MASS LIMITS for Excited e (e^*)

Most e^+e^- experiments assume one-photon or Z exchange. The limits from some e^+e^- experiments which depend on λ have assumed transition couplings which are chirality violating ($\eta_L = \eta_R$). However they can be interpreted as limits for chirality-conserving interactions after multiplying the coupling value λ by $\sqrt{2}$; see Note.

Excited leptons have the same quantum numbers as other ortholeptons. See also the searches for ortholeptons in the "Searches for Heavy Leptons" section.

Limits for Excited e (e^*) from Pair Production

These limits are obtained from $e^+e^- \to e^{*+}e^{*-}$ and thus rely only on the (electroweak) charge of e^*. Form factor effects are ignored unless noted. For the case of limits from Z decay, the e^* coupling is assumed to be of sequential type. Possible t channel contribution from transition magnetic coupling is neglected. All limits assume $e^* \to e\gamma$ decay except the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review **D45,** 1 June, Part II (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>45.6	95	ADRIANI	93M	L3	$Z \to e^*e^*$
>45.6	95	ABREU	92C	DLPH	$Z \to e^*e^*$
>46.1	95	DECAMP	92	ALEP	$Z \to e^*e^*$
>44.9	95	AKRAWY	90I	OPAL	$Z \to e^*e^*$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>29.8	95	[43] BARDADIN-...	92	RVUE	$\Gamma(Z)$
>26.1	95	[44] DECAMP	92	ALEP	$Z \to e^*e^*$; $\Gamma(Z)$
>33	95	[44] ABREU	91F	DLPH	$Z \to e^*e^*$; $\Gamma(Z)$
>45.0	95	[45] ADEVA	90F	L3	$Z \to e^*e^*$
>44.6	95	[46] DECAMP	90G	ALEP	$e^+e^- \to e^*e^*$
>30.2	95	ADACHI	89B	TOPZ	$e^+e^- \to e^*e^*$
>28.3	95	KIM	89	AMY	$e^+e^- \to e^*e^*$
>27.9	95	[47] ABE	88B	VNS	$e^+e^- \to e^*e^*$

[43] BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on $\Delta\Gamma(Z)$<36 MeV.
[44] Limit is independent of e^* decay mode.
[45] ADEVA 90F is superseded by ADRIANI 93M.
[46] Superseded by DECAMP 92.
[47] ABE 88B limits assume $e^+e^- \to e^{*+}e^{*-}$ with one photon exchange only and $e^* \to e\gamma$ giving $ee\gamma\gamma$.

Limits for Excited e (e^*) from Single Production

These limits are from $e^+e^- \to e^*e$, $W \to e^*\nu$, or $ep \to e^*X$ and depend on transition magnetic coupling between e and e^*. All limits assume $e^* \to e\gamma$ decay except as noted. Limits from LEP, UA2, and H1 are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L = \eta_R = 1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda - m_{e^*}$ plane. See the original papers.

For limits prior to 1987, see our 1992 edition (Physical Review **D45,** 1 June, Part II (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>89	95	ADRIANI	93M	L3	$Z \to ee^*$, $\lambda_Z > 0.5$
>88	95	ABREU	92C	DLPH	$Z \to ee^*$, $\lambda_Z > 0.5$
>91	95	DECAMP	92	ALEP	$Z \to ee^*$, λ_Z >1
>87	95	AKRAWY	90I	OPAL	$Z \to ee^*$, $\lambda_Z > 0.5$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[48] ABT	93	H1	$ep \to e^*X$
>86	95	ADRIANI	93M	L3	$\lambda_\gamma > 0.04$
		[49] DERRICK	93B	ZEUS	$ep \to e^*X$
>86	95	ABREU	92C	DLPH	$e^+e^- \to ee^*$, $\lambda_\gamma >$ 0.1
>88	95	[50] ADEVA	90F	L3	$Z \to ee^*$, $\lambda_Z > 0.5$
>86	95	[50] ADEVA	90F	L3	$Z \to ee^*$, $\lambda_Z > 0.04$
>81	95	[51] DECAMP	90G	ALEP	$Z \to ee^*$, λ_Z >1
>50	95	ADACHI	89B	TOPZ	$e^+e^- \to ee^*$, $\lambda_\gamma >$ 0.04
>56	95	KIM	89	AMY	$e^+e^- \to ee^*$, $\lambda_\gamma >$ 0.03
none 23–54	95	[52] ABE	88B	VNS	$e^+e^- \to ee^*$ $\lambda_\gamma >$ 0.04
>75	95	[53] ANSARI	87D	UA2	$W \to e^*\nu$; $\lambda_W > 0.7$
>63	95	[53] ANSARI	87D	UA2	$W \to e^*\nu$; $\lambda_W > 0.2$
>40	95	[53] ANSARI	87D	UA2	$W \to e^*\nu$; $\lambda_W > 0.09$

[48] ABT 93 search for single e^* production via $e^*e\gamma$ coupling in ep collisions with the decays $e^* \to e\gamma$, eZ, νW. See their Fig. 4 for exclusion plot in the m_{e^*}–λ_γ plane.
[49] DERRICK 93B search for single e^* production via $e^*e\gamma$ coupling in ep collisions with the decays $e^* \to e\gamma$, eZ, νW. See their Fig. 3 for exclusion plot in the m_{e^*}–λ_γ plane.
[50] Superseded by ADRIANI 93M.
[51] Superseded by DECAMP 92.
[52] ABE 88B limits use $e^+e^- \to ee^*$ where t-channel photon exchange dominates giving $e\gamma(e)$ (quasi-real compton scattering).
[53] ANSARI 87D is at $E_{\rm cm}$ = 546–630 GeV.

Limits for Excited e (e^*) from $e^+e^- \to \gamma\gamma$

These limits are derived from indirect effects due to e^* exchange in the t channel and depend on transition magnetic coupling between e and e^*. All limits are for $\lambda_\gamma = 1$. All limits except ABE 89J are for nonchiral coupling with $\eta_L = \eta_R = 1$.

For limits prior to 1987, see our 1992 edition (Physical Review **D45,** 1 June, Part II (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>127	95	ADRIANI	92B	L3	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[54] BUSKULIC	93Q	ALEP	
>114	95	[55] BARDADIN-...	92	RVUE	
> 99	95	DECAMP	92	ALEP	
		[56] SHIMOZAWA	92	TOPZ	
>100	95	ABREU	91E	DLPH	
>116	95	AKRAWY	91F	OPAL	
> 83	95	ADEVA	90K	L3	
> 82	95	AKRAWY	90F	OPAL	
> 68	95	[57] ABE	89J	VNS	η_L=1, η_R=0
> 90.2	95	ADACHI	89B	TOPZ	
> 65	95	KIM	89	AMY	

[54] BUSKULIC 93Q obtain Λ^+ >121 GeV (95%CL) from ALEPH experiment and Λ^+ >135 GeV from combined TRISTAN and ALEPH data. These limits roughly correspond to limits on m_{e^*}.
[55] BARDADIN-OTWINOWSKA 92 limit from fit to the combined data of DECAMP 92, ABREU 91E, ADEVA 90K, AKRAWY 91F.
[56] SHIMOZAWA 92 fit the data to the limiting form of the cross section with $m_{e^*} \gg E_{\rm cm}$ and obtain m_{e^*} >168 GeV at 95%CL. Use of the full form would reduce this limit by a few GeV. The statistically unexpected large value is due to fluctuation in the data.
[57] The ABE 89J limit assumes chiral coupling. This corresponds to λ_γ = 0.7 for nonchiral coupling.

Indirect Limits for Excited e (e^*)

These limits make use of loop effects involving e^* and are therefore subject to theoretical uncertainty.

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[58] DORENBOS...	89	CHRM	$\overline{\nu}_\mu e \to \overline{\nu}_\mu e$ and $\nu_\mu e \to \nu_\mu e$
	[59] GRIFOLS	86	THEO	$\nu_\mu e \to \nu_\mu e$
	[60] RENARD	82	THEO	$g-2$ of electron

[58] DORENBOSCH 89 obtain the limit $\lambda_\gamma^2 \Lambda_{\rm cut}^2 / m_{e^*}^2 <$ 2.6 (95% CL), where $\Lambda_{\rm cut}$ is the cutoff scale, based on the one-loop calculation by GRIFOLS 86. If one assumes that $\Lambda_{\rm cut}$ = 1 TeV and λ_γ = 1, one obtains m_{e^*} > 620 GeV. However, one generally expects $\lambda_\gamma \approx m_{e^*}/\Lambda_{\rm cut}$ in composite models.
[59] GRIFOLS 86 uses $\nu_\mu e \to \nu_\mu e$ and $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$ data from CHARM Collaboration to derive mass limits which depend on the scale of compositeness.
[60] RENARD 82 derived from $g-2$ data limits on mass and couplings of e^* and μ^*. See figures 2 and 3 of the paper.

MASS LIMITS for Excited μ (μ^*)

Limits for Excited μ (μ^*) from Pair Production

These limits are obtained from $e^+e^- \to \mu^{*+}\mu^{*-}$ and thus rely only on the (electroweak) charge of μ^*. Form factor effects are ignored unless noted. For the case of limits from Z decay, the μ^* coupling is assumed to be of sequential type. All limits assume $\mu^* \to \mu\gamma$ decay except for the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review **D45,** 1 June, Part II (1992)).

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>45.6	95	ADRIANI	93M	L3	$Z \to \mu^*\mu^*$
>45.6	95	ABREU	92C	DLPH	$Z \to \mu^*\mu^*$
>46.1	95	DECAMP	92	ALEP	$Z \to \mu^*\mu^*$
>44.9	95	AKRAWY	90I	OPAL	$Z \to \mu^*\mu^*$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>29.8	95	[61] BARDADIN-...	92	RVUE	$\Gamma(Z)$
>26.1	95	[62] DECAMP	92	ALEP	$Z \to \mu^*\mu^*$; $\Gamma(Z)$
>33	95	[62] ABREU	91F	DLPH	$Z \to \mu^*\mu^*$; $\Gamma(Z)$
>45.3	95	[63] ADEVA	90F	L3	$Z \to \mu^*\mu^*$
>44.6	95	[64] DECAMP	90G	ALEP	$e^+e^- \to \mu^*\mu^*$
>29.9	95	ADACHI	89B	TOPZ	$e^+e^- \to \mu^*\mu^*$
>28.3	95	KIM	89	AMY	$e^+e^- \to \mu^*\mu^*$

[61] BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on $\Delta\Gamma(Z)$<36 MeV.
[62] Limit is independent of μ^* decay mode.
[63] Superseded by ADRIANI 93M.
[64] Superseded by DECAMP 92.