=10 keV |
| $<0.1$ | 68 | [3] SHROCK 80 | THEO | $m_{\nu_j}$=0.1–3 MeV |
| $<1 \times 10^{-5}$ | 68 | [4] SHROCK 80 | THEO | $m_{\nu_j}$=80 MeV |
| $<3 \times 10^{-6}$ | 68 | [4] SHROCK 80 | THEO | $m_{\nu_j}$=160 MeV |

[1] 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.
[2] Application of kink search test to tritium $\beta$ decay Kurie plot.
[3] Application of test to search for kinks in $\beta$ decay Kurie plots.
[4] Analysis of $(K^+ \rightarrow e^+\nu_e)$ spectrum.

### New Experiments to Apply Peak and Kink Search Tests

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

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| **$<1 \times 10^{-7}$** | 90 | [5] 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 | | $m_{\nu_j}$ = 20 MeV |
| $<5 \times 10^{-7}$ | 90 | DELEENER-... 91 | | $m_{\nu_j}$ = 40 MeV |
| $<3 \times 10^{-7}$ | 90 | DELEENER-... 91 | | $m_{\nu_j}$ = 60 MeV |
| $<1 \times 10^{-6}$ | 90 | DELEENER-... 91 | | $m_{\nu_j}$ = 80 MeV |
| $<1 \times 10^{-6}$ | 90 | DELEENER-... 91 | | $m_{\nu_j}$ = 100 MeV |
| $<5 \times 10^{-7}$ | 90 | AZUELOS 86 | CNTR | $m_{\nu_j}$=60 MeV |
| $<2 \times 10^{-7}$ | 90 | AZUELOS 86 | CNTR | $m_{\nu_j}$=80 MeV |
| $<3 \times 10^{-7}$ | 90 | AZUELOS 86 | CNTR | $m_{\nu_j}$=100 MeV |
| $<1 \times 10^{-6}$ | 90 | AZUELOS 86 | CNTR | $m_{\nu_j}$=120 MeV |
| $<2 \times 10^{-7}$ | 90 | AZUELOS 86 | CNTR | $m_{\nu_j}$=130 MeV |
| $<8 \times 10^{-6}$ | | DELEENER-... 86 | CNTR | $m_{\nu_j}$=20 MeV |
| $<4 \times 10^{-7}$ | | DELEENER-... 86 | CNTR | $m_{\nu_j}$=60 MeV |
| $<2 \times 10^{-6}$ | | DELEENER-... 86 | CNTR | $m_{\nu_j}$=100 MeV |
| $<7 \times 10^{-6}$ | | DELEENER-... 86 | CNTR | $m_{\nu_j}$=120 MeV |
| $<1 \times 10^{-4}$ | 90 | [6] BRYMAN 83B | CNTR | $m_{\nu_j}$=5 MeV |
| $<1.5 \times 10^{-6}$ | 90 | BRYMAN 83B | CNTR | $m_{\nu_j}$=53 MeV |
| $<1 \times 10^{-5}$ | 90 | BRYMAN 83B | CNTR | $m_{\nu_j}$=70 MeV |
| $<1 \times 10^{-4}$ | 90 | BRYMAN 83B | CNTR | $m_{\nu_j}$=130 MeV |

[5] 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.
[6] 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).

### Searches for Decays of Massive $\nu$

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

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| $<1 \times 10^{-5}$ | 90 | [7] BARANOV 93 | | $m_{\nu_j}$= 100 MeV |
| $<1 \times 10^{-6}$ | 90 | [7] BARANOV 93 | | $m_{\nu_j}$= 200 MeV |
| $<3 \times 10^{-7}$ | 90 | [7] BARANOV 93 | | $m_{\nu_j}$= 300 MeV |
| $<2 \times 10^{-7}$ | 90 | [7] BARANOV 93 | | $m_{\nu_j}$= 400 MeV |
| $<6.2 \times 10^{-8}$ | 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 | [8] BURCHAT 90 | MRK2 | $m_{\nu_j} <$ 19.6 GeV |
| $<1 \times 10^{-10}$ | 95 | [8] BURCHAT 90 | MRK2 | $m_{\nu_j}$ = 22 GeV |
| $<1 \times 10^{-11}$ | 95 | [8] 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 | $m_{\nu_j}$= 42.7–45.7 GeV |
| $<5 \times 10^{-3}$ | 90 | AKERLOF 88 | HRS | $m_{\nu_j}$=1.8 GeV |
| $<2 \times 10^{-5}$ | 90 | AKERLOF 88 | HRS | $m_{\nu_j}$=4 GeV |
| $<3 \times 10^{-6}$ | 90 | AKERLOF 88 | HRS | $m_{\nu_j}$=6 GeV |
| $<1.2 \times 10^{-7}$ | 90 | BERNARDI 88 | CNTR | $m_{\mu_j}$=100 MeV |
| $<1 \times 10^{-8}$ | 90 | BERNARDI 88 | CNTR | $m_{\mu_j}$=200 MeV |
| $<2.4 \times 10^{-9}$ | 90 | BERNARDI 88 | CNTR | $m_{\mu_j}$=300 MeV |
| $<2.1 \times 10^{-9}$ | 90 | BERNARDI 88 | CNTR | $m_{\mu_j}$=400 MeV |
| $<2 \times 10^{-2}$ | 68 | [9] OBERAUER 87 | | $m_{\nu_j}$=1.5 MeV |
| $<8 \times 10^{-4}$ | 68 | [9] OBERAUER 87 | | $m_{\nu_j}$=4.0 MeV |
| $<8 \times 10^{-3}$ | 90 | BADIER 86 | CNTR | $m_{\nu_j}$=400 MeV |
| $<8 \times 10^{-5}$ | 90 | BADIER 86 | CNTR | $m_{\nu_j}$=1.7 GeV |
| $<8 \times 10^{-8}$ | 90 | BERNARDI 86 | CNTR | $m_{\nu_j}$=100 MeV |
| $<4 \times 10^{-8}$ | 90 | BERNARDI 86 | CNTR | $m_{\nu_j}$=200 MeV |
| $<6 \times 10^{-9}$ | 90 | BERNARDI 86 | CNTR | $m_{\nu_j}$=400 MeV |
| $<3 \times 10^{-5}$ | 90 | DORENBOS... 86 | CNTR | $m_{\nu_j}$=150 MeV |
| $<1 \times 10^{-6}$ | 90 | DORENBOS... 86 | CNTR | $m_{\nu_j}$=500 MeV |
| $<1 \times 10^{-7}$ | 90 | DORENBOS... 86 | CNTR | $m_{\nu_j}$=1.6 GeV |
| $<7 \times 10^{-7}$ | 90 | [10] COOPER-... 85 | HLBC | $m_{\nu_j}$=0.4 GeV |
| $<8 \times 10^{-8}$ | 90 | [10] COOPER-... 85 | HLBC | $m_{\nu_j}$=1.5 GeV |
| $<1 \times 10^{-2}$ | 90 | [11] BERGSMA 83B | CNTR | $m_{\nu_j}$=10 MeV |
| $<1 \times 10^{-5}$ | 90 | [11] BERGSMA 83B | CNTR | $m_{\nu_j}$=110 MeV |
| $<6 \times 10^{-7}$ | 90 | [11] BERGSMA 83B | CNTR | $m_{\nu_j}$=410 MeV |
| $<1 \times 10^{-5}$ | 90 | GRONAU 83 | | $m_{\nu_j}$=160 MeV |
| $<1 \times 10^{-6}$ | 90 | GRONAU 83 | | $m_{\nu_j}$=480 MeV |

[7] 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.
[8] BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.
[9] OBERAUER 87 bounds from search for $\nu \rightarrow \nu' ee$ decay mode using reactor (anti)neutrinos.
[10] COOPER-SARKAR 85 also give limits based on model-dependent assumptions for $\nu_\tau$ flux. We do not list these. Note that for this bound to be nontrivial, $j$ is not equal to 3, i.e. $\nu_j$ cannot be the dominant mass eigenstate in $\nu_\tau$ 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.
[11] BERGSMA 83B also quote limits on $|U_{13}|^2$ where the index 3 refers to the mass eigenstate dominantly coupled to the $\tau$. 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.

### Kink Search in Nuclear $\beta$ Decay

| VALUE (units $10^{-3}$) | CL% | $m_{\nu_j}$ (keV) | ISOTOPE | METHOD | DOCUMENT ID |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $<$ 1.9 | 90 | 17 | $^{35}$S | Si+guide field | [12] ABELE 93 |
| 0.3 $\pm$ 1.5 $\pm$ 0.8 | | 17 | $^{35}$S | Mag spect | [13] BERMAN 93 |
| $<$ 5 | 95 | 17 | $^{71}$Ge | IBEC; $\gamma$ det | [14] DIGREGORIO 93 |
| | | | $^{35}$S | Si(Li) det | [15] HIME 93 |
| $<$ 2.8 | 99 | 17 | $^{3}$H | Prop chamber | [16] KALBFLEISCH 93 |
| $<$ 1 | 99 | 14.4–15.2 | $^{3}$H | Prop chamber | [16] KALBFLEISCH 93 |
| $<$ 0.7 | 99 | 16.3–16.6 | $^{3}$H | Prop chamber | [16] KALBFLEISCH 93 |
| $<$ 2 | 95 | 13–40 | $^{35}$S | Si(Li) | [17] MORTARA 93 |
| 0.73 | 95 | 17 | $^{63}$Ni | Mag spect | OHSHIMA 93 |
| 1.5 | 95 | 10.5–25.0 | $^{63}$Ni | Mag spect | [18] OHSHIMA 93 |
| $<$ 6 | 95 | 5–25 | $^{55}$Fe | IBEC in Ge | [19] WIETFELDT 93 |
| $<$ 2 | 95 | 17 | $^{55}$Fe | IBEC in Ge | [19] WIETFELDT 93 |
| $<$ 4 | 99 | 17 | $^{3}$H | Prop chamber | [20] BAHRAN 92 |
| $<$ 2 | 90 | 17 | $^{35}$S | Mag spect. | [21] CHEN 92 |
| $<$ 0.95 | 95 | 17 | $^{63}$Ni | Mag spect | [22] KAWAKAMI 92 |
| $<$ 1.0 | 95 | 10–24 | $^{63}$Ni | Mag spect | KAWAKAMI 92 |
| 8.4 $\pm$ 0.6 $\pm$ 0.5 | | 17.0 $\pm$ 0.4 | $^{35}$S | Si(Li) det | HIME 91 |
| 9.9 $\pm$ 1.2 $\pm$ 1.8 | | 16.75 $\pm$ 0.35 $\pm$ 0.15 | $^{63}$Ni | Solid state det | HIME 91B |
| 14.0 $\pm$ 4.5 $\pm$ 1.4 | | 17 $\pm$ 2 | $^{14}$C | $^{14}$C in HPGe | [23] SUR 91 |
| 16 $\pm$ 7 | | $17.2^{+1.9}_{-1.1}$ | $^{71}$Ge | $\gamma$ in Ge | [24] ZLIMEN 91 |
| | | 17 | | THEO | [25] DRUKAREV 89 |
| 6 to 16 | | 16.9 $\pm$ 0.4 | $^{3}$H | In HPGe | HIME 89 |
| 5 to 18 | | 17.1 $\pm$ 0.2 | $^{3}$H | In Si(Li) | [26] HIME 89 |
| 7.3 $\pm$ 0.9 $\pm$ 0.6 | | 16.9 $\pm$ 0.4 | $^{35}$S | Si(Li) | [27] SIMPSON 89 |
| $<$ 7.4 | 99.7 | 16.4–17.4 | $^{55}$Fe | IBEC; $\gamma$ det | [28] ZLIMEN 88 |
| $<$ 3 | 90 | 17 | $^{63}$Ni | Mag spect | [29] HETHERING... 87 |
| $<$ 10 | 90 | 16–35 | $^{125}$I | IBEC; $\gamma$ det | [30] BORGE 86 |
| 10 to 20 | | 17 | | RVUE | [31] SIMPSON 86 |
| $<$ 4 | 99 | 17 | $^{35}$S | Mag spect | ALTZITZOG... 85 |
| $<$ 7.5 | 99 | 5–50 | $^{35}$S | Mag spect | ALTZITZOG... 85 |
| $<$ 8 | 90 | 80 | $^{35}$S | Mag spect | [32] 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 |