Charged Long-Lived Heavy Lepton MASS LIMITS

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>0.1	0	[35] ANSORGE	73B	HBC	−	Long-lived
none 0.55–4.5		[36] BUSHNIN	73	CNTR	−	Long-lived
none 0.2–0.92		[37] BARNA	68	CNTR	−	Long-lived
none 0.97–1.03		[37] BARNA	68	CNTR	−	Long-lived

[35] ANSORGE 73B looks for electron pair production and electron-like Bremsstrahlung.

[36] BUSHNIN 73 is SERPUKOV 70 GeV p experiment. Masses assume mean life above 7×10^{-10} and 3×10^{-8} respectively. Calculated from cross section (see "Charged Quasi-Stable Lepton Production Differential Cross Section" below) and 30 GeV muon pair production data.

[37] BARNA 68 is SLAC photoproduction experiment.

Doubly-Charged Heavy Lepton MASS LIMITS

VALUE (GeV)	CL%	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 1–9 GeV	90	[38] CLARK	81	SPEC	$++$

[38] CLARK 81 is FNAL experiment with 209 GeV muons. Bounds apply to μ_P which couples with full weak strength to muon. See also section on "Doubly-Charged Lepton Produciton Cross Section."

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	[39] ADEVA	90S	L3	Dirac
>34.8	95	[39] ADEVA	90S	L3	Majorana
>42.7	95	DECAMP	90F	ALEP	Dirac

[39] 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.

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. L, e_P, μ_P, e_O, μ_O stand for sequential lepton, para-electron, para-muon, ortho-electron, ortho-muon respectively. For a review, see GAN 88.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
none 2.5–50	95	[40] ADRIANI	92I	L3	$\lvert U_{\tau \text{ or } \mu}\rvert^2 < 3 \times 10^{-4}$
none 4–50	95	[40] ADRIANI	92I	L3	$\lvert U_{\tau}\rvert^2 < 3 \times 10^{-4}$
>46.4	95	[41] ADEVA	90S	L3	Dirac
>45.1	95	[41] ADEVA	90S	L3	Majorana
>46.5	95	[42] AKRAWY	90L	OPAL	Coupling to e or μ
>45.7	95	[42] AKRAWY	90L	OPAL	Coupling to τ
>19.6	95	[43,44] BURCHAT	90	MRK2	Dirac, all $\lvert U_{\ell j}\rvert^2$
none 25–45.7	95	[43,45] DECAMP	90F	ALEP	Dirac $\lvert U_{\ell j}\rvert^2 > 10^{-13}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>44.5	95	[46] ABREU	92B	DLPH	Dirac
>39.0	95	[46] ABREU	92B	DLPH	Majorana
>41	95	[43,44] BURCHAT	90	MRK2	Dirac, $\lvert U_{\ell j}\rvert^2 > 10^{-10}$
none 8.2–26.5	95	[47] SHAW	89	AMY	Dirac L^0, $\lvert U_{ej}\rvert^2 > 10^{-6}$
none 8.3–22.4	95	[47] SHAW	89	AMY	Majorana L^0, $\lvert U_{ej}\rvert^2 > 10^{-6}$
none 8.1–24.9	95	[47] SHAW	89	AMY	Majorana L^0, $\lvert U_{\mu j}\rvert^2 > 10^{-6}$
none 1.8–6.7	90	[48] AKERLOF	88	HRS	$\lvert U_{ej}\rvert^2$=1
none 1.8–6.4	90	[48] AKERLOF	88	HRS	$\lvert U_{\mu j}\rvert^2$=1
none 2.5–6.3	80	[48] AKERLOF	88	HRS	$\lvert U_{\tau j}\rvert^2$=1
none 0.6–34.6	95	[49] BEHREND	88C	CELL	L^0=e^0_P, $V-A$ coupling $\lvert U_{ej}\rvert^2$=1
none 0.4–37.4	95	[49] BEHREND	88C	CELL	L^0=e^0_P, $V+A$ coupling $\lvert U_{ej}\rvert^2$=1
none 0.25–14	90	[50] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2$=1.
none 0.25–10	90	[50] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2$=0.1
none 0.25–7.7	90	[50] MISHRA	87	CNTR	$\lvert U_{\mu j}\rvert^2$=0.03
none 1.–2.	90	[51] WENDT	87	MRK2	$\lvert U_{e \text{ or } \mu j}\rvert^2$=0.1
none 2.2–4.	90	[51] WENDT	87	MRK2	$\lvert U_{e \text{ or } \mu j}\rvert^2$=0.001
none 2.3–3.	90	[51] WENDT	87	MRK2	$\lvert U_{\tau j}\rvert^2$=0.1
none 3.2–4.8	90	[51] WENDT	87	MRK2	$\lvert U_{\tau j}\rvert^2$=0.001
none 0.3–0.9	90	[52] BADIER	86	CNTR	$\lvert U_{ej}\rvert^2$=0.8
none 0.33–2.0	90	[52] BADIER	86	CNTR	$\lvert U_{ej}\rvert^2$=0.03
none 0.6–0.7	90	[52] BADIER	86	CNTR	$\lvert U_{\mu j}\rvert^2$=0.8
none 0.6–2.0	90	[52] BADIER	86	CNTR	$\lvert U_{\mu j}\rvert^2$=0.01–0.001
>24.5	95	[53] BARTEL	83	JADE	e^0_P or e^0_O, $V+A$
>22.5	95	[53] BARTEL	83	JADE	e^0_P or e^0_O, $V-A$
none 1–9	90	[54] CLARK	81	SPEC	μ^0_P
> 1.2		MEYER	77	MRK1	Neutral

[40] 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.

[41] 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.

[42] 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.

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

[44] 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.

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

[46] 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.

[47] 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.

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

[49] The first bound of BEHREND 88C applies for a general L^0. The second and third have their assumptions indicated.

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

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

[52] 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_{mj} 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".

[53] BARTEL 83 is PETRA e^+e^- experiment with average $W_{\text{cm}} = 34.2$ GeV. First (second) limit is for $V+A(V-A)$ type $W^- e_P e$ coupling.

[54] CLARK 81 is FNAL experiment with 209 GeV muons. Bounds apply to para-muon which couples with full weak strength to muon. See also section on "Neutral Heavy Lepton Production Cross Section (μ Nucleon)" below.

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 6 – hundreds		[55,56] MORI	92B	KAM2	Dirac neutrino
none 24 – hundreds		[55,56] MORI	92B	KAM2	Majorana neutrino
none 10–2400	90	[57] REUSSER	91	CNTR	HPGe search
none 3–100	90	SATO	91	KAM2	Kamiokande II
		[58] ENQVIST	89	COSM	
none 12–1400		[59] CALDWELL	88	COSM	Dirac ν
none 4–16	90	[55,59] 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	[59] AHLEN	87	COSM	Dirac ν
>4.1		GRIEST	87	COSM	Dirac ν

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

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

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

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

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

Doubly-Charged Lepton Production Cross Section (μN Scattering)

VALUE (cm^2)	EVTS	DOCUMENT ID		TECN	CHG
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6. \times 10^{-38}$	0	[60] CLARK	81	SPEC	$++$

[60] CLARK 81 is FNAL experiment with 209 GeV muon. Looked for μ^+ nucleon $\rightarrow \overline{\mu}^0_P X$, $\overline{\mu}^0_P \rightarrow \mu^+\mu^-\overline{\nu}_\mu$ and $\mu^+ n \rightarrow \mu^{++}_P X$, $\mu^{++}_P \rightarrow 2\mu^+\nu_\mu$. Above limits are for $\sigma\times$BR taken from their mass-dependence plot figure 2.