# Heavy Charged Lepton Searches

## 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 $\nu_L$ (or $L^0$) where $\nu_L$ was stable, or that $L^{\pm}$ decays to a light $\nu_\ell$ via mixing.

See the "Quark and Lepton Compositeness, Searches for" Listings for limits on radiatively decaying excited leptons, *i.e.* $\ell^* \rightarrow \ell\gamma$. See the "WIMPs and other Particle Searches" section for heavy charged particle search limits in which the charged particle could be a lepton.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >93.9 | 95 | ACCIARRI | 99L | L3 | $m_{L^{\pm}} - m_{L^0} > 10$ GeV |
| **>92.4** | 95 | ACCIARRI | 99L | L3 | Decay to massless $\nu$'s |
| >81.5 | 95 | ACKERSTAFF | 98C | OPAL | Assumed $m_{L^{\pm}} - m_{L^0} > 8.4$ GeV |
| >80.2 | 95 | ACKERSTAFF | 98C | OPAL | $m_{L^0} > m_{L^{\pm}}$ and $L^{\pm} \rightarrow \nu W$ |
| >72 | 95 | ACCIARRI | 97P | L3 | Assumed $m_{L^{\pm}} - m_{\nu_L} > 10$ GeV |
| >81 | 95 | ACCIARRI | 97P | L3 | Assumed $m_{L^{\pm}} - m_{\nu_L} > 20$ GeV |
| >78.7 | 95 | ACCIARRI | 97P | L3 | Light $\nu$, $\sqrt{s}$=161, 172 GeV |
| < 48 or > 61 | 95 | [1] ACCIARRI | 96G | L3 | |
| >64.5 | 95 | ALEXANDER | 96P | OPAL | $m_L - m_{L^0} > 10$ GeV |
| >63.5 | 95 | BUSKULIC | 96S | ALEP | $m_L - m_{L^0} > 7$ GeV |
| >42.8 | 95 | ADEVA | 90S | L3 | Decay to Dirac $\nu_L$ |
| >44.3 | 95 | AKRAWY | 90G | OPAL | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >73.5 | 95 | ACKERSTAFF | 97D | OPAL | Assumed $m_{L^{\pm}} - m_{\nu_L} > 13$ GeV |
| >76.7 | 95 | ACKERSTAFF | 97D | OPAL | $m_{\nu_L} > m_{L^{\pm}}$ and $L^{\pm} \rightarrow \nu W^*$ |
| >63.9 | 95 | ALEXANDER | 96P | OPAL | Decay to massless $\nu$'s |
| >65 | 95 | BUSKULIC | 96S | ALEP | Decay to massless $\nu$'s |
| none 10–225 | | [2] AHMED | 94 | CNTR | H1 Collab. at HERA |
| none 12.6–29.6 | 95 | KIM | 91B | AMY | Massless $\nu$ assumed |
| >42.7 | 95 | DECAMP | 90F | ALEP | |
| none 0.5–10 | 95 | [3] RILES | 90 | MRK2 | For ($m_{L^0}$-$m_{L^0}$)> 0.25–0.4GeV |
| > 8 | | [4] STOKER | 89 | MRK2 | For ($m_{L^+} - m_{L^0}$)= 0.4 GeV |
| >12 | | [4] STOKER | 89 | MRK2 | For $m_{L^0}$=0.9 GeV |
| none 18.4–27.6 | 95 | [5] ABE | 88 | VNS | |
| >25.5 | 95 | [6] ADACHI | 88B | TOPZ | |
| none 1.5–22.0 | 95 | BEHREND | 88C | CELL | |
| >41 | 90 | [7] ALBAJAR | 87B | UA1 | |
| >22.5 | 95 | [8] ADEVA | 85 | MRKJ | |
| >18.0 | 95 | [9] BARTEL | 83 | JADE | |
| none 4–14.5 | 95 | [10] BERGER | 81B | PLUT | |
| >15.5 | 95 | [11] BRANDELIK | 81 | TASS | |
| >13. | | [12] AZIMOV | 80 | | |
| >16. | 95 | [13] BARBER | 80B | CNTR | |
| > 0.490 | | [14] ROTHE | 69 | RVUE | |

[1] ACCIARRI 96G assumes LEP result that the associated neutral heavy lepton mass > 40 GeV.

[2] The AHMED 94 limits are from a search for neutral and charged sequential heavy leptons at HERA via the decay channels $L^- \rightarrow e\gamma$, $L^- \rightarrow \nu W^-$, $L^- \rightarrow eZ$; and $L^0 \rightarrow \nu\gamma$, $L^0 \rightarrow e^- W^+$, $L^- \rightarrow \nu Z$, where the $W$ decays to $\ell\nu_\ell$, or to jets, and $Z$ decays to $\ell^+\ell^-$ or jets.

[3] 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.

[4] 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.

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

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

[7] Assumes associated neutrino is approximately massless.

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

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

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

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

[12] 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).

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

[14] ROTHE 69 examines previous data on $\mu$ pair production and $\pi$ and $K$ decays.

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

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN |
|---|---|---|---|---|
| **>93.5** | 95 | ACCIARRI | 99L | L3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| >84.2 | 95 | ACCIARRI | 97P | L3 |
| >28.2 | 95 | [15] ADACHI | 90C | TOPZ |
| none 18.5–42.8 | 95 | AKRAWY | 90O | OPAL |
| >26.5 | 95 | DECAMP | 90F | ALEP |
| none $m_\mu$–36.3 | 95 | SODERSTROM | 90 | MRK2 |

[15] 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 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 | [16] ANSORGE | 73B | HBC | – | Long-lived |
| none 0.55–4.5 | | [17] BUSHNIN | 73 | CNTR | – | Long-lived |
| none 0.2–0.92 | | [18] BARNA | 68 | CNTR | – | Long-lived |
| none 0.97–1.03 | | [18] BARNA | 68 | CNTR | – | Long-lived |

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

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

[18] 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 | [19] CLARK | 81 | SPEC | ++ |

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

## Doubly-Charged Lepton Production Cross Section ($\mu N$ 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 | [20] CLARK | 81 | SPEC | ++ |

[20] CLARK 81 is FNAL experiment with 209 GeV muon. Looked for $\mu^+$ 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.

## REFERENCES FOR Heavy Charged Lepton Searches


| | | | | |
|---|---|---|---|---|
| ACCIARRI | 99L | PL B462 354 | M. Acciarri *et al.* | (L3 Collab.) |
| ACKERSTAFF | 98C | EPJ C1 45 | K. Ackerstaff *et al.* | (OPAL Collab.) |
| ACCIARRI | 97P | PL B412 189 | M. Acciarri *et al.* | (L3 Collab.) |
| ACKERSTAFF | 97D | PL B393 217 | K. Ackerstaff *et al.* | (OPAL Collab.) |
| ACCIARRI | 96G | PL B377 304 | M. Acciarri *et al.* | (L3 Collab.) |
| ALEXANDER | 96P | PL B385 433 | G. Alexander *et al.* | (OPAL Collab.) |
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| AHMED | 94 | PL B340 205 | T. Ahmed *et al.* | (H1 Collab.) |
| KIM | 91B | IJMP A6 2583 | G.N. Kim *et al.* | (AMY Collab.) |
| ADACHI | 90C | PL B244 352 | I. Adachi *et al.* | (TOPAZ Collab.) |
| ADEVA | 90S | PL B251 321 | B. Adeva *et al.* | (L3 Collab.) |
| AKRAWY | 90G | PL B240 250 | M.Z. Akrawy *et al.* | (OPAL Collab.) |
| AKRAWY | 90O | PL B252 290 | M.Z. Akrawy *et al.* | (OPAL Collab.) |
| DECAMP | 90F | PL B236 511 | D. Decamp *et al.* | (ALEPH Collab.) |
| RILES | 90 | PR D42 1 | K. Riles *et al.* | (Mark II Collab.) |
| SODERSTROM | 90 | PRL 64 2980 | E. Soderstrom *et al.* | (Mark II Collab.) |
| STOKER | 89 | PR D39 1811 | D.P. Stoker *et al.* | (Mark II Collab.) |
| ABE | 88 | PRL 61 915 | K. Abe *et al.* | (VENUS Collab.) |
| ADACHI | 88B | PR D37 1339 | I. Adachi *et al.* | (TOPAZ Collab.) |
| BEHREND | 88C | ZPHY C41 7 | H.J. Behrend *et al.* | (CELLO Collab.) |
| ALBAJAR | 87B | PL B185 241 | C. Albajar *et al.* | (UA1 Collab.) |
| ADEVA | 85 | PL 152B 439 | B. Adeva *et al.* | (Mark-J Collab.) |
| Also | 84C | PRPL 109 131 | B. Adeva *et al.* | (Mark-J Collab.) |
| BARTEL | 83 | PL 123B 353 | W. Bartel *et al.* | (JADE Collab.) |
| BERGER | 81B | PL 99B 489 | C. Berger *et al.* | (PLUTO Collab.) |
| BRANDELIK | 81 | PL 99B 163 | R. Brandelik *et al.* | (TASSO Collab.) |
| CLARK | 81 | PRL 46 299 | A.R. Clark *et al.* | (UCB, LBL, FNAL+) |
| Also | 82 | PR D25 2762 | W.H. Smith *et al.* | (LBL, FNAL, PRIN) |
| AZIMOV | 80 | JETPL 32 664<br>Translated from ZETFP 32 677. | Y.I. Azimov, V.A. Khoze | (PNPI) |

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|---|---|---|---|---|
| BARBER | 80B | PRL 45 1904 | D.P. Barber *et al.* | (Mark-J Collab.) |
| BRANDELIK | 80 | PL 92B 199 | R. Brandelik *et al.* | (TASSO Collab.) |
| ANSORGE | 73B | PR D7 26 | R.E. Ansorge *et al.* | (CAVE) |
| BUSHNIN | 73 | NP B58 476 | Y.B. Bushnin *et al.* | (SERP) |
| Also | 72 | PL 42B 136 | S.V. Golovkin *et al.* | (SERP) |
| ROTHE | 69 | NP B10 241 | K.W. Rothe, A.M. Wolsky | (PENN) |
| BARNA | 68 | PR 173 1391 | A. Barna *et al.* | (SLAC, STAN) |


## OTHER RELATED PAPERS


| | | | | |
|---|---|---|---|---|
| PERL | 81 | SLAC-PUB-2752 | M.L. Perl | (SLAC) |
| Physics in Collision Conference. | | | | |