| | | | | | | |
|---|---|---|---|---|---|---|
| $<$ 45 | 90 | 4 | $^{35}$S | Mag spect | APALIKOV | 85 |
| $<$ 6 | 90 | 17 | $^{35}$S | Si(Li) | DATAR | 85 |
| $<$ 10 | 90 | 5–30 | $^{35}$S | Si(Li) | DATAR | 85 |
| $<$ 3.0 | 90 | 5–50 | | Mag spect | MARKEY | 85 |
| $<$ 2.5 | 90 | 17 | | 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 |
| 30 $\pm$10 | | 17.1 $\pm$ 0.2 | $^{3}$H | In Si(Li) | [33] SIMPSON | 85 |
| $<$ 25 | 90 | 30 | $^{64}$Cu | Mag spect | [34] SCHRECK... | 83 |
| $<$ 4 | 90 | 140 | $^{64}$Cu | Mag spect | [34] SCHRECK... | 83 |
| $<$ 8 | 90 | 440 | $^{64}$Cu | Mag spect | [34] SCHRECK... | 83 |
| $<$100 | 90 | 0.1–3000 | | THEO | [35] SHROCK | 80 |
| | | | $^{3}$H | Prop. cntr | [36] CONWAY | 59 |

[12] ABELE 93: "It appears to us that we have succeeded in isolating experimentally the very same effect that was proposed in HIME 93 to resolve the '17 keV condrum'."

[13] BERMAN 93 uses an iron-free intermediate-image magnetic spectrometer to measure $^{35}$S $\beta$ 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.

[14] DIGREGORIO 93 is an experiment on $^{71}$Ge IBEC to search for a possible admixture of a massive neutrino. The authors state that their results "exclude the presence of a massive component of 17.2 $\pm$ 1.3 $\pm$ 1.1 keV and (1.6 $\pm$ 0.6)% mixing fraction claimed by [ZLIMEN 91] for this same nucleus, at the 99.0% confidence level."

[15] HIME 93 is a reanalysis of HIME 91 data and states that the effect, which was previously attributed to the emission of a massive neutrino, can be explained by electron energy loss without the need for any neutrino mass or mixing.

[16] 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 $m_{\nu_j}$ 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 and BAHRAN 93B, on theoretical aspects of beta spectra and fitting methods for heavy neutrinos.

[17] 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."

[18] 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. Using the Particle Data Group recipe gives the slightly more conservative 95%CL of $0.80 \times 10^{-3}$. An earlier report of this experiment was given in KAWAKAMI 92.

[19] 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 particular, a 17 keV neutrino with $\sin^2\theta$ ($|U_{1j}|^2$ in our notation) = 0.008 is excluded at the 7$\sigma$ 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.

[20] BAHRAN 92 minor errors corrected in BAHRAN 92B.

[21] 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 6$\sigma$ 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 $\nu_e$; see their Fig. 4 for a graphical set of measured values of $|U_{1j}|^2$ for various hypothetical values of $m_{\nu_j}$ in this range.

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

[23] SUR 91 reports an LBL experiment using a solid state Ge crystal grown with $^{14}$C inside. In a conference report (NORMAN 91), the authors also report indications for the emission of a 17 keV neutrino in the $^{55}$Fe inner bremsstrahlung transition: $m_{\nu_j}$ = 21 $\pm$ 2 keV with $|U_{1j}|^2$ = 0.0085 $\pm$ 0.0045.

[24] ZLIMEN 91 used a HPGe detector to observe the inner bremsstrahlung electron capture transition of $^{71}$Ge in an external source. Reported errors on both parameters are given as 95%CL limits, which in the case of normal distributions corresponds to 1.96$\sigma$.

[25] DRUKAREV 89 claims that taking into account screening effects can explain Simpson's claims without invoking a massive neutrino or other unconventional physics. A similar criticism concerning screening corrections had been made by LINDHARD 86.

[26] HIME 89 corrects the analysis of the data of SIMPSON 85 for screening effects as suggested by LINDHARD 86, giving a smaller range for $|U_{1j}|^2$, as cited above. This value should therefore replace that given in SIMPSON 85, which has been retracted.

[27] SIMPSON 89 and HIME 89 report kinks due to the emission of a massive neutrino in $^{35}$S and $^{3}$H$\beta$ decays, respectively.

[28] ZLIMEN 88 report an experiment on $^{55}$Fe, observing internal bremsstrahlung in electron capture (IBEC). For a contemporary review of IBEC, see LOGAN 89.

[29] HETHERINGTON 87 reports no evidence for any massive neutrino signal for $m_{\nu_j}$ in the range from 4 to 40 keV, and, in particular, set the upper limit cited above on $|U_{1j}|^2$ for a hypothetical 17 keV neutrino.

[30] 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.

[31] SIMPSON 86 is a reanalysis of the OHI 85 data and claims that these data show evidence of heavy neutrino emission with $m_{\nu_j}$ = 17 keV and $|U_{1j}|^2$ = from 0.01 to 0.02, consistent with the earlier reported observation by SIMPSON 85. This conclusion strongly disagrees with the conclusion reached by OHI 85 from their analysis of their own data. SIMPSON 86 also states that "a similar threshold effect (due to supposed heavy neutrino emission) is seen in several of the other published $^{35}$S experiments as well."

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

[33] SIMPSON 85. See footnotes on SIMPSON 89 and SIMPSON 86, as well as comments by HAXTON 85, KALBFLEISCH 85, EMAN 86, LINDHARD 86, DRUKAREV 86, and further discussion by SIMPSON 89 and HIME 89.

[34] SCHRECKENBACH 83 is a combined measurement of the $\beta^+$ and $\beta^-$ spectrum.

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

[36] CONWAY 59 first reported a spectral excess of about 1% at electron kinetic energy of 1 keV in $^{3}$H$\beta$ decay, but did not interpret it as the emission of a massive neutrino. Indeed, no searches for masses admixed neutrinos were performed prior to 1980; cf. SHROCK 80. This spectral excess was again observed in SIMPSON 85, apparently without knowledge of the CONWAY 59 finding. Spectral excesses in this kinetic energy region were also reported in HAMILTON 58 and JOHNSON 58, and in other references cited therein.

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

### Application of Peak Search Test to Existing Data

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $<6 \times 10^{-6}$ | 95 | [37] ASANO | 81 | | $m_{\nu_j}$=240 MeV |
| $<5 \times 10^{-7}$ | 95 | [37] ASANO | 81 | | $m_{\nu_j}$=280 MeV |
| $<6 \times 10^{-6}$ | 95 | [37] ASANO | 81 | | $m_{\nu_j}$=300 MeV |
| $<3 \times 10^{-2}$ | 95 | [38] SHROCK | 81 | THEO | $m_{\nu_j}$=7 MeV |
| $<1 \times 10^{-2}$ | 95 | [38] SHROCK | 81 | THEO | $m_{\nu_j}$=13 MeV |
| $<1 \times 10^{-4}$ | 68 | [38] SHROCK | 81 | THEO | $m_{\nu_j}$=13 MeV |
| $<3 \times 10^{-5}$ | 68 | [38] SHROCK | 81 | THEO | $m_{\nu_j}$=33 MeV |
| $<6 \times 10^{-3}$ | 68 | [39] SHROCK | 81 | THEO | $m_{\nu_j}$=80 MeV |
| $<5 \times 10^{-3}$ | 68 | [39] SHROCK | 81 | THEO | $m_{\nu_j}$=120 MeV |
| $<5 \times 10^{-2}$ | 95 | [38] SHROCK | 80 | THEO | $m_{\nu_j}$=4–6 MeV |

[37] Analysis of experiment on $K^+ \rightarrow \mu^+ \nu_\mu \nu_X \overline{\nu}_X$ decay.

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

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

### Application of Peak Search Test to New Experiments

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

| VALUE | CL% | DOCUMENT ID | | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| $<2 \times 10^{-2}$ | 90 | DAUM | 87 | $m_{\nu_j}$=1 MeV |
| $<1 \times 10^{-3}$ | 90 | DAUM | 87 | $m_{\nu_j}$=2 MeV |
| $<6 \times 10^{-5}$ | 90 | DAUM | 87 | 3 MeV $< m_{\nu_j} <$ 19.5 MeV |
| $<3 \times 10^{-2}$ | 90 | [40] MINEHART | 84 | $m_{\nu_j}$=2 MeV |
| $<1 \times 10^{-3}$ | 90 | [40] MINEHART | 84 | $m_{\nu_j}$=4 MeV |
| $<3 \times 10^{-4}$ | 90 | [40] MINEHART | 84 | $m_{\nu_j}$=10 MeV |
| $<5 \times 10^{-6}$ | 90 | [41] HAYANO | 82 | $m_{\nu_j}$=330 MeV |
| $<1 \times 10^{-4}$ | 90 | [41] HAYANO | 82 | $m_{\nu_j}$=70 MeV |
| $<9 \times 10^{-7}$ | 90 | [41] HAYANO | 82 | $m_{\nu_j}$=250 MeV |
| $<1 \times 10^{-1}$ | 90 | [40] ABELA | 81 | $m_{\nu_j}$=4 MeV |
| $<7 \times 10^{-5}$ | 90 | [40] ABELA | 81 | $m_{\nu_j}$=10.5 MeV |
| $<2 \times 10^{-4}$ | 90 | [40] ABELA | 81 | $m_{\nu_j}$=11.5 MeV |
| $<2 \times 10^{-5}$ | 90 | [40] ABELA | 81 | $m_{\nu_j}$=16–30 MeV |
| $<2 \times 10^{-5}$ | 95 | [41] ASANO | 81 | $m_{\nu_j}$=170 MeV |
| $<3 \times 10^{-6}$ | 95 | [41] ASANO | 81 | $m_{\nu_j}$=210 MeV |
| $<3 \times 10^{-6}$ | 95 | [41] ASANO | 81 | $m_{\nu_j}$=230 MeV |
| $<1 \times 10^{-2}$ | 95 | [40] CALAPRICE | 81 | $m_{\nu_j}$=7 MeV |
| $<3 \times 10^{-3}$ | 95 | [40] CALAPRICE | 81 | $m_{\nu_j}$=33 MeV |

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

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