

# 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
<b>&gt;100.8</b>	95	ACHARD	01B L3	Decay to $\nu W$
>101.9	95	ACHARD	01B L3	$m_L - m_{L^0} > 15$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 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 $L^\pm \rightarrow \nu W$
< 48 or > 61	95	<sup>1</sup> ACCIARRI	96G L3	
> 63.9	95	ALEXANDER	96P OPAL	Decay to massless $\nu$ 's
> 63.5	95	BUSKULIC	96S ALEP	$m_L - m_{L^0} > 7$ GeV
> 65	95	BUSKULIC	96S ALEP	Decay to massless $\nu$ 's
none 10–225		<sup>2</sup> AHMED	94 CNTR	H1 Collab. at HERA
none 12.6–29.6	95	KIM	91B AMY	Massless $\nu$ assumed
> 44.3	95	AKRAWY	90G OPAL	
none 0.5–10	95	<sup>3</sup> RILES	90 MRK2	For $(m_{L^0} - m_{L^0}) > 0.25 - 0.4$ GeV
> 8		<sup>4</sup> STOKER	89 MRK2	For $(m_{L^+} - m_{L^0}) = 0.4$ GeV
> 12		<sup>4</sup> STOKER	89 MRK2	For $m_{L^0} = 0.9$ GeV
none 18.4–27.6	95	<sup>5</sup> ABE	88 VNS	
> 25.5	95	<sup>6</sup> ADACHI	88B TOPZ	
none 1.5–22.0	95	BEHREND	88C CELL	
> 41	90	<sup>7</sup> ALBAJAR	87B UA1	
> 22.5	95	<sup>8</sup> ADEVA	85 MRKJ	
> 18.0	95	<sup>9</sup> BARTEL	83 JADE	
none 4–14.5	95	<sup>10</sup> BERGER	81B PLUT	
> 15.5	95	<sup>11</sup> BRANDELIK	81 TASS	
> 13.		<sup>12</sup> AZIMOV	80	
> 16.	95	<sup>13</sup> BARBER	80B CNTR	
> 0.490		<sup>14</sup> ROTHE	69 RVUE	

<sup>1</sup> ACCIARRI 96G assumes LEP result that the associated neutral heavy lepton mass  $> 40$  GeV.

<sup>2</sup> 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.

<sup>3</sup> 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.

- <sup>4</sup> 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.
- <sup>5</sup> ABE 88 search for  $L^+$  and  $L^- \rightarrow$  hadrons looking for acoplanar jets. The bound is valid for  $m_{\nu} < 10$  GeV.
- <sup>6</sup> ADACHI 88B search for hadronic decays giving acoplanar events with large missing energy.  $E_{\text{cm}}^{ee} = 52$  GeV.
- <sup>7</sup> Assumes associated neutrino is approximately massless.
- <sup>8</sup> ADEVA 85 analyze one-isolated-muon data and sensitive to  $\tau < 10$  nanosec. Assume  $B(\text{lepton}) = 0.30$ .  $E_{\text{cm}} = 40\text{--}47$  GeV.
- <sup>9</sup> BARTEL 83 limit is from PETRA  $e^+e^-$  experiment with average  $E_{\text{cm}} = 34.2$  GeV.
- <sup>10</sup> BERGER 81B is DESY DORIS and PETRA experiment. Looking for  $e^+e^- \rightarrow L^+L^-$ .
- <sup>11</sup> BRANDELIK 81 is DESY-PETRA experiment. Looking for  $e^+e^- \rightarrow L^+L^-$ .
- <sup>12</sup> 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  $E_{\text{cm}} = (2/3)m_L$ . Obtained above limit comparing these with  $e^+e^-$  data (BRANDELIK 80).
- <sup>13</sup> BARBER 80B looked for  $e^+e^- \rightarrow L^+L^-$ ,  $L \rightarrow \nu_L^+ X$  with MARK-J at DESY-PETRA.
- <sup>14</sup> 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
>102.6	95	ACHARD	01B L3

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

> 28.2	95	<sup>15</sup> ADACHI	90C TOPZ
none 18.5–42.8	95	AKRAWY	90O OPAL
> 26.5	95	DECAMP	90F ALEP
none $m_\mu$ –36.3	95	SODERSTROM90	MRK2

- <sup>15</sup> ADACHI 90C put lower limits on the mass of stable charged particles with electric charge  $Q$  satisfying  $2/3 < Q/e < 4/3$  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)	CL%	DOCUMENT ID	TECN	CHG	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

>574	95	CHATRCHYAN 13AB	CMS		Leptons singlet model
>102.0	95	ABBIENDI	03L OPAL		pair produced in $e^+e^-$
> 0.1		<sup>16</sup> ANSORGE	73B HBC	–	Long-lived
none 0.55–4.5		<sup>17</sup> BUSHNIN	73 CNTR	–	Long-lived
none 0.2–0.92		<sup>18</sup> BARNA	68 CNTR	–	Long-lived
none 0.97–1.03		<sup>18</sup> BARNA	68 CNTR	–	Long-lived

- <sup>16</sup> ANSORGE 73B looks for electron pair production and electron-like Bremsstrahlung.
- <sup>17</sup> BUSHNIN 73 is SERPUKHOV 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.
- <sup>18</sup> BARNA 68 is SLAC photoproduction experiment.

## Doubly-Charged Heavy Lepton MASS LIMITS

VALUE (GeV)	CL%	DOCUMENT ID	TECN	CHG
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• • • We do not use the following data for averages, fits, limits, etc. • • •

none 1–9 GeV	90	<sup>19</sup> CLARK	81	SPEC ++
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<sup>19</sup>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 Production Cross Section.”

## Doubly-Charged Lepton Production Cross Section ( $\mu N$ Scattering)

VALUE (cm <sup>2</sup> )	EVTS	DOCUMENT ID	TECN	CHG
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$<6. \times 10^{-38}$	0	<sup>20</sup> CLARK	81	SPEC ++
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<sup>20</sup>CLARK 81 is FNAL experiment with 209 GeV muon. Looked for  $\mu^+$  nucleon  $\rightarrow \bar{\mu}_P^0 X$ ,  $\bar{\mu}_P^0 \rightarrow \mu^+ \mu^- \bar{\nu}_\mu$  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

CHATRCHYAN	13AB	JHEP 1307 122	S. Chatrchyan <i>et al.</i>	(CMS Collab.)
ABBIENDI	03L	PL B572 8	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ACHARD	01B	PL B517 75	P. Achard <i>et al.</i>	(L3 Collab.)
ACKERSTAFF	98C	EPJ C1 45	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACCIARRI	96G	PL B377 304	M. Acciarri <i>et al.</i>	(L3 Collab.)
ALEXANDER	96P	PL B385 433	G. Alexander <i>et al.</i>	(OPAL Collab.)
BUSKULIC	96S	PL B384 439	D. Buskulic <i>et al.</i>	(ALEPH Collab.)
AHMED	94	PL B340 205	T. Ahmed <i>et al.</i>	(H1 Collab.)
KIM	91B	IJMP A6 2583	G.N. Kim <i>et al.</i>	(AMY Collab.)
ADACHI	90C	PL B244 352	I. Adachi <i>et al.</i>	(TOPAZ Collab.)
AKRAWY	90G	PL B240 250	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
AKRAWY	90O	PL B252 290	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
DECAMP	90F	PL B236 511	D. Decamp <i>et al.</i>	(ALEPH Collab.)
RILES	90	PR D42 1	K. Riles <i>et al.</i>	(Mark II Collab.)
SODERSTROM	90	PRL 64 2980	E. Soderstrom <i>et al.</i>	(Mark II Collab.)
STOKER	89	PR D39 1811	D.P. Stoker <i>et al.</i>	(Mark II Collab.)
ABE	88	PRL 61 915	K. Abe <i>et al.</i>	(VENUS Collab.)
ADACHI	88B	PR D37 1339	I. Adachi <i>et al.</i>	(TOPAZ Collab.)
BEHREND	88C	ZPHY C41 7	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
ALBAJAR	87B	PL B185 241	C. Albajar <i>et al.</i>	(UA1 Collab.)
ADEVA	85	PL 152B 439	B. Adeva <i>et al.</i>	(Mark-J Collab.)
Also		PRPL 109 131	B. Adeva <i>et al.</i>	(Mark-J Collab.)
BARTEL	83	PL 123B 353	W. Bartel <i>et al.</i>	(JADE Collab.)
BERGER	81B	PL 99B 489	C. Berger <i>et al.</i>	(PLUTO Collab.)
BRANDELIK	81	PL 99B 163	R. Brandelik <i>et al.</i>	(TASSO Collab.)
CLARK	81	PRL 46 299	A.R. Clark <i>et al.</i>	(UCB, LBL, FNAL+)
Also		PR D25 2762	W.H. Smith <i>et al.</i>	(LBL, FNAL, PRIN)
AZIMOV	80	JETPL 32 664	Y.I. Azimov, V.A. Khoze	(PNPI)
		Translated from ZETFP 32 677.		
BARBER	80B	PRL 45 1904	D.P. Barber <i>et al.</i>	(Mark-J Collab.)
BRANDELIK	80	PL 92B 199	R. Brandelik <i>et al.</i>	(TASSO Collab.)
ANSORGE	73B	PR D7 26	R.E. Ansorge <i>et al.</i>	(CAVE)
BUSHNIN	73	NP B58 476	Y.B. Bushnin <i>et al.</i>	(SERP)
Also		PL 42B 136	S.V. Golovkin <i>et al.</i>	(SERP)
ROTHE	69	NP B10 241	K.W. Rothe, A.M. Wolsky	(PENN)
BARNA	68	PR 173 1391	A. Barna <i>et al.</i>	(SLAC, STAN)

## OTHER RELATED PAPERS

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