References

1. M.L. Perl and P. Rapidis, SLAC-PUB-1496 (October 1974).
2. J.D. Bjorken and C.H. Llewellyn Smith, Phys. Rev. **D7**, 887 (1973).
3. M. Perl, SLAC-PUB-2752 (1981).

Limits apply only to heavy lepton types specified. See review above for description of types. $L, e_P, \mu_P, \tau_P, e_O, \mu_O$, and τ_O denote sequential lepton, para-electron, para-muon, para-tau, ortho-electron, ortho-muon, and ortho-tau, respectively. As noted, limits for excited leptons (e^*, μ^*, τ^*) are included in the section on "Searches for Quark and Lepton Compositeness."

Charged Heavy Lepton MASS LIMITS

Sequential Charged Heavy Lepton ($L^\pm$) MASS LIMITS

These experiments assumed that a fourth generation $L^\pm$ decayed to a fourth generation ν_L (or L^0) where ν_L was stable. New data show that stable ν_L have $m_{\nu_L} > 42.7$ GeV so that the above assumption is not valid for any mass limit ≤ 42.7 GeV. One can instead assume that $L^\pm$ decays via mixing to ν_e, ν_μ and/or ν_τ, and in that context the limits below are meaningful.

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
>42.8	95	ADEVA	90S	L3	Dirac
>44.3	95	AKRAWY	90G	OPAL	
>42.7	95	DECAMP	90F	ALEP	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 12.6–29.6	95	KIM	91B	AMY	Massless ν assumed
none 0.5–10	95	[1] RILES	90	MRK2	For $(m_{L^-} - m_{L^0}) >$ 0.25–0.4 GeV
> 8		[2] STOKER	89	MRK2	For $(m_{L^+} - m_{L^0})$= 0.4 GeV
>12		[2] STOKER	89	MRK2	For m_{L^0}=0.9 GeV
>27.6	95	[3] ABE	88	VNS	
>25.5	95	[4] ADACHI	88B	TOPZ	
none 1.5–22.0	95	BEHREND	88C	CELL	
>25.0	95	[5] IGARASHI	88	AMY	
>27.6	95	[6] KIM	88	AMY	
>41	90	[7] ALBAJAR	87B	UA1	
>25.0	95	YOSHIDA	87B	VNS	
>22.5	95	[8] ADEVA	85	MRKJ	
>18.		[9] ADEVA	83B	MRKJ	
>18.0	95	[10] BARTEL	83	JADE	
>14.	95	ADEVA	82	MRKJ	
none 4–14.5	95	[11] BERGER	81B	PLUT	
>15.5	95	[12] BRANDELIK	81	TASS	
>13.		[13] AZIMOV	80		
>16.	95	[14] BARBER	80B	CNTR	
> 0.490		[15] ROTHE	69	RVUE	

[1] RILES 90 limits were the result of a special analysis of the data in the case where the mass difference $m_{L^-} - m_{L^0}$ was allowed to be quite small, where L^0 denotes the neutrino into which the sequential charged lepton decays. With a slightly reduced $m_{L^\pm}$ range, the mass difference extends to about 4 GeV.

[2] STOKER 89 (Mark II at PEP) gives bounds on charged heavy lepton (L^+) mass for the generalized case in which the corresponding neutral heavy lepton (L^0) in the SU(2) doublet is not of negligible mass.

[3] ABE 88 search for L^+ and $L^- \rightarrow$ hadrons looking for acoplanar jets. The bound is valid for $m_\nu < 10$ GeV.

[4] ADACHI 88B search for hadronic decays giving acoplanar events with large missing energy. $E_{cm}^{ee} = 52$ GeV.

[5] IGARASHI 88 search for multi-hadron events with isolated leptons. E_{cm}^{ee} = 50–52 GeV.

[6] KIM 88 search for $L^\pm \rightarrow$ hadrons with $L^\mp \rightarrow$ isolated lepton X and for $L^\pm$ and $L^\mp \rightarrow$ hadrons. $E_{cm}^{ee} = 56$ GeV.

[7] Assumes associated neutrino is approximately massless.

[8] ADEVA 85 analyze one-isolated-muon data and sensitive to τ <10 nanosec. Assume B(lepton) = 0.30. E_{cm} = 40–47 GeV.

[9] ADEVA 83B looked for muon opposite against a hadron jet.

[10] BARTEL 83 limit is from PETRA e^+e^- experiment with average $E_{cm} = 34.2$ GeV.

[11] BERGER 81B is DESY DORIS and PETRA experiment. Looking for $e^+e^- \rightarrow L^+L^-$.

[12] BRANDELIK 81 is DESY-PETRA experiment. Looking for $e^+e^- \rightarrow L^+L^-$.

[13] AZIMOV 80 estimated probabilities for $M + N$ type events in $e^+e^- \rightarrow L^+L^-$ deducing semi-hadronic decay multiplicities of L from e^+e^- annihilation data at $E_{cm} = (2/3)m_L$. Obtained above limit comparing these with e^+e^- data (BRANDELIK 80).

[14] BARBER 80B looked for $e^+e^- \rightarrow L^+L^-$, $L \rightarrow \nu_L^+$X with MARK-J at DESY-PETRA.

[15] ROTHE 69 examines previous data on μ pair production and π and K decays.

Stable Charged Heavy Lepton ($L^\pm$) MASS LIMITS

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*
>42.8 (CL = 95%) OUR LIMIT				
>28.2	95	[16] ADACHI	90C	TOPZ
none 18.5–42.8	95	AKRAWY	90O	OPAL
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>26.5	95	DECAMP	90F	ALEP
none m_μ–36.3	95	SODERSTROM	90	MRK2

[16] ADACHI 90C put lower limits on the mass of stable charged particles with electric charge Q satisying $2/3 < Q/e < 4/3$ and with spin 0 or 1/2. We list here the special case for a stable charged heavy lepton.

Charged Ortho-Electron ($e_O^\pm$) MASS LIMITS

See also the section "MASS LIMITS for Excited e" in the section on "Searches for Quark and Lepton Compositeness."

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 0.25–2.3		[17] BACCI	77B	SPEC	±
>0.6	0	[18] BACCI	73	ELEC	±
>2.2	0	[18] BACCI	73	ELEC	±
none 0.263–1.32		[19] LICHTENSTEIN	70	SPEC	−
none 0.1–1.3		[20] BOLEY	68	SPEC	−
none 0.3–0.7		[21] BUDNITZ	66	SPEC	−
>1.0	0	[22] BEHREND	65	SPEC	−
none 0.12–0.57		[23] BETOURNE	65	SPEC	−

[17] BACCI 77B is same type as BACCI 73. Lower mass limit corresponds to λ^2 limit of 4×10^{-5}, upper value is for λ^2 limit of 1.5×10^{-3}.

[18] BACCI 73 is Frascati e^+e^- experiment. Looks for $e_O \rightarrow e\gamma$. Mass limit depends on coupling constant λ for this decay. First value above is for $\lambda^2 > 9 \times 10^{-5}$, second is for $\lambda^2 > 10^{-3}$.

[19] LICHTENSTEIN 70 is Cornell experiment measuring e Bremsstrahlung. Mass limit depends on coupling constant. First value above is for λ^2 >0.17, second is for λ^2 >0.42.

[20] BOLEY 68 is CEA experiment. Looks for $ep \rightarrow e_O p$. Mass of 0.1 corresponds to coupling constant $\lambda^2 > 3 \times 10^{-4}$, mass limit of 1.3 to λ^2 >0.01.

[21] BUDNITZ 66 is CEA experiment. Looks for $ep \rightarrow e_O p$.

[22] BEHREND 65 is DESY experiment. Looks for $ep \rightarrow e_O p$, $e_O \rightarrow e\gamma$. This mass limit corresponds to a limit on λ^2 of 6.25×10^{-4}.

[23] BETOURNE 65 is Orsay experiment. Looks for $ep \rightarrow e_O p$. Mass of 0.12 corresponds to coupling constant λ^2 >0.0016, mass of 0.57 to λ^2 >0.22.

Charged Ortho-Muon ($\mu_O^\pm$) MASS LIMITS

See also the section "MASS LIMITS for Excited μ" in the section on "Searches for Quark and Lepton Compositeness."

VALUE (GeV)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
• • • We do not use the following data for averages, fits, limits, etc. • • •						
>10.3	98		[24] ASRATYAN	78		−
> 7.5		0	[25] CNOPS	78	HLBC	−
> 1.8	90		[26] ASRATYAN	74	HLBC	±
none 0–2.0			[27] GITTLESON	74	SPEC	
none 0.2–0.6			[28] LIBERMAN	69	OSPK	−

[24] ASRATYAN 78 analyzes dependence of (neutral current/charged current) on energy of associated hadrons. Uses data of HOLDER 77 — ν_μ interactions at CERN-SPS.

[25] CNOPS 78 is FNAL experiment looking for ν_μNe $\rightarrow L^\pm$, followed by $L^\pm \rightarrow e^\pm\nu\nu$.

[26] ASRATYAN 74 uses EICHTEN 73 data on νnucleon $\rightarrow e^-$ hadrons and $\overline{\nu}$nucleon $\rightarrow e^+$ hadrons to set limits on orthomuon production.

[27] GITTLESON 74 is $\mu p \rightarrow p\,\mu_O$ search. Coupling constant λ^2 is <0.01 for mass up to 0.7 GeV, limit on λ^2 rises to <0.1 for mass of 2.0 GeV.

[28] LIBERMAN 69 is a BNL experiment measuring muon Bremsstrahlung.

Charged Para-Muon ($\mu_P^\pm$) MASS LIMITS

VALUE (GeV)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*
• • • We do not use the following data for averages, fits, limits, etc. • • •						
> 9.0		0	[29] CNOPS	78	HLBC	+
>10.0			[30] ERRIQUEZ	78	BEBC	+
>12.	90		[31] HOLDER	78	CNTR	+
> 8.4	90		[32] BARISH	74	SPEC	+
> 2.0	90	0	[33] BARISH	73B	ASPK	+
> 2.4	90	0	[34] EICHTEN	73	HLBC	+

[29] CNOPS 78 is FNAL experiment looking for ν_μNe $\rightarrow L^\pm$, followed by $L^\pm \rightarrow e^\pm\nu\nu$.

[30] ERRIQUEZ 78 is CERN SPS experiment. Looks for $\nu_\mu$nucleon $\rightarrow \mu^- e^+$X. Finds cross section for producing heavy lepton $\rightarrow e^+ < 0.7 \times 10^{-3}$ ×CC cross section.

[31] HOLDER 78 is a CERN ν experiment looking for $\nu_\mu$nucleon $\rightarrow \mu^+$anything. Assumes $\mu_P^+ \rightarrow \mu^+ 2\nu_\mu$ with BR = 0.2.

[32] BARISH 74 is FNAL 50,135 GeV ν experiment. Looks for (νnucleon $\rightarrow \mu_P^+$X). Assumes $(\mu_P^+ \rightarrow \mu^+\nu_\mu\nu_\mu)$ with BR = 0.3.

[33] BARISH 73B is FNAL 50,145 GeV ν experiment. Looks for (νnucleon $\rightarrow \mu_P^+$X). Assumes $(\mu_P^+ \rightarrow \mu^+\nu_\mu\nu_\mu)$ with BR = 0.3.

[34] EICHTEN 73 is CERN 1–10 GeV ν experiment. Looks for μ_P^+ produced in νnucleon $\rightarrow \mu_P^+$hadrons assuming 15% decay to $e^+\nu_\mu\nu_e$.