

# Heavy Neutral Leptons, Searches for

## (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	<sup>1</sup> ADEVA	90S	L3 Dirac
>34.8	95	<sup>1</sup> ADEVA	90S	L3 Majorana
>42.7	95	DECAMP	90F	ALEP Dirac

<sup>1</sup>ADEVA 90S limits for the heavy neutrino apply if the mixing with the charged leptons satisfies  $|U_{1j}|^2 + |U_{2j}|^2 + |U_{3j}|^2 > 6.2 \times 10^{-8}$  at  $m_{L0} = 20$  GeV and  $> 5.1 \times 10^{-10}$  for  $m_{L0} = 40$  GeV.

### Heavy Neutral Lepton MASS LIMITS

Limits apply only to heavy lepton type given in comment at right of data Listings.

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
>101.3	95	ACHARD	01B	L3 Dirac coupling to $e$
>101.5	95	ACHARD	01B	L3 Dirac coupling to $\mu$
> 90.3	95	ACHARD	01B	L3 Dirac coupling to $\tau$
> 89.5	95	ACHARD	01B	L3 Majorana coupling to $e$
> 90.7	95	ACHARD	01B	L3 Majorana coupling to $\mu$
> 80.5	95	ACHARD	01B	L3 Majorana coupling to $\tau$

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

> 76.0	95	ABBIENDI	00i	OPAL Majorana, coupling to $e$
> 88.0	95	ABBIENDI	00i	OPAL Dirac, coupling to $e$
> 76.0	95	ABBIENDI	00i	OPAL Majorana, coupling to $\mu$
> 88.1	95	ABBIENDI	00i	OPAL Dirac, coupling to $\mu$
> 53.8	95	ABBIENDI	00i	OPAL Majorana, coupling to $\tau$
> 71.1	95	ABBIENDI	00i	OPAL Dirac, coupling to $\tau$
> 76.5	95	ABREU	990	DLPH Dirac coupling to $e$
> 79.5	95	ABREU	990	DLPH Dirac coupling to $\mu$
> 60.5	95	ABREU	990	DLPH Dirac coupling to $\tau$
> 63	95	<sup>2,3</sup> BUSKULIC	96S	ALEP Dirac
> 54.3	95	<sup>2,4</sup> BUSKULIC	96S	ALEP Majorana

<sup>2</sup> 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  $10^{-10}$ .

<sup>3</sup> BUSKULIC 96S limit for mixing with  $\tau$ . Mass is  $> 63.6$  GeV for mixing with  $e$  or  $\mu$ .

<sup>4</sup> BUSKULIC 96S limit for mixing with  $\tau$ . Mass is  $> 55.2$  GeV for mixing with  $e$  or  $\mu$ .

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

<u>VALUE (GeV)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
none 60–115		<sup>5</sup> FARGION	95	ASTR Dirac
none 9.2–2000		<sup>6</sup> GARCIA	95	COSM Nucleosynthesis
none 26–4700		<sup>6</sup> BECK	94	COSM Dirac
none 6 – hundreds		<sup>7,8</sup> MORI	92B	KAM2 Dirac neutrino
none 24 – hundreds		<sup>7,8</sup> MORI	92B	KAM2 Majorana neutrino
none 10–2400	90	<sup>9</sup> REUSSER	91	CNTR HPGe search
none 3–100	90	SATO	91	KAM2 Kamiokande II
		<sup>10</sup> ENQVIST	89	COSM
none 12–1400		<sup>6</sup> CALDWELL	88	COSM Dirac $\nu$
none 4–16	90	<sup>6,7</sup> OLIVE	88	COSM Dirac $\nu$
none 4–35	90	OLIVE	88	COSM Majorana $\nu$
$>4.2$ to $4.7$		SREDNICKI	88	COSM Dirac $\nu$
$>5.3$ to $7.4$		SREDNICKI	88	COSM Majorana $\nu$
none 20–1000	95	<sup>6</sup> AHLEN	87	COSM Dirac $\nu$
$>4.1$		GRIEST	87	COSM Dirac $\nu$

<sup>5</sup> FARGION 95 bound is sensitive to assumed  $\nu$  concentration in the Galaxy. See also KONOPLICH 94.

<sup>6</sup> These results assume that neutrinos make up dark matter in the galactic halo.

<sup>7</sup> Limits based on annihilations in the sun and are due to an absence of high energy neutrinos detected in underground experiments.

<sup>8</sup> MORI 92B results assume that neutrinos make up dark matter in the galactic halo. Limits based on annihilations in earth are also given.

<sup>9</sup> REUSSER 91 uses existing  $\beta\beta$  detector (see FISHER 89) to search for CDM Dirac neutrinos.

<sup>10</sup> ENQVIST 89 argue that there is no cosmological upper bound on heavy neutrinos.

———— **(B) Other Bounds from Nuclear and Particle Decays** ————

———— **Limits on  $|U_{ex}|^2$  as Function of  $m_{\nu_x}$**  ————

**Peak and kink search tests**

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

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$<1 \times 10^{-7}$	90	<sup>11</sup> BRITTON	92B	CNTR 50 MeV $< m_{\nu_x} < 130$ MeV

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

<5 × 10 <sup>-6</sup>	90	DELEENER-...	91		$m_{\nu_x} = 20$ MeV
<5 × 10 <sup>-7</sup>	90	DELEENER-...	91		$m_{\nu_x} = 40$ MeV
<3 × 10 <sup>-7</sup>	90	DELEENER-...	91		$m_{\nu_x} = 60$ MeV
<1 × 10 <sup>-6</sup>	90	DELEENER-...	91		$m_{\nu_x} = 80$ MeV
<1 × 10 <sup>-6</sup>	90	DELEENER-...	91		$m_{\nu_x} = 100$ MeV
<5 × 10 <sup>-7</sup>	90	AZUELOS	86	CNTR	$m_{\nu_x} = 60$ MeV
<2 × 10 <sup>-7</sup>	90	AZUELOS	86	CNTR	$m_{\nu_x} = 80$ MeV
<3 × 10 <sup>-7</sup>	90	AZUELOS	86	CNTR	$m_{\nu_x} = 100$ MeV
<1 × 10 <sup>-6</sup>	90	AZUELOS	86	CNTR	$m_{\nu_x} = 120$ MeV
<2 × 10 <sup>-7</sup>	90	AZUELOS	86	CNTR	$m_{\nu_x} = 130$ MeV
<1 × 10 <sup>-4</sup>	90	<sup>12</sup> BRYMAN	83B	CNTR	$m_{\nu_x} = 5$ MeV
<1.5 × 10 <sup>-6</sup>	90	BRYMAN	83B	CNTR	$m_{\nu_x} = 53$ MeV
<1 × 10 <sup>-5</sup>	90	BRYMAN	83B	CNTR	$m_{\nu_x} = 70$ MeV
<1 × 10 <sup>-4</sup>	90	BRYMAN	83B	CNTR	$m_{\nu_x} = 130$ MeV
<1 × 10 <sup>-4</sup>	68	<sup>13</sup> SHROCK	81	THEO	$m_{\nu_x} = 10$ MeV
<5 × 10 <sup>-6</sup>	68	<sup>13</sup> SHROCK	81	THEO	$m_{\nu_x} = 60$ MeV
<1 × 10 <sup>-5</sup>	68	<sup>14</sup> SHROCK	80	THEO	$m_{\nu_x} = 80$ MeV
<3 × 10 <sup>-6</sup>	68	<sup>14</sup> SHROCK	80	THEO	$m_{\nu_x} = 160$ MeV

<sup>11</sup>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.

<sup>12</sup>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).

<sup>13</sup>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.

<sup>14</sup>Analysis of  $(K^+ \rightarrow e^+ \nu_e)$  spectrum.

### Kink search in nuclear $\beta$ 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)) and in the 1998 edition (The European Physical Journal **C3** 1 (1998)). We list below only the best limits on  $|U_{ex}|^2$  for each  $m_{\nu_x}$ . See WIETFELDT 96 for a comprehensive review.

VALUE (units 10 <sup>-3</sup> )	CL%	$m_{\nu_j}$ (keV)	ISOTOPE	METHOD	DOCUMENT ID
< 4–20	90	700–3500	<sup>38</sup> mK	Trap	<sup>15</sup> TRINCZEK 03
< 9–116	95	1–0.1	<sup>187</sup> Re	cryog.	<sup>16</sup> GALEAZZI 01
< 1	95	10–90	<sup>35</sup> S	Mag spect	<sup>17</sup> HOLZSCHUH 00
< 4	95	14–17	<sup>241</sup> Pu	Electrostatic spec	<sup>18</sup> DRAGOUN 99
< 1	95	4–30	<sup>63</sup> Ni	Mag spect	<sup>19</sup> HOLZSCHUH 99
< 10–40	90	370–640	<sup>37</sup> Ar	EC ion recoil	<sup>20</sup> HINDI 98
< 10	95	1	<sup>3</sup> H	SPEC	<sup>21</sup> HIDDEMANN 95

< 6	95	2	$^3\text{H}$	SPEC	$^{21}$ HIDDEMANN	95
< 2	95	3	$^3\text{H}$	SPEC	$^{21}$ HIDDEMANN	95
< 0.7	99	16.3–16.6	$^3\text{H}$	Prop chamber	$^{22}$ KALBFLEISCH	93
< 2	95	13–40	$^{35}\text{S}$	Si(Li)	$^{23}$ MORTARA	93
< 0.73	95	17	$^{63}\text{Ni}$	Mag spect	OHSHIMA	93
< 1.0	95	10–24	$^{63}\text{Ni}$	Mag spect	KAWAKAMI	92
< 0.9–2.5	90	1200–6800	$^{20}\text{F}$	beta spectrum	$^{24}$ DEUTSCH	90
< 8	90	80	$^{35}\text{S}$	Mag spect	$^{25}$ APALIKOV	85
< 1.5	90	60	$^{35}\text{S}$	Mag spect	APALIKOV	85
< 3.0	90	5–50		Mag spect	MARKEY	85
< 0.62	90	48	$^{35}\text{S}$	Si(Li)	OHI	85
< 0.90	90	30	$^{35}\text{S}$	Si(Li)	OHI	85
< 4	90	140	$^{64}\text{Cu}$	Mag spect	$^{26}$ SCHRECK...	83
< 8	90	440	$^{64}\text{Cu}$	Mag spect	$^{26}$ SCHRECK...	83
<100	90	0.1–3000		THEO	$^{27}$ SHROCK	80
< 0.1	68	80		THEO	$^{28}$ SHROCK	80

<sup>15</sup> TRINCZEK 03 is a search for admixture of heavy neutrino to  $\nu_e$ , in contrast to  $\bar{\nu}_e$  used in many other searches. Full kinematic reconstruction of the neutrino momentum by use of a magneto optical trap.

<sup>16</sup> GALEAZZI 01 use an cryogenic microcalorimeter to search for mass 50–1000 eV neutrino admixtures using the  $^{187}\text{Re}$  beta spectrum with 2.4 keV endpoint. They derive limits for the admixture of heavy neutrinos, ranging from  $9 \times 10^{-3}$  for mass 1 keV to 0.116 for mass 100 eV. This is a significant improvement with respect to HIDDEMANN 95, especially for masses below  $\sim 500$  MeV, where the limit is about a factor of  $\sim 2$  higher.

<sup>17</sup> HOLZSCHUH 00 use an iron-free  $\beta$  spectrometer to measure the  $^{35}\text{S}$   $\beta$  decay spectrum. An analysis of the spectrum in the energy range 56–173 keV is used to derive limits for the admixture of heavy neutrinos. This extends the range of neutrino masses explored in HOLZSCHUH 99.

<sup>18</sup> DRAGON 99 analyze the  $\beta$  decay spectrum of  $^{241}\text{Pu}$  in the energy range 0.2–9.2 keV to derive limits for the admixture of heavy neutrinos. It is not competitive with HOLZSCHUH 99.

<sup>19</sup> HOLZSCHUH 99 use an iron-free  $\beta$  spectrometer to measure the  $^{63}\text{Ni}$   $\beta$  decay spectrum. An analysis of the spectrum in the energy range 33–67.8 keV is used to derive limits for the admixture of heavy neutrinos.

<sup>20</sup> HINDI 98 obtain a limit on heavy neutrino admixture from EC decay of  $^{37}\text{Ar}$  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  $|U_{ex}|^2$  of  $\approx 3\%$  for  $m_{\nu_x}=500$  keV, 1% for  $m_{\nu_x}=550$  keV, 2% for  $m_{\nu_x}=600$  keV, and 4% for  $m_x=650$  keV. Their reported limits for  $m_{\nu_x} \leq 450$  keV are inferior to the limits of SCHRECKENBACH 83.

<sup>21</sup> In the beta spectrum from tritium  $\beta$  decay nonvanishing or mixed  $m_{\bar{\nu}_1}$  state in the mass region 0.01–4 keV. For  $m_{\nu_x} < 1$  keV, their upper limit on  $|U_{ex}|^2$  becomes less

<sup>22</sup> KALBFLEISCH 93 extends the 17 keV neutrino search of BAHRAN 92, using an improved proportional chamber to which a small amount of  $^3\text{H}$  is added. Systematics are significantly reduced, allowing for an improved upper limit. The authors give a 99% confidence limit on  $|U_{ex}|^2$  as a function of  $m_{\nu_x}$  in the range from 13.5 keV to 17.5 keV. See also the related papers BAHRAN 93, BAHRAN 93B, and BAHRAN 95 on theoretical aspects of beta spectra and fitting methods for heavy neutrinos.

<sup>23</sup> 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  $^{35}\text{S}$  and  $^{14}\text{C}$ , which artificially produces a distortion in the beta spectrum similar to that expected from the massive neutrino.”

- <sup>24</sup> DEUTSCH 90 search for emission of heavy  $\bar{\nu}_e$  in super-allowed beta decay of  $^{20}\text{F}$  by spectral analysis of the electrons.  
<sup>25</sup> 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%.  
<sup>26</sup> SCHRECKENBACH 83 is a combined measurement of the  $\beta^+$  and  $\beta^-$  spectrum.  
<sup>27</sup> SHROCK 80 was a retroactive analysis of data on several superallowed  $\beta$  decays to search for kinks in the Kurie plot.  
<sup>28</sup> Application of test to search for kinks in  $\beta$  decay Kurie plots.

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

Limits on  $|U_{eX}|^2$  as function of  $m_{\nu_X}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$<1.6 \times 10^{-4}$	90	<sup>29</sup> BACK	03A CNTR	$m_{\nu_X} = 4 \text{ MeV}$
$<4.5 \times 10^{-5}$	90	<sup>29</sup> BACK	03A CNTR	$m_{\nu_X} = 7 \text{ MeV}$
$<3.8 \times 10^{-5}$	90	<sup>29</sup> BACK	03A CNTR	$m_{\nu_X} = 10 \text{ MeV}$
$<1.5 \times 10^{-3}$	95	ACHARD	01 L3	$m_{\nu_X} = 80 \text{ GeV}$
$<2 \times 10^{-2}$	95	ACHARD	01 L3	$m_{\nu_X} = 175 \text{ GeV}$
$<0.3$	95	ACHARD	01 L3	$m_{\nu_X} = 200 \text{ GeV}$
$<4 \times 10^{-3}$	95	ACCIARRI	99K L3	$m_{\nu_X} = 80 \text{ GeV}$
$<5 \times 10^{-2}$	95	ACCIARRI	99K L3	$m_{\nu_X} = 175 \text{ GeV}$
$<2 \times 10^{-5}$	95	<sup>30</sup> ABREU	97I DLPH	$m_{\nu_X} = 6 \text{ GeV}$
$<3 \times 10^{-5}$	95	<sup>30</sup> ABREU	97I DLPH	$m_{\nu_X} = 50 \text{ GeV}$
$<1.8 \times 10^{-3}$	90	<sup>31</sup> HAGNER	95 MWPC	$m_{\nu_h} = 1.5 \text{ MeV}$
$<2.5 \times 10^{-4}$	90	<sup>31</sup> HAGNER	95 MWPC	$m_{\nu_h} = 4 \text{ MeV}$
$<4.2 \times 10^{-3}$	90	<sup>31</sup> HAGNER	95 MWPC	$m_{\nu_h} = 9 \text{ MeV}$
$<1 \times 10^{-5}$	90	<sup>32</sup> BARANOV	93	$m_{\nu_X} = 100 \text{ MeV}$
$<1 \times 10^{-6}$	90	<sup>32</sup> BARANOV	93	$m_{\nu_X} = 200 \text{ MeV}$
$<3 \times 10^{-7}$	90	<sup>32</sup> BARANOV	93	$m_{\nu_X} = 300 \text{ MeV}$
$<2 \times 10^{-7}$	90	<sup>32</sup> BARANOV	93	$m_{\nu_X} = 400 \text{ MeV}$
$<6.2 \times 10^{-8}$	95	ADEVA	90S L3	$m_{\nu_X} = 20 \text{ GeV}$
$<5.1 \times 10^{-10}$	95	ADEVA	90S L3	$m_{\nu_X} = 40 \text{ GeV}$
all values ruled out	95	<sup>33</sup> BURCHAT	90 MRK2	$m_{\nu_X} < 19.6 \text{ GeV}$
$<1 \times 10^{-10}$	95	<sup>33</sup> BURCHAT	90 MRK2	$m_{\nu_X} = 22 \text{ GeV}$
$<1 \times 10^{-11}$	95	<sup>33</sup> BURCHAT	90 MRK2	$m_{\nu_X} = 41 \text{ GeV}$
all values ruled out	95	DECAMP	90F ALEP	$m_{\nu_X} = 25.0\text{--}42.7 \text{ GeV}$
$<1 \times 10^{-13}$	95	DECAMP	90F ALEP	$m_{\nu_X} = 42.7\text{--}45.7 \text{ GeV}$
$<5 \times 10^{-3}$	90	AKERLOF	88 HRS	$m_{\nu_X} = 1.8 \text{ GeV}$
$<2 \times 10^{-5}$	90	AKERLOF	88 HRS	$m_{\nu_X} = 4 \text{ GeV}$
$<3 \times 10^{-6}$	90	AKERLOF	88 HRS	$m_{\nu_X} = 6 \text{ GeV}$
$<1.2 \times 10^{-7}$	90	BERNARDI	88 CNTR	$m_{\nu_X} = 100 \text{ MeV}$
$<1 \times 10^{-8}$	90	BERNARDI	88 CNTR	$m_{\nu_X} = 200 \text{ MeV}$
$<2.4 \times 10^{-9}$	90	BERNARDI	88 CNTR	$m_{\nu_X} = 300 \text{ MeV}$

$<2.1 \times 10^{-9}$	90	BERNARDI	88	CNTR	$m_{\nu_x} = 400$ MeV
$<2 \times 10^{-2}$	68	<sup>34</sup> OBERAUER	87		$m_{\nu_x} = 1.5$ MeV
$<8 \times 10^{-4}$	68	<sup>34</sup> OBERAUER	87		$m_{\nu_x} = 4.0$ MeV
$<8 \times 10^{-3}$	90	BADIER	86	CNTR	$m_{\nu_x} = 400$ MeV
$<8 \times 10^{-5}$	90	BADIER	86	CNTR	$m_{\nu_x} = 1.7$ GeV
$<8 \times 10^{-8}$	90	BERNARDI	86	CNTR	$m_{\nu_x} = 100$ MeV
$<4 \times 10^{-8}$	90	BERNARDI	86	CNTR	$m_{\nu_x} = 200$ MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR	$m_{\nu_x} = 400$ MeV
$<3 \times 10^{-5}$	90	DORENBOS...	86	CNTR	$m_{\nu_x} = 150$ MeV
$<1 \times 10^{-6}$	90	DORENBOS...	86	CNTR	$m_{\nu_x} = 500$ MeV
$<1 \times 10^{-7}$	90	DORENBOS...	86	CNTR	$m_{\nu_x} = 1.6$ GeV
$<7 \times 10^{-7}$	90	<sup>35</sup> COOPER-...	85	HLBC	$m_{\nu_x} = 0.4$ GeV
$<8 \times 10^{-8}$	90	<sup>35</sup> COOPER-...	85	HLBC	$m_{\nu_x} = 1.5$ GeV
$<1 \times 10^{-2}$	90	<sup>36</sup> BERGSMA	83B	CNTR	$m_{\nu_x} = 10$ MeV
$<1 \times 10^{-5}$	90	<sup>36</sup> BERGSMA	83B	CNTR	$m_{\nu_x} = 110$ MeV
$<6 \times 10^{-7}$	90	<sup>36</sup> BERGSMA	83B	CNTR	$m_{\nu_x} = 410$ MeV
$<1 \times 10^{-5}$	90	GRONAU	83		$m_{\nu_x} = 160$ MeV
$<1 \times 10^{-6}$	90	GRONAU	83		$m_{\nu_x} = 480$ MeV

<sup>29</sup> BACK 03A searched for heavy neutrinos emitted from  $^8\text{B}$  decay in the Sun using the decay  $\nu_h \rightarrow \nu_e e^+ e^-$  in the Counting Test Facility (the prototype of the Borexino detector) and obtained limits on heavy neutrino admixture for the  $\nu_h$  mass range 1.1–12 MeV.

<sup>30</sup> ABREU 97i long-lived  $\nu_x$  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.

<sup>31</sup> HAGNER 95 obtain limits on heavy neutrino admixture from the decay  $\nu_h \rightarrow \nu_e e^+ e^-$  at a nuclear reactor for the  $\nu_h$  mass range 2–9 MeV.

<sup>32</sup> 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.

<sup>33</sup> BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89c, and WENDT 87.

<sup>34</sup> OBERAUER 87 bounds from search for  $\nu \rightarrow \nu' e e$  decay mode using reactor (anti)neutrinos.

<sup>35</sup> 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,  $x$  is not equal to 3, i.e.  $\nu_x$  cannot be the dominant mass eigenstate in  $\nu_\tau$  since  $m_{\nu_3} < 70$  MeV (ALBRECHT 85i). Also, of course,  $x$  is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

<sup>36</sup> BERGSMA 83B also quote limits on  $|U_{e3}|^2$  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.

————— Limits on Coupling of  $\mu$  to  $\nu_x$  as Function of  $m_{\nu_x}$  —————

**Peak search test**

Limits on  $B(\pi$  (or  $K$ )  $\rightarrow \mu\nu_x$ ).

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		37 ASTIER	02 NOMD	$\pi \rightarrow \mu X$ for $m_X=33.9$ MeV
$<6.0 \times 10^{-10}$	95	38 DAUM	00 CNTR	$\pi \rightarrow \mu X$ for $m_X=33.9$ MeV
		39 FORMAGGIO	00 CNTR	$\pi \rightarrow \mu X$ for $m_X=33.9$ MeV
$<0.22$	90	40 ASSAMAGAN	98 SILI	$m_{\nu_x} = 0.53$ MeV
$<0.029$	90	40 ASSAMAGAN	98 SILI	$m_{\nu_x} = 0.75$ MeV
$<0.016$	90	40 ASSAMAGAN	98 SILI	$m_{\nu_x} = 1.0$ MeV
$<4-6 \times 10^{-5}$		41 BRYMAN	96 CNTR	$m_{\nu_x} = 30-33.91$ MeV
$\sim 1 \times 10^{-16}$		42 ARMBRUSTER	95 KARM	$m_{\nu_x} = 33.9$ MeV
$<4 \times 10^{-7}$	95	43 BILGER	95 LEPS	$m_{\overline{\nu}_x} = 33.9$ MeV
$<7 \times 10^{-8}$	95	43 BILGER	95 LEPS	$m_{\nu_x} = 33.9$ MeV
$<2.6 \times 10^{-8}$	95	43 DAUM	95B TOF	$m_{\nu_x} = 33.9$ MeV
$<2 \times 10^{-2}$	90	DAUM	87	$m_{\nu_x} = 1$ MeV
$<1 \times 10^{-3}$	90	DAUM	87	$m_{\nu_x} = 2$ MeV
$<6 \times 10^{-5}$	90	DAUM	87	$3 \text{ MeV} < m_{\nu_x} < 19.5 \text{ MeV}$
$<3 \times 10^{-2}$	90	44 MINEHART	84	$m_{\nu_x} = 2$ MeV
$<1 \times 10^{-3}$	90	44 MINEHART	84	$m_{\nu_x} = 4$ MeV
$<3 \times 10^{-4}$	90	44 MINEHART	84	$m_{\nu_x} = 10$ GeV
$<5 \times 10^{-6}$	90	45 HAYANO	82	$m_{\nu_x} = 330$ MeV
$<1 \times 10^{-4}$	90	45 HAYANO	82	$m_{\nu_x} = 70$ MeV
$<9 \times 10^{-7}$	90	45 HAYANO	82	$m_{\nu_x} = 250$ MeV
$<1 \times 10^{-1}$	90	44 ABELA	81	$m_{\nu_x} = 4$ MeV
$<7 \times 10^{-5}$	90	44 ABELA	81	$m_{\nu_x} = 10.5$ MeV
$<2 \times 10^{-4}$	90	44 ABELA	81	$m_{\nu_x} = 11.5$ MeV
$<2 \times 10^{-5}$	90	44 ABELA	81	$m_{\nu_x} = 16-30$ MeV

37 ASTIER 02 search for anomalous pion decay into a 33.9 MeV neutral particle. No evidence was found and the sensitivity to the branching ratio  $B(\pi \rightarrow \mu X) \cdot B(X \rightarrow \nu e^+ e^-)$  is as low as  $3.7 \times 10^{-15}$ , depending on the X lifetime.

38 DAUM 00 search for anomalous pion decay into a 33.9 MeV neutral particle that might be responsible for the time-distribution anomaly observed by the KARMEN Collaboration.

39 FORMAGGIO 00 search for anomalous pion decay into a 33.9 MeV neutral particle  $Q^0$  that might be responsible for the time-distribution anomaly observed by the KARMEN Collaboration. In the E815 (NuTeV) experiment at Fermilab no evidence was found, with sensitivity for the pion branching ratio  $B(\pi \rightarrow \mu Q^0) \cdot B(Q^0 \rightarrow \text{visible})$  as low as  $10^{-13}$ .

40 ASSAMAGAN 98 obtain a limit on heavy neutrino admixture from  $\pi^+$  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

$|U_{\mu x}|^2$  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.

- 41 BRYMAN 96 search for massive unconventional neutrinos of mass  $m_{\nu_x}$  in  $\pi^+$  decay.
- 42 ARMBRUSTER 95 study the reactions  $^{12}\text{C}(\nu_e, e^-) ^{12}\text{N}$  and  $^{12}\text{C}(\nu, \nu') ^{12}\text{C}^*$  induced by neutrinos from  $\pi^+$  and  $\mu^+$  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  $\nu_x$  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.
- 43 From experiments of  $\pi^+$  and  $\pi^-$  decay in flight at PSI, to check the claim of the KARMEN Collaboration quoted above (ARMBRUSTER 95).
- 44  $\pi^+ \rightarrow \mu^+ \nu_\mu$  peak search experiment.
- 45  $K^+ \rightarrow \mu^+ \nu_\mu$  peak search experiment.

### Peak search test

Limits on  $|U_{\mu x}|^2$  as function of  $m_{\nu_x}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$< 1-10 \times 10^{-4}$		46 BRYMAN 96	CNTR	$m_{\nu_x} = 30-33.91$ MeV
$< 2 \times 10^{-5}$	95	47 ASANO 81		$m_{\nu_x} = 70$ MeV
$< 3 \times 10^{-6}$	95	47 ASANO 81		$m_{\nu_x} = 210$ MeV
$< 3 \times 10^{-6}$	95	47 ASANO 81		$m_{\nu_x} = 230$ MeV
$< 6 \times 10^{-6}$	95	48 ASANO 81		$m_{\nu_x} = 240$ MeV
$< 5 \times 10^{-7}$	95	48 ASANO 81		$m_{\nu_x} = 280$ MeV
$< 6 \times 10^{-6}$	95	48 ASANO 81		$m_{\nu_x} = 300$ MeV
$< 1 \times 10^{-2}$	95	CALAPRICE 81		$m_{\nu_x} = 7$ MeV
$< 3 \times 10^{-3}$	95	49 CALAPRICE 81		$m_{\nu_x} = 33$ MeV
$< 1 \times 10^{-4}$	68	50 SHROCK 81	THEO	$m_{\nu_x} = 13$ MeV
$< 3 \times 10^{-5}$	68	50 SHROCK 81	THEO	$m_{\nu_x} = 33$ MeV
$< 6 \times 10^{-3}$	68	51 SHROCK 81	THEO	$m_{\nu_x} = 80$ MeV
$< 5 \times 10^{-3}$	68	51 SHROCK 81	THEO	$m_{\nu_x} = 120$ MeV

- 46 BRYMAN 96 search for massive unconventional neutrinos of mass  $m_{\nu_x}$  in  $\pi^+$  decay. They interpret the result as an upper limit for the admixture of a heavy sterile or otherwise
- 47  $K^+ \rightarrow \mu^+ \nu_\mu$  peak search experiment.
- 48 Analysis of experiment on  $K^+ \rightarrow \mu^+ \nu_\mu \nu_x \bar{\nu}_x$  decay.
- 49  $\pi^+ \rightarrow \mu^+ \nu_\mu$  peak search experiment.
- 50 Analysis of magnetic spectrometer experiment, bubble chamber experiment, and emulsion experiment on  $\pi^+ \rightarrow \mu^+ \nu_\mu$  decay.
- 51 Analysis of magnetic spectrometer experiment on  $K \rightarrow \mu, \nu_\mu$  decay.

**Peak Search in Muon Capture**Limits on  $|U_{\mu x}|^2$  as function of  $m_{\nu_x}$ 

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

**Searches for Decays of Massive  $\nu$** Limits on  $|U_{\mu x}|^2$  as function of  $m_{\nu_x}$ 

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$<5 \times 10^{-7}$	90	52 VAITAITIS	99 CCFR	$m_{\nu_x} = 0.28$ GeV
$<8 \times 10^{-8}$	90	52 VAITAITIS	99 CCFR	$m_{\nu_x} = 0.37$ GeV
$<5 \times 10^{-7}$	90	52 VAITAITIS	99 CCFR	$m_{\nu_x} = 0.50$ GeV
$<6 \times 10^{-8}$	90	52 VAITAITIS	99 CCFR	$m_{\nu_x} = 1.50$ GeV
$<2 \times 10^{-5}$	95	53 ABREU	97I DLPH	$m_{\nu_x} = 6$ GeV
$<3 \times 10^{-5}$	95	53 ABREU	97I DLPH	$m_{\nu_x} = 50$ GeV
$<3 \times 10^{-6}$	90	GALLAS	95 CNTR	$m_{\nu_x} = 1$ GeV
$<3 \times 10^{-5}$	90	54 VILAIN	95C CHM2	$m_{\nu_x} = 2$ GeV
$<6.2 \times 10^{-8}$	95	ADEVA	90S L3	$m_{\nu_x} = 20$ GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S L3	$m_{\nu_x} = 40$ GeV
all values ruled out	95	55 BURCHAT	90 MRK2	$m_{\nu_x} < 19.6$ GeV
$<1 \times 10^{-10}$	95	55 BURCHAT	90 MRK2	$m_{\nu_x} = 22$ GeV
$<1 \times 10^{-11}$	95	55 BURCHAT	90 MRK2	$m_{\nu_x} = 41$ GeV
all values ruled out	95	DECAMP	90F ALEP	$m_{\nu_x} = 25.0-42.7$ GeV
$<1 \times 10^{-13}$	95	DECAMP	90F ALEP	$m_{\nu_x} = 42.7-45.7$ GeV
$<5 \times 10^{-3}$	90	AKERLOF	88 HRS	$m_{\nu_x} = 1.8$ GeV
$<2 \times 10^{-5}$	90	AKERLOF	88 HRS	$m_{\nu_x} = 4$ GeV
$<3 \times 10^{-6}$	90	AKERLOF	88 HRS	$m_{\nu_x} = 6$ GeV
$<1 \times 10^{-7}$	90	BERNARDI	88 CNTR	$m_{\nu_x} = 200$ MeV
$<3 \times 10^{-9}$	90	BERNARDI	88 CNTR	$m_{\nu_x} = 300$ MeV
$<4 \times 10^{-4}$	90	56 MISHRA	87 CNTR	$m_{\nu_x} = 1.5$ GeV
$<4 \times 10^{-3}$	90	56 MISHRA	87 CNTR	$m_{\nu_x} = 2.5$ GeV
$<0.9 \times 10^{-2}$	90	56 MISHRA	87 CNTR	$m_{\nu_x} = 5$ GeV
$<0.1$	90	56 MISHRA	87 CNTR	$m_{\nu_x} = 10$ GeV
$<8 \times 10^{-4}$	90	BADIER	86 CNTR	$m_{\nu_x} = 600$ MeV
$<1.2 \times 10^{-5}$	90	BADIER	86 CNTR	$m_{\nu_x} = 1.7$ GeV
$<3 \times 10^{-8}$	90	BERNARDI	86 CNTR	$m_{\nu_x} = 200$ MeV
$<6 \times 10^{-9}$	90	BERNARDI	86 CNTR	$m_{\nu_x} = 350$ MeV
$<1 \times 10^{-6}$	90	DORENBOS...	86 CNTR	$m_{\nu_x} = 500$ MeV

- $<1 \times 10^{-7}$  90 DORENBOS... 86 CNTR  $m_{\nu_x} = 1600$  MeV  
 $<0.8 \times 10^{-5}$  90 57 COOPER-... 85 HLBC  $m_{\nu_x} = 0.4$  GeV  
 $<1.0 \times 10^{-7}$  90 57 COOPER-... 85 HLBC  $m_{\nu_x} = 1.5$  GeV
- <sup>52</sup>VAITAITIS 99 search for  $L_{\mu}^0 \rightarrow \mu X$ . See paper for rather complicated limit as function of  $m_{\nu_x}$ .
- <sup>53</sup>ABREU 97I long-lived  $\nu_x$  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.
- <sup>54</sup>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.
- <sup>55</sup>BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.
- <sup>56</sup>See also limits on  $|U_{3x}|$  from WENDT 87.
- <sup>57</sup>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,  $x$  is not equal to 3, i.e.  $\nu_x$  cannot be the dominant mass eigenstate in  $\nu_{\tau}$  since  $m_{\nu_3} < 70$  MeV (ALBRECHT 85). Also, of course,  $x$  is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

### Limits on $|U_{\tau x}|^2$ as a Function of $m_{\nu_x}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$<1 \times 10^{-2}$	90	58 ORLOFF	02 CHRM	$m_{\nu_x} = 45$ MeV
$<1.4 \times 10^{-4}$	90	58 ORLOFF	02 CHRM	$m_{\nu_x} = 180$ MeV
$<0.025$	90	ASTIER	01	$m_{\nu_x} = 45$ MeV
$<0.002$	90	ASTIER	01	$m_{\nu_x} = 140$ MeV
$<2 \times 10^{-5}$	95	59 ABREU	97I DLPH	$m_{\nu_x} = 6$ GeV
$<3 \times 10^{-5}$	95	59 ABREU	97I DLPH	$m_{\nu_x} = 50$ GeV
$<6.2 \times 10^{-8}$	95	ADEVA	90S L3	$m_{\nu_x} = 20$ GeV
$<5.1 \times 10^{-10}$	95	ADEVA	90S L3	$m_{\nu_x} = 40$ GeV
all values ruled out	95	60 BURCHAT	90 MRK2	$m_{\nu_x} < 19.6$ GeV
$<1 \times 10^{-10}$	95	60 BURCHAT	90 MRK2	$m_{\nu_x} = 22$ GeV
$<1 \times 10^{-11}$	95	60 BURCHAT	90 MRK2	$m_{\nu_x} = 41$ GeV
all values ruled out	95	DECAMP	90F ALEP	$m_{\nu_x} = 25.0-42.7$ GeV
$<1 \times 10^{-13}$	95	DECAMP	90F ALEP	$m_{\nu_x} = 42.7-45.7$ GeV
$<5 \times 10^{-2}$	80	AKERLOF	88 HRS	$m_{\nu_x} = 2.5$ GeV
$<9 \times 10^{-5}$	80	AKERLOF	88 HRS	$m_{\nu_x} = 4.5$ GeV

- <sup>58</sup>ORLOFF 02 use the negative result of a search for neutral particles decaying into two electrons performed by CHARM to get these limits for a mostly isosinglet heavy neutrino.
- <sup>59</sup>ABREU 97I long-lived  $\nu_x$  analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity.
- <sup>60</sup>BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89C, and WENDT 87.

### Limits on $|U_{ax}|^2$

Where  $a = e, \mu$  from  $\rho$  parameter in  $\mu$  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 $m_{\nu_x} = 10$ GeV
$<2 \times 10^{-3}$	68	SHROCK	81B	THEO $m_{\nu_x} = 40$ MeV
$<4 \times 10^{-2}$	68	SHROCK	81B	THEO $m_{\nu_x} = 70$ MeV

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$<3 \times 10^{-5}$	90	<sup>61</sup> BARANOV	93	$m_{\nu_j} = 80$ MeV
$<3 \times 10^{-6}$	90	<sup>61</sup> BARANOV	93	$m_{\nu_j} = 160$ MeV
$<6 \times 10^{-7}$	90	<sup>61</sup> BARANOV	93	$m_{\nu_j} = 240$ MeV
$<2 \times 10^{-7}$	90	<sup>61</sup> BARANOV	93	$m_{\nu_j} = 320$ MeV
$<9 \times 10^{-5}$	90	BERNARDI	86	CNTR $m_{\nu_j} = 25$ MeV
$<3.6 \times 10^{-7}$	90	BERNARDI	86	CNTR $m_{\nu_j} = 100$ MeV
$<3 \times 10^{-8}$	90	BERNARDI	86	CNTR $m_{\nu_j} = 200$ MeV
$<6 \times 10^{-9}$	90	BERNARDI	86	CNTR $m_{\nu_j} = 350$ MeV
$<1 \times 10^{-2}$	90	BERGSMA	83B	CNTR $m_{\nu_j} = 10$ MeV
$<1 \times 10^{-5}$	90	BERGSMA	83B	CNTR $m_{\nu_j} = 140$ MeV
$<7 \times 10^{-7}$	90	BERGSMA	83B	CNTR $m_{\nu_j} = 370$ MeV

<sup>61</sup>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.

### REFERENCES FOR Heavy Neutral Leptons, Searches for

BACK	03A	JETPL 78 261	H.O. Back <i>et al.</i>	(Borexino Collab.)
		Translated from ZETFP 78 707.		
TRINCZEK	03	PRL 90 012501	M. Trinczek <i>et al.</i>	
ASTIER	02	PL B527 23	P. Astier <i>et al.</i>	(NOMAD Collab.)
ORLOFF	02	PL B550 8	J. Orloff <i>et al.</i>	
ACHARD	01	PL B517 67	P. Achard <i>et al.</i>	(L3 Collab.)
ACHARD	01B	PL B517 75	P. Achard <i>et al.</i>	(L3 Collab.)
ASTIER	01	PL B506 27	P. Astier <i>et al.</i>	(NOMAD Collab.)
GALEAZZI	01	PRL 86 1978	M. Galeazzi <i>et al.</i>	
ABBIENDI	00I	EPJ C14 73	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
DAUM	00	PRL 85 1815	M. Daum <i>et al.</i>	
FORMAGGIO	00	PRL 84 4043	J.A. Formaggio <i>et al.</i>	
HOLZSCHUH	00	PL B482 1	E. Holzschuh <i>et al.</i>	
ABREU	99O	EPJ C8 41	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	99K	PL B461 397	M. Acciarri <i>et al.</i>	(L3 Collab.)
DRAGOUN	99	JPG 25 1839	O. Dragoun <i>et al.</i>	
HOLZSCHUH	99	PL B451 247	E. Holzschuh <i>et al.</i>	
VAITAITIS	99	PRL 83 4943	A. Vaitaitis <i>et al.</i>	(CCFR Collab.)
ASSAMAGAN	98	PL B434 158	K. Assamagan <i>et al.</i>	
HINDI	98	PR C58 2512	M.M. Hindi <i>et al.</i>	
PDG	98	EPJ C3 1	C. Caso <i>et al.</i>	
ABREU	97I	ZPHY C74 57	P. Abreu <i>et al.</i>	(DELPHI Collab.)
	Also	ZPHY C75 580 (erratum)	P. Abreu <i>et al.</i>	(DELPHI Collab.)
BRYMAN	96	PR D53 558	D.A. Bryman, T. Numao	(TRIU)
BUSKULIC	96S	PL B384 439	D. Buskalic <i>et al.</i>	(ALEPH Collab.)
WIETFELDT	96	PRPL 273 149	F.E. Wietfeldt, E.B. Norman	(LBL)

ARMBRUSTER	95	PL B348 19	B. Armbruster <i>et al.</i>	(KARMEN Collab.)
BAHRAN	95	PL B354 481	M.Y. Bahran, G.R. Kalbfleisch	(OKLA)
BILGER	95	PL B363 41	R. Bilger <i>et al.</i>	(TUBIN, KARLE, PSI)
DAUM	95B	PL B361 179	M. Daum <i>et al.</i>	(PSI, VIRG)
FARGION	95	PR D52 1828	D. Fargion <i>et al.</i>	(ROMA, KIAM, MPEI)
GALLAS	95	PR D52 6	E. Gallas <i>et al.</i>	(MSU, FNAL, MIT, FLOR)
GARCIA	95	PR D51 1458	E. Garcia <i>et al.</i>	(ZARA, SCUC, PNL)
HAGNER	95	PR D52 1343	C. Hagner <i>et al.</i>	(MUNT, LAPP, CPPM)
HIDDEMANN	95	JPG 21 639	K.H. Hiddemann, H. Daniel, O. Schwentker	(MUNT)
VILAIN	95C	PL B351 387	P. Vilain <i>et al.</i>	(CHARM II Collab.)
Also		PL B343 453	P. Vilain <i>et al.</i>	(CHARM II Collab.)
BECK	94	PL B336 141	M. Beck <i>et al.</i>	(MPIH, KIAE, SASSO)
KONOPLICH	94	PAN 57 425	R.V. Konoplich, M.Y. Khlopov	(MPEI)
PDG	94	PR D50 1173	L. Montanet <i>et al.</i>	(CERN, LBL, BOST+)
BAHRAN	93	PR D47 R754	M. Bahran, G.R. Kalbfleisch	(OKLA)
BAHRAN	93B	PR D47 R759	M. Bahran, G.R. Kalbfleisch	(OKLA)
BARANOV	93	PL B302 336	S.A. Baranov <i>et al.</i>	(JINR, SERP, BUDA)
KALBFLEISCH	93	PL B303 355	G.R. Kalbfleisch, M.Y. Bahran	(OKLA)
MORTARA	93	PRL 70 394	J.L. Mortara <i>et al.</i>	(ANL, LBL, UCB)
OHSHIMA	93	PR D47 4840	T. Ohshima <i>et al.</i>	(KEK, TUAT, RIKEN+)
ABREU	92B	PL B274 230	P. Abreu <i>et al.</i>	(DELPHI Collab.)
BAHRAN	92	PL B291 336	M.Y. Bahran, G.R. Kalbfleisch	(OKLA)
BRITTON	92	PRL 68 3000	D.I. Britton <i>et al.</i>	(TRIU, CARL)
Also		PR D49 28	D.I. Britton <i>et al.</i>	(TRIU, CARL)
BRITTON	92B	PR D46 R885	D.I. Britton <i>et al.</i>	(TRIU, CARL)
KAWAKAMI	92	PL B287 45	H. Kawakami <i>et al.</i>	(INUS, KEK, SCUC+)
MORI	92B	PL B289 463	M. Mori <i>et al.</i>	(KAM2 Collab.)
ALEXANDER	91F	ZPHY C52 175	G. Alexander <i>et al.</i>	(OPAL Collab.)
DELEENER...	91	PR D43 3611	N. de Leener-Rosier <i>et al.</i>	(LOUV, ZURI+)
REUSSER	91	PL B255 143	D. Reusser <i>et al.</i>	(NEUC, CIT, PSI)
SATO	91	PR D44 2220	N. Sato <i>et al.</i>	(Kamiokande Collab.)
ADEVA	90S	PL B251 321	B. Adeva <i>et al.</i>	(L3 Collab.)
BURCHAT	90	PR D41 3542	P.R. Burchat <i>et al.</i>	(Mark II Collab.)
DECAMP	90F	PL B236 511	D. Decamp <i>et al.</i>	(ALEPH Collab.)
DEUTSCH	90	NP A518 149	J. Deutsch, M. Lebrun, R. Prieels	
JUNG	90	PRL 64 1091	C. Jung <i>et al.</i>	(Mark II Collab.)
ABRAMS	89C	PRL 63 2447	G.S. Abrams <i>et al.</i>	(Mark II Collab.)
ENQVIST	89	NP B317 647	K. Enqvist, K. Kainulainen, J. Maalampi	(HELS)
FISHER	89	PL B218 257	P.H. Fisher <i>et al.</i>	(CIT, NEUC, PSI)
AKERLOF	88	PR D37 577	C.W. Akerlof <i>et al.</i>	(HRS Collab.)
BERNARDI	88	PL B203 332	G. Bernardi <i>et al.</i>	(PARIN, CERN, INFN+)
CALDWELL	88	PRL 61 510	D.O. Caldwell <i>et al.</i>	(UCSB, UCB, LBL)
OLIVE	88	PL B205 553	K.A. Olive, M. Srednicki	(MINN, UCSB)
SREDNICKI	88	NP B310 693	M. Srednicki, R. Watkins, K.A. Olive	(MINN, UCSB)
AHLEN	87	PL B195 603	S.P. Ahlen <i>et al.</i>	(BOST, SCUC, HARV+)
DAUM	87	PR D36 2624	M. Daum <i>et al.</i>	(SIN, VIRG)
GRIEST	87	NP B283 681	K. Griest, D. Seckel	(UCSC, CERN)
Also		NP B296 1034 (erratum)	K. Griest, D. Seckel	(UCSC, CERN)
MISHRA	87	PRL 59 1397	S.R. Mishra <i>et al.</i>	(COLU, CIT, FNAL+)
OBERAUER	87	PL B198 113	L.F. Oberauer, F. von Feilitzsch, R.L. Mossbauer	
WENDT	87	PRL 58 1810	C. Wendt <i>et al.</i>	(Mark II Collab.)
AZUELOS	86	PRL 56 2241	G. Azuelos <i>et al.</i>	(TRIU, CNRC)
BADIER	86	ZPHY C31 21	J. Badier <i>et al.</i>	(NA3 Collab.)
BERNARDI	86	PL 166B 479	G. Bernardi <i>et al.</i>	(CURIN, INFN, CDEF+)
DORENBOS...	86	PL 166B 473	J. Dorenbosch <i>et al.</i>	(CHARM Collab.)
ALBRECHT	85I	PL 163B 404	H. Albrecht <i>et al.</i>	(ARGUS Collab.)
APALIKOV	85	JETPL 42 289	A.M. Apalikov <i>et al.</i>	(ITEP)
		Translated from ZETFP 42 233.		
COOPER...	85	PL 160B 207	A.M. Cooper-Sarkar <i>et al.</i>	(CERN, LOIC+)
MARKEY	85	PR C32 2215	J. Markey, F. Boehm	(CIT)
OHI	85	PL 160B 322	T. Ohi <i>et al.</i>	(TOKY, INUS, KEK)
MINEHART	84	PRL 52 804	R.C. Minehart <i>et al.</i>	(VIRG, SIN)
BERGSMA	83	PL 122B 465	F. Bergsma <i>et al.</i>	(CHARM Collab.)
BERGSMA	83B	PL 128B 361	F. Bergsma <i>et al.</i>	(CHARM Collab.)
BRYMAN	83B	PRL 50 1546	D.A. Bryman <i>et al.</i>	(TRIU, CNRC)
DEUTSCH	83	PR D27 1644	J.P. Deutsch, M. Lebrun, R. Prieels	(LOUV)
GRONAU	83	PR D28 2762	M. Gronau	(HAIF)
SCHRECK...	83	PL 129B 265	K. Schreckenbach <i>et al.</i>	(ISNG, ILLG)
HAYANO	82	PRL 49 1305	R.S. Hayano <i>et al.</i>	(TOKY, KEK, TSUK)
ABELA	81	PL 105B 263	R. Abela <i>et al.</i>	(SIN)
ASANO	81	PL 104B 84	Y. Asano <i>et al.</i>	(KEK, TOKY, INUS, OSAK)

CALAPRICE	81	PL 106B 175	F.P. Calaprice <i>et al.</i>	(PRIN, IND)
SHROCK	81	PR D24 1232	R.E. Shrock	(STON)
SHROCK	81B	PR D24 1275	R.E. Shrock	(STON)
SHROCK	80	PL 96B 159	R.E. Shrock	(STON)

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