

# Quark and Lepton Compositeness, Searches for

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## SCALE LIMITS for Contact Interactions: $\Lambda(eeee)$

Limits are for  $\Lambda_{LL}^{\pm}$  only. For other cases, see each reference.

$\Lambda_{LL}^+(\text{TeV})$	$\Lambda_{LL}^-(\text{TeV})$	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;8.3</b>	<b>&gt;10.3</b>	95	<sup>1</sup> BOURILKOV 01	RVUE	$E_{\text{cm}} = 192\text{--}208$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
>5.3	>6.8	95	ABDALLAH 06C	DLPH	$E_{\text{cm}} = 130\text{--}207$ GeV
>4.7	>6.1	95	<sup>2</sup> ABBIENDI 04G	OPAL	$E_{\text{cm}} = 130\text{--}207$ GeV
>3.8	>5.6	95	ABBIENDI 00R	OPAL	$E_{\text{cm}} = 189$ GeV
>4.4	>5.4	95	ABREU 00S	DLPH	$E_{\text{cm}} = 183\text{--}189$ GeV
>4.3	>4.9	95	ACCIARRI 00P	L3	$E_{\text{cm}} = 130\text{--}189$ GeV
>3.5	>3.2	95	BARATE 00I	ALEP	$E_{\text{cm}} = 130\text{--}183$ GeV
>6.0	>7.7	95	<sup>3</sup> BOURILKOV 00	RVUE	$E_{\text{cm}} = 183\text{--}189$ GeV
>3.1	>3.8	95	ABBIENDI 99	OPAL	$E_{\text{cm}} = 130\text{--}136, 161\text{--}172, 183$ GeV
>2.2	>2.8	95	ABREU 99A	DLPH	$E_{\text{cm}} = 130\text{--}172$ GeV
>2.7	>2.4	95	ACCIARRI 98J	L3	$E_{\text{cm}} = 130\text{--}172$ GeV
>3.0	>2.5	95	ACKERSTAFF 98V	OPAL	$E_{\text{cm}} = 130\text{--}172$ GeV
>2.4	>2.2	95	ACKERSTAFF 97C	OPAL	$E_{\text{cm}} = 130\text{--}136, 161$ GeV
>1.7	>2.3	95	ARIMA 97	VNS	$E_{\text{cm}} = 57.77$ GeV
>1.6	>2.0	95	<sup>4</sup> BUSKULIC 93Q	ALEP	$E_{\text{cm}} = 88.25\text{--}94.25$ GeV
>1.6		95	<sup>4,5</sup> BUSKULIC 93Q	RVUE	
	>2.2	95	BUSKULIC 93Q	RVUE	
	>3.6	95	<sup>6</sup> KROHA 92	RVUE	
>1.3		95	<sup>6</sup> KROHA 92	RVUE	
>0.7	>2.8	95	BEHREND 91C	CELL	$E_{\text{cm}} = 35$ GeV
>1.3	>1.3	95	KIM 89	AMY	$E_{\text{cm}} = 50\text{--}57$ GeV
>1.4	>3.3	95	<sup>7</sup> BRAUNSCH... 88	TASS	$E_{\text{cm}} = 12\text{--}46.8$ GeV
>1.0	>0.7	95	<sup>8</sup> FERNANDEZ 87B	MAC	$E_{\text{cm}} = 29$ GeV
>1.1	>1.4	95	<sup>9</sup> BARTEL 86C	JADE	$E_{\text{cm}} = 12\text{--}46.8$ GeV
>1.17	>0.87	95	<sup>10</sup> DERRICK 86	HRS	$E_{\text{cm}} = 29$ GeV
>1.1	>0.76	95	<sup>11</sup> BERGER 85B	PLUT	$E_{\text{cm}} = 34.7$ GeV

<sup>1</sup> A combined analysis of the data from ALEPH, DELPHI, L3, and OPAL.

<sup>2</sup> ABBIENDI 04G limits are from  $e^+e^- \rightarrow e^+e^-$  cross section at  $\sqrt{s} = 130\text{--}207$  GeV.

<sup>3</sup> A combined analysis of the data from ALEPH, L3, and OPAL.

<sup>4</sup> BUSKULIC 93Q uses the following prescription to obtain the limit: when the naive 95%CL limit is better than the statistically expected sensitivity for the limit, the latter is adopted for the limit.

<sup>5</sup> This BUSKULIC 93Q value is from ALEPH data plus PEP/PETRA/TRISTAN data re-analyzed by KROHA 92.

<sup>6</sup> KROHA 92 limit is from fit to BERGER 85B, BARTEL 86C, DERRICK 86B, FERNANDEZ 87B, BRAUNSCHWEIG 88, BEHREND 91B, and BEHREND 91C. The fit gives  $\eta/\Lambda_{LL}^2 = +0.230 \pm 0.206$  TeV<sup>-2</sup>.

<sup>7</sup> BRAUNSCHWEIG 88 assumed  $m_Z = 92$  GeV and  $\sin^2\theta_W = 0.23$ .

<sup>8</sup> FERNANDEZ 87B assumed  $\sin^2\theta_W = 0.22$ .

<sup>9</sup> BARTEL 86C assumed  $m_Z = 93$  GeV and  $\sin^2\theta_W = 0.217$ .

<sup>10</sup> DERRICK 86 assumed  $m_Z = 93$  GeV and  $g_V^2 = (-1/2 + 2\sin^2\theta_W)^2 = 0.004$ .

<sup>11</sup> BERGER 85B assumed  $m_Z = 93$  GeV and  $\sin^2\theta_W = 0.217$ .

## SCALE LIMITS for Contact Interactions: $\Lambda(ee\mu\mu)$

Limits are for  $\Lambda_{LL}^\pm$  only. For other cases, see each reference.

$\Lambda_{LL}^+$ (TeV)	$\Lambda_{LL}^-$ (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
>7.3	<b>&gt;7.6</b>	95	ABDALLAH	06C DLPH	$E_{cm} = 130\text{--}207$ GeV
<b>&gt;8.5</b>	>3.8	95	ACCIARRI	00P L3	$E_{cm} = 130\text{--}189$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
>8.1	>7.3	95	<sup>12</sup> ABBIENDI	04G OPAL	$E_{cm} = 130\text{--}207$ GeV
>7.3	>4.6	95	ABBIENDI	00R OPAL	$E_{cm} = 189$ GeV
>6.6	>6.3	95	ABREU	00S DLPH	$E_{cm} = 183\text{--}189$ GeV
>4.0	>4.7	95	BARATE	00I ALEP	$E_{cm} = 130\text{--}183$ GeV
>4.5	>4.3	95	ABBIENDI	99 OPAL	$E_{cm} = 130\text{--}136, 161\text{--}172, 183$ GeV
>3.4	>2.7	95	ABREU	99A DLPH	$E_{cm} = 130\text{--}172$ GeV
>3.6	>2.4	95	ACCIARRI	98J L3	$E_{cm} = 130\text{--}172$ GeV
>2.9	>3.4	95	ACKERSTAFF	98V OPAL	$E_{cm} = 130\text{--}172$ GeV
>3.1	>2.0	95	MIURA	98 VNS	$E_{cm} = 57.77$ GeV
>2.4	>2.9	95	ACKERSTAFF	97C OPAL	$E_{cm} = 130\text{--}136, 161$ GeV
>1.7	>2.2	95	<sup>13</sup> VELISSARIS	94 AMY	$E_{cm} = 57.8$ GeV
>1.3	>1.5	95	<sup>13</sup> BUSKULIC	93Q ALEP	$E_{cm} = 88.25\text{--}94.25$ GeV
>2.6	>1.9	95	<sup>13,14</sup> BUSKULIC	93Q RVUE	
>2.3	>2.0	95	HOWELL	92 TOPZ	$E_{cm} = 52\text{--}61.4$ GeV
	>1.7	95	<sup>15</sup> KROHA	92 RVUE	
>2.5	>1.5	95	BEHREND	91C CELL	$E_{cm} = 35\text{--}43$ GeV
>1.6	>2.0	95	<sup>16</sup> ABE	90I VNS	$E_{cm} = 50\text{--}60.8$ GeV
>1.9	>1.0	95	KIM	89 AMY	$E_{cm} = 50\text{--}57$ GeV
>2.3	>1.3	95	BRAUNSCH...	88D TASS	$E_{cm} = 30\text{--}46.8$ GeV
>4.4	>2.1	95	<sup>17</sup> BARTEL	86C JADE	$E_{cm} = 12\text{--}46.8$ GeV
>2.9	>0.86	95	<sup>18</sup> BERGER	85 PLUT	$E_{cm} = 34.7$ GeV

<sup>12</sup> ABBIENDI 04G limits are from  $e^+e^- \rightarrow \mu\mu$  cross section at  $\sqrt{s} = 130\text{--}207$  GeV.

<sup>13</sup> BUSKULIC 93Q and VELISSARIS 94 use the following prescription to obtain the limit: when the naive 95%CL limit is better than the statistically expected sensitivity for the limit, the latter is adopted for the limit.

<sup>14</sup> This BUSKULIC 93Q value is from ALEPH data plus PEP/PETRA/TRISTAN data re-analyzed by KROHA 92.

<sup>15</sup> KROHA 92 limit is from fit to BARTEL 86C, BEHREND 87C, BRAUNSCHWEIG 88D, BRAUNSCHWEIG 89C, ABE 90I, and BEHREND 91C. The fit gives  $\eta/\Lambda_{LL}^2 = -0.155 \pm 0.095$  TeV<sup>-2</sup>.

<sup>16</sup> ABE 90I assumed  $m_Z = 91.163$  GeV and  $\sin^2\theta_W = 0.231$ .

<sup>17</sup> BARTEL 86C assumed  $m_Z = 93$  GeV and  $\sin^2\theta_W = 0.217$ .

<sup>18</sup> BERGER 85 assumed  $m_Z = 93$  GeV and  $\sin^2\theta_W = 0.217$ .

## SCALE LIMITS for Contact Interactions: $\Lambda(e\tau\tau)$

Limits are for  $\Lambda_{LL}^{\pm}$  only. For other cases, see each reference.

$\Lambda_{LL}^+$ (TeV)	$\Lambda_{LL}^-$ (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;7.9</b>	>4.6	95	ABDALLAH	06C	DLPH $E_{cm} = 130\text{--}207$ GeV
>4.9	<b>&gt;7.2</b>	95	<sup>19</sup> ABBIENDI	04G	OPAL $E_{cm} = 130\text{--}207$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
>3.9	>6.5	95	ABBIENDI	00R	OPAL $E_{cm} = 189$ GeV
>5.2	>5.4	95	ABREU	00S	DLPH $E_{cm} = 183\text{--}189$ GeV
>5.4	>4.7	95	ACCIARRI	00P	L3 $E_{cm} = 130\text{--}189$ GeV
>3.9	>3.7	95	BARATE	00I	ALEP $E_{cm} = 130\text{--}183$ GeV
>3.8	>4.0	95	ABBIENDI	99	OPAL $E_{cm} = 130\text{--}136, 161\text{--}172, 183$ GeV
>2.8	>2.6	95	ABREU	99A	DLPH $E_{cm} = 130\text{--}172$ GeV
>2.4	>2.8	95	ACCIARRI	98J	L3 $E_{cm} = 130\text{--}172$ GeV
>2.3	>3.7	95	ACKERSTAFF	98V	OPAL $E_{cm} = 130\text{--}172$ GeV
>1.9	>3.0	95	ACKERSTAFF	97C	OPAL $E_{cm} = 130\text{--}136, 161$ GeV
>1.4	>2.0	95	<sup>20</sup> VELISSARIS	94	AMY $E_{cm} = 57.8$ GeV
>1.0	>1.5	95	<sup>20</sup> BUSKULIC	93Q	ALEP $E_{cm} = 88.25\text{--}94.25$ GeV
>1.8	>2.3	95	<sup>20,21</sup> BUSKULIC	93Q	RVUE
>1.9	>1.7	95	HOWELL	92	TOPZ $E_{cm} = 52\text{--}61.4$ GeV
>1.9	>2.9	95	<sup>22</sup> KROHA	92	RVUE
>1.6	>2.3	95	BEHREND	91C	CELL $E_{cm} = 35\text{--}43$ GeV
>1.8	>1.3	95	<sup>23</sup> ABE	90I	VNS $E_{cm} = 50\text{--}60.8$ GeV
>2.2	>3.2	95	<sup>24</sup> BARTEL	86	JADE $E_{cm} = 12\text{--}46.8$ GeV

<sup>19</sup> ABBIENDI 04G limits are from  $e^+e^- \rightarrow \tau\tau$  cross section at  $\sqrt{s} = 130\text{--}207$  GeV.

<sup>20</sup> BUSKULIC 93Q and VELISSARIS 94 use the following prescription to obtain the limit: when the naive 95%CL limit is better than the statistically expected sensitivity for the limit, the latter is adopted for the limit.

<sup>21</sup> This BUSKULIC 93Q value is from ALEPH data plus PEP/PETRA/TRISTAN data re-analyzed by KROHA 92.

<sup>22</sup> KROHA 92 limit is from fit to BARTEL 86C BEHREND 89B, BRAUNSCHWEIG 89C, ABE 90I, and BEHREND 91C. The fit gives  $\eta/\Lambda_{LL}^2 = +0.095 \pm 0.120$  TeV<sup>-2</sup>.

<sup>23</sup> ABE 90I assumed  $m_Z = 91.163$  GeV and  $\sin^2\theta_W = 0.231$ .

<sup>24</sup> BARTEL 86 assumed  $m_Z = 93$  GeV and  $\sin^2\theta_W = 0.217$ .

## SCALE LIMITS for Contact Interactions: $\Lambda(\ell\ell\ell\ell)$

Lepton universality assumed. Limits are for  $\Lambda_{LL}^{\pm}$  only. For other cases, see each reference.

$\Lambda_{LL}^+$ (TeV)	$\Lambda_{LL}^-$ (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;9.1</b>	>8.2	95	ABDALLAH	06C	DLPH $E_{cm} = 130\text{--}207$ GeV
>7.7	<b>&gt;9.5</b>	95	<sup>25</sup> ABBIENDI	04G	OPAL $E_{cm} = 130\text{--}207$ GeV

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

			26	BABICH	03	RVUE	
>6.4	>7.2	95		ABBIENDI	00R	OPAL	$E_{cm} = 189$ GeV
>7.3	>7.8	95		ABREU	00S	DLPH	$E_{cm} = 183-189$ GeV
>9.0	>5.2	95		ACCIARRI	00P	L3	$E_{cm} = 130-189$ GeV
>5.3	>5.5	95		BARATE	00I	ALEP	$E_{cm} = 130-183$ GeV
>5.2	>5.3	95		ABBIENDI	99	OPAL	$E_{cm} = 130-136, 161-172, 183$ GeV
>4.4	>4.2	95		ABREU	99A	DLPH	$E_{cm} = 130-172$ GeV
>4.0	>3.1	95	27	ACCIARRI	98J	L3	$E_{cm} = 130-172$ GeV
>3.4	>4.4	95		ACKERSTAFF	98V	OPAL	$E_{cm} = 130-172$ GeV
>2.7	>3.8	95		ACKERSTAFF	97C	OPAL	$E_{cm} = 130-136, 161$ GeV
>3.0	>2.3	95	27,28	BUSKULIC	93Q	ALEP	$E_{cm} = 88.25-94.25$ GeV
>3.5	>2.8	95	28,29	BUSKULIC	93Q	RVUE	
>2.5	>2.2	95	30	HOWELL	92	TOPZ	$E_{cm} = 52-61.4$ GeV
>3.4	>2.7	95	31	KROHA	92	RVUE	

25 ABBIENDI 04G limits are from  $e^+e^- \rightarrow \ell^+\ell^-$  cross section at  $\sqrt{s} = 130-207$  GeV.

26 BABICH 03 obtain a bound  $-0.175 \text{ TeV}^{-2} < 1/\Lambda_{LL}^2 < 0.095 \text{ TeV}^{-2}$  (95%CL) in a model independent analysis allowing all of  $\Lambda_{LL}, \Lambda_{LR}, \Lambda_{RL}, \Lambda_{RR}$  to coexist.

27 From  $e^+e^- \rightarrow e^+e^-, \mu^+\mu^-,$  and  $\tau^+\tau^-$ .

28 BUSKULIC 93Q uses the following prescription to obtain the limit: when the naive 95%CL limit is better than the statistically expected sensitivity for the limit, the latter is adopted for the limit.

29 This BUSKULIC 93Q value is from ALEPH data plus PEP/PETRA/TRISTAN data re-analyzed by KROHA 92.

30 HOWELL 92 limit is from  $e^+e^- \rightarrow \mu^+\mu^-$  and  $\tau^+\tau^-$ .

31 KROHA 92 limit is from fit to most PEP/PETRA/TRISTAN data. The fit gives  $\eta/\Lambda_{LL}^2 = -0.0200 \pm 0.0666 \text{ TeV}^{-2}$ .

## SCALE LIMITS for Contact Interactions: $\Lambda(eeqq)$

Limits are for  $\Lambda_{LL}^\pm$  only. For other cases, see each reference.

$\Lambda_{LL}^+$ (TeV)	$\Lambda_{LL}^-$ (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;23.3</b>	<b>&gt;12.5</b>	95	32 CHEUNG	01B	RVUE ( $eeuu$ )
<b>&gt;11.1</b>	<b>&gt;26.4</b>	95	32 CHEUNG	01B	RVUE ( $eedd$ )
<b>&gt; 5.6</b>	<b>&gt;4.9</b>	95	33 BARATE	00I	ALEP ( $eebb$ )
<b>&gt; 1.0</b>	<b>&gt;2.1</b>	95	34 ABREU	99A	DLPH ( $eecc$ )

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

> 3.7	>5.9	95	35	ABULENCIA	06L	CDF	( $eeqq$ )
> 8.2	>3.7	95	36	ABBIENDI	04G	OPAL	( $eeqq$ )
> 5.9	>9.1	95	36	ABBIENDI	04G	OPAL	( $eeuu$ )
> 8.6	>5.5	95	36	ABBIENDI	04G	OPAL	( $eedd$ )
> 2.7	>1.7	95		CHEKANOV	04B	ZEUS	( $eeqq$ )
> 2.8	>1.6	95	37	ADLOFF	03	H1	( $eeqq$ )
> 2.7	>2.7	95	38	ACHARD	02J	L3	( $eeec$ )
> 5.5	>3.1	95	39	ABBIENDI	00R	OPAL	( $eeqq$ )
> 4.9	>6.1	95	39	ABBIENDI	00R	OPAL	( $eeuu$ )
> 5.7	>4.5	95	39	ABBIENDI	00R	OPAL	( $eedd$ )
> 4.2	>2.8	95	40	ACCIARRI	00P	L3	( $eeqq$ )
> 2.4	>1.3	95	41	ADLOFF	00	H1	( $eeqq$ )

> 5.4	>6.2	95	42	BARATE	00I	ALEP	( <i>eeqq</i> )
			43	BREITWEG	00B	ZEUS	
> 4.4	>2.8	95	44	ABBIENDI	99	OPAL	( <i>eeqq</i> )
> 4.0	>4.8	95	45	ABBIENDI	99	OPAL	( <i>eebb</i> )
> 3.3	>4.2	95	46	ABBOTT	99D	D0	( <i>eeqq</i> )
> 2.4	>2.8	95	34	ABREU	99A	DLPH	( <i>eeqq</i> ) ( <i>d</i> or <i>s</i> quark)
> 4.4	>3.9	95	34	ABREU	99A	DLPH	( <i>eebb</i> )
> 1.0	>2.4	95	34	ABREU	99A	DLPH	( <i>eeuu</i> )
> 4.0	>3.4	95	47	ZARNECKI	99	RVUE	( <i>eedd</i> )
> 4.3	>5.6	95	47	ZARNECKI	99	RVUE	( <i>eeuu</i> )
> 3.0	>2.1	95	48	ACCIARRI	98J	L3	( <i>eeqq</i> )
> 3.4	>2.2	95	49	ACKERSTAFF	98V	OPAL	( <i>eeqq</i> )
> 4.0	>2.8	95	50	ACKERSTAFF	98V	OPAL	( <i>eebb</i> )
> 9.3	>12.0	95	51	BARGER	98E	RVUE	( <i>eeuu</i> )
> 8.8	>11.9	95	51	BARGER	98E	RVUE	( <i>eedd</i> )
> 2.5	>3.7	95	52	ABE	97T	CDF	( <i>eeqq</i> ) (isosinglet)
> 2.5	>2.1	95	53	ACKERSTAFF	97C	OPAL	( <i>eeqq</i> )
> 3.1	>2.9	95	54	ACKERSTAFF	97C	OPAL	( <i>eebb</i> )
> 7.4	>11.7	95	55	DEANDREA	97	RVUE	<i>eeuu</i> , atomic parity violation
> 2.3	>1.0	95	56	AID	95	H1	( <i>eeqq</i> ) ( <i>u</i> , <i>d</i> quarks)
1.7	>2.2	95	57	ABE	91D	CDF	( <i>eeqq</i> ) ( <i>u</i> , <i>d</i> quarks)
> 1.2		95	58	ADACHI	91	TOPZ	( <i>eeqq</i> ) (flavor-universal)
	>1.6	95	58	ADACHI	91	TOPZ	( <i>eeqq</i> ) (flavor-universal)
> 0.6	>1.7	95	59	BEHREND	91C	CELL	( <i>eecc</i> )
> 1.1	>1.0	95	59	BEHREND	91C	CELL	( <i>eebb</i> )
> 0.9		95	60	ABE	89L	VNS	( <i>eeqq</i> ) (flavor-universal)
	>1.7	95	60	ABE	89L	VNS	( <i>eeqq</i> ) (flavor-universal)
> 1.05	>1.61	95	61	HAGIWARA	89	RVUE	( <i>eecc</i> )
> 1.21	>0.53	95	62	HAGIWARA	89	RVUE	( <i>eebb</i> )

<sup>32</sup> CHEUNG 01B is an update of BARGER 98E.

<sup>33</sup> BARATE 00I limits are from  $R_b$  and jet-charge asymmetry at 130–183 GeV.

<sup>34</sup> ABREU 99A limits are from flavor-tagged  $e^+e^- \rightarrow q\bar{q}$  cross section at 130–172 GeV.

<sup>35</sup> ABULENCIA 06L limits are from  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV.

<sup>36</sup> ABBIENDI 04G limits are from  $e^+e^- \rightarrow q\bar{q}$  cross section at  $\sqrt{s} = 130$ –207 GeV.

<sup>37</sup> ADLOFF 03 limits are from the  $d\sigma/dQ^2$  measurement of  $e^\pm p \rightarrow e^\pm X$ .

<sup>38</sup> ACHARD 02J limit is from the bound on the  $e^+e^- \rightarrow t\bar{c}$  cross section.  $\Lambda_{LL} = \Lambda_{LR} = \Lambda_{RL} = \Lambda_{RR}$  and  $m_t = 175$  GeV are assumed.

<sup>39</sup> ABBIENDI 00R limits are from  $e^+e^- \rightarrow q\bar{q}$  cross section at  $\sqrt{s} = 130$ –189 GeV.

<sup>40</sup> ACCIARRI 00P limit is from  $e^+e^- \rightarrow qq$  cross section at  $\sqrt{s} = 130$ –189 GeV.

<sup>41</sup> ADLOFF 00 limits are from the  $Q^2$  spectrum measurement of  $e^+p \rightarrow e^+X$ .

<sup>42</sup> BARATE 00I limits are from  $e^+e^- \rightarrow q\bar{q}$  cross section and jet-charge asymmetry at 130–183 GeV.

<sup>43</sup> BREITWEG 00B limits are from  $Q^2$  spectrum measurement of  $e^+p$  collisions. See their Table 3 for the limits of various models.

<sup>44</sup> ABBIENDI 99 limits are from  $e^+e^- \rightarrow q\bar{q}$  cross section at 130–136, 161–172, 183 GeV.

<sup>45</sup> ABBIENDI 99 limits are from  $R_b$  at 130–136, 161–172, 183 GeV.

- 46 ABBOTT 99D limits are from  $e^+e^-$  mass distribution in  $p\bar{p} \rightarrow e^+e^-X$  at  $E_{\text{cm}} = 1.8$  TeV.
- 47 ZARNECKI 99 use data from HERA, LEP, Tevatron, and various low-energy experiments.
- 48 ACCIARRI 98J limits are from  $e^+e^- \rightarrow q\bar{q}$  cross section at  $E_{\text{cm}} = 130\text{--}172$  GeV.
- 49 ACKERSTAFF 98V limits are from  $e^+e^- \rightarrow q\bar{q}$  at  $E_{\text{cm}} = 130\text{--}172$  GeV.
- 50 ACKERSTAFF 98V limits are from  $R_b$  measurements at  $E_{\text{cm}} = 130\text{--}172$  GeV.
- 51 BARGER 98E use data from HERA, LEP, Tevatron, and various low-energy experiments.
- 52 ABE 97T limits are from  $e^+e^-$  mass distribution in  $\bar{p}p \rightarrow e^+e^-X$  at  $E_{\text{cm}} = 1.8$  TeV.
- 53 ACKERSTAFF 97C limits are from  $e^+e^- \rightarrow q\bar{q}$  cross section at  $E_{\text{cm}} = 130\text{--}136$  GeV and 161 GeV.
- 54 ACKERSTAFF 97C limits are  $R_b$  measurements at  $E_{\text{cm}} = 133$  GeV and 161 GeV.
- 55 DEANDREA 97 limit is from atomic parity violation of cesium. The limit is excluded if the contact interactions are parity conserving.
- 56 AID 95 limits are from the  $Q^2$  spectrum measurement of  $ep \rightarrow eX$ .
- 57 ABE 91D limits are from  $e^+e^-$  mass distribution in  $p\bar{p} \rightarrow e^+e^-X$  at  $E_{\text{cm}} = 1.8$  TeV.
- 58 ADACHI 91 limits are from differential jet cross section. Universality of  $\Lambda(eeqq)$  for five flavors is assumed.
- 59 BEHREND 91C is from data at  $E_{\text{cm}} = 35\text{--}43$  GeV.
- 60 ABE 89L limits are from jet charge asymmetry. Universality of  $\Lambda(eeqq)$  for five flavors is assumed.
- 61 The HAGIWARA 89 limit is derived from forward-backward asymmetry measurements of  $D/D^*$  mesons by ALTHOFF 83C, BARTEL 84E, and BARINGER 88.
- 62 The HAGIWARA 89 limit is derived from forward-backward asymmetry measurement of  $b$  hadrons by BARTEL 84D.

### SCALE LIMITS for Contact Interactions: $\Lambda(\mu\mu qq)$

$\Lambda_{LL}^+$ (TeV)	$\Lambda_{LL}^-$ (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt; 2.9</b>	<b>&gt; 4.2</b>	95	<sup>63</sup> ABE	97T CDF	$(\mu\mu qq)$ (isosinglet)
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
>1.4	>1.6	95	ABE	92B CDF	$(\mu\mu qq)$ (isosinglet)
<sup>63</sup> ABE 97T limits are from $\mu^+\mu^-$ mass distribution in $\bar{p}p \rightarrow \mu^+\mu^-X$ at $E_{\text{cm}} = 1.8$ TeV.					

### SCALE LIMITS for Contact Interactions: $\Lambda(\ell\nu\ell\nu)$

VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;3.10</b>	90	<sup>64</sup> JODIDIO	86 SPEC	$\Lambda_{LR}^\pm(\nu_\mu\nu_e\mu e)$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>3.8		<sup>65</sup> DIAZCRUZ	94 RVUE	$\Lambda_{LL}^+(\tau\nu_\tau e\nu_e)$
>8.1		<sup>65</sup> DIAZCRUZ	94 RVUE	$\Lambda_{LL}^-(\tau\nu_\tau e\nu_e)$
>4.1		<sup>66</sup> DIAZCRUZ	94 RVUE	$\Lambda_{LL}^+(\tau\nu_\tau\mu\nu_\mu)$
>6.5		<sup>66</sup> DIAZCRUZ	94 RVUE	$\Lambda_{LL}^-(\tau\nu_\tau\mu\nu_\mu)$

- <sup>64</sup> JODIDIO 86 limit is from  $\mu^+ \rightarrow \bar{\nu}_\mu e^+ \nu_e$ . Chirality invariant interactions  $L = (g^2/\Lambda^2) [\eta_{LL} (\bar{\nu}_\mu L \gamma^\alpha \mu_L) (\bar{e} L \gamma_\alpha \nu_e L) + \eta_{LR} (\bar{\nu}_\mu L \gamma^\alpha \nu_e L) (\bar{e} R \gamma_\alpha \mu_R)]$  with  $g^2/4\pi = 1$  and  $(\eta_{LL}, \eta_{LR}) = (0, \pm 1)$  are taken. No limits are given for  $\Lambda_{LL}^\pm$  with  $(\eta_{LL}, \eta_{LR}) = (\pm 1, 0)$ . For more general constraints with right-handed neutrinos and chirality nonconserving contact interactions, see their text.
- <sup>65</sup> DIAZCRUZ 94 limits are from  $\Gamma(\tau \rightarrow e \nu \nu)$  and assume flavor-dependent contact interactions with  $\Lambda(\tau \nu_\tau e \nu_e) \ll \Lambda(\mu \nu_\mu e \nu_e)$ .
- <sup>66</sup> DIAZCRUZ 94 limits are from  $\Gamma(\tau \rightarrow \mu \nu \nu)$  and assume flavor-dependent contact interactions with  $\Lambda(\tau \nu_\tau \mu \nu_\mu) \ll \Lambda(\mu \nu_\mu e \nu_e)$ .

### SCALE LIMITS for Contact Interactions: $\Lambda(e\nu qq)$

VALUE (TeV)	CL%	DOCUMENT ID	TECN
>2.81	95	<sup>67</sup> AFFOLDER 01i	CDF

<sup>67</sup> AFFOLDER 00i bound is for a scalar interaction  $\bar{q}_R q_L \bar{\nu} e_L$ .

### SCALE LIMITS for Contact Interactions: $\Lambda(qqqq)$

Limits are for  $\Lambda_{LL}^\pm$  with color-singlet isoscalar exchanges among  $u_L$ 's and  $d_L$ 's only, unless otherwise noted. See EICHTEN 84 for details.

VALUE (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
>2.7	95	<sup>68</sup> ABBOTT 99C	D0	$p\bar{p} \rightarrow$ dijet mass. $\Lambda_{LL}^+$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>2.0	95	<sup>69</sup> ABBOTT 00E	D0	$H_T$ distribution; $\Lambda_{LL}^+$
>2.1	95	<sup>70</sup> ABBOTT 98G	D0	$p\bar{p} \rightarrow$ dijet angl. $\Lambda_{LL}^+$
		<sup>71</sup> BERTRAM 98	RVUE	$p\bar{p} \rightarrow$ dijet mass
		<sup>72</sup> ABE 96	CDF	$p\bar{p} \rightarrow$ jets inclusive
>1.6	95	<sup>73</sup> ABE 96S	CDF	$p\bar{p} \rightarrow$ dijet angl.; $\Lambda_{LL}^+$
>1.3	95	<sup>74</sup> ABE 93G	CDF	$p\bar{p} \rightarrow$ dijet mass
>1.4	95	<sup>75</sup> ABE 92D	CDF	$p\bar{p} \rightarrow$ jets inclusive
>1.0	99	<sup>76</sup> ABE 92M	CDF	$p\bar{p} \rightarrow$ dijet angl.
>0.825	95	<sup>77</sup> ALITTI 91B	UA2	$p\bar{p} \rightarrow$ jets inclusive
>0.700	95	<sup>75</sup> ABE 89	CDF	$p\bar{p} \rightarrow$ jets inclusive
>0.330	95	<sup>78</sup> ABE 89H	CDF	$p\bar{p} \rightarrow$ dijet angl.
>0.400	95	<sup>79</sup> ARNISON 86C	UA1	$p\bar{p} \rightarrow$ jets inclusive
>0.415	95	<sup>80</sup> ARNISON 86D	UA1	$p\bar{p} \rightarrow$ dijet angl.
>0.370	95	<sup>81</sup> APPEL 85	UA2	$p\bar{p} \rightarrow$ jets inclusive
>0.275	95	<sup>82</sup> BAGNAIA 84C	UA2	Repl. by APPEL 85

<sup>68</sup> The quoted limit is from inclusive dijet mass spectrum in  $p\bar{p}$  collisions at  $E_{cm}=1.8$  TeV. ABBOTT 99C also obtain  $\Lambda_{LL}^- > 2.4$  TeV. All quarks are assumed composite.

<sup>69</sup> The quoted limit for ABBOTT 00E is from  $H_T$  distribution in  $p\bar{p}$  collisions at  $E_{cm}=1.8$  TeV. CTEQ4M PDF and  $\mu=E_T^{\max}$  are assumed. For limits with different assumptions, see their Tables 2 and 3. All quarks are assumed composite.

<sup>70</sup> ABBOTT 98G limit is from dijet angular distribution in  $p\bar{p}$  collisions at  $E_{cm}=1.8$  TeV. All quarks are assumed composite.

- 71 BERTRAM 98 obtain limit on the scale of color-octet axial-vector flavor-universal contact interactions:  $\Lambda_{A8} > 2.1$  TeV. They also obtain a limit  $\Lambda_{V8} > 2.4$  TeV on a color-octet flavor-universal vectorial contact interaction.
- 72 ABE 96 finds that the inclusive jet cross section for  $E_T > 200$  GeV is significantly higher than the  $\mathcal{O}(\alpha_s^3)$  perturbative QCD prediction. This could be interpreted as the effect of a contact interaction with  $\Lambda_{LL} \sim 1.6$  TeV. However, ABE 96 state that uncertainty in the parton distribution functions, higher-order QCD corrections, and the detector calibration may possibly account for the effect.
- 73 ABE 96S limit is from dijet angular distribution in  $p\bar{p}$  collisions at  $E_{cm} = 1.8$  TeV. The limit for  $\Lambda_{LL}^-$  is  $> 1.4$  TeV. ABE 96S also obtain limits for flavor symmetric contact interactions among all quark flavors:  $\Lambda_{LL}^+ > 1.8$  TeV and  $\Lambda_{LL}^- > 1.6$  TeV.
- 74 ABE 93G limit is from dijet mass distribution in  $p\bar{p}$  collisions at  $E_{cm} = 1.8$  TeV. The limit is the weakest from several choices of structure functions and renormalization scale.
- 75 Limit is from inclusive jet cross-section data in  $p\bar{p}$  collisions at  $E_{cm} = 1.8$  TeV. The limit takes into account uncertainties in choice of structure functions and in choice of process scale.
- 76 ABE 92M limit is from dijet angular distribution for  $m_{dijet} > 550$  GeV in  $p\bar{p}$  collisions at  $E_{cm} = 1.8$  TeV.
- 77 ALITTI 91B limit is from inclusive jet cross section in  $p\bar{p}$  collisions at  $E_{cm} = 630$  GeV. The limit takes into account uncertainties in choice of structure functions and in choice of process scale.
- 78 ABE 89H limit is from dijet angular distribution for  $m_{dijet} > 200$  GeV at the Fermilab Tevatron Collider with  $E_{cm} = 1.8$  TeV. The QCD prediction is quite insensitive to choice of structure functions and choice of process scale.
- 79 ARNISON 86C limit is from the study of inclusive high- $p_T$  jet distributions at the CERN  $\bar{p}p$  collider ( $E_{cm} = 546$  and  $630$  GeV). The QCD prediction renormalized to the low- $p_T$  region gives a good fit to the data.
- 80 ARNISON 86D limit is from the study of dijet angular distribution in the range  $240 < m(\text{dijet}) < 300$  GeV at the CERN  $\bar{p}p$  collider ( $E_{cm} = 630$  GeV). QCD prediction using EHLQ structure function (EICHTEN 84) with  $\Lambda_{QCD} = 0.2$  GeV for the choice of  $Q^2 = p_T^2$  gives the best fit to the data.
- 81 APPEL 85 limit is from the study of inclusive high- $p_T$  jet distributions at the CERN  $\bar{p}p$  collider ( $E_{cm} = 630$  GeV). The QCD prediction renormalized to the low- $p_T$  region gives a good description of the data.
- 82 BAGNAIA 84C limit is from the study of jet  $p_T$  and dijet mass distributions at the CERN  $\bar{p}p$  collider ( $E_{cm} = 540$  GeV). The limit suffers from the uncertainties in comparing the data with the QCD prediction.

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### SCALE LIMITS for Contact Interactions: $\Lambda(\nu\nu qq)$

Limits are for  $\Lambda_{LL}^\pm$  only. For other cases, see each reference.

$\Lambda_{LL}^+$ (TeV)	$\Lambda_{LL}^-$ (TeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;5.0</b>	<b>&gt;5.4</b>	95	83 MCFARLAND 98	CCFR	$\nu N$ scattering

83 MCFARLAND 98 assumed a flavor universal interaction. Neutrinos were mostly of muon type.

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## 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  $\lambda$  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  $\lambda$  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  $e^+e^- \rightarrow e^{*+}e^{*-}$  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 a dominant  $e^* \rightarrow e\gamma$  decay except the limits from  $\Gamma(Z)$ .

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>103.2	95	84 ABBIENDI	02G OPAL	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>102.8	95	85 ACHARD	03B L3	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
>100.0	95	86 ACCIARRI	01D L3	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 91.3	95	87 ABBIENDI	00I OPAL	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 94.2	95	88 ACCIARRI	00E L3	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 90.7	95	89 ABREU	99O DLPH	Homodoublet type
> 85.0	95	90 ACKERSTAFF	98C OPAL	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
		91 BARATE	98U ALEP	$Z \rightarrow e^*e^*$
> 79.6	95	92,93 ABREU	97B DLPH	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 77.9	95	92,94 ABREU	97B DLPH	$e^+e^- \rightarrow e^*e^*$ Sequential type
> 79.7	95	92 ACCIARRI	97G L3	$e^+e^- \rightarrow e^*e^*$ Sequential type
> 79.9	95	92,95 ACKERSTAFF	97 OPAL	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 62.5	95	96 ABREU	96K DLPH	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 64.7	95	97 ACCIARRI	96D L3	$e^+e^- \rightarrow e^*e^*$ Sequential type
> 66.5	95	97 ALEXANDER	96Q OPAL	$e^+e^- \rightarrow e^*e^*$ Homodoublet type
> 65.2	95	97 BUSKULIC	96W ALEP	$e^+e^- \rightarrow e^*e^*$ Sequential type
> 45.6	95	ADRIANI	93M L3	$Z \rightarrow e^*e^*$
> 45.6	95	ABREU	92C DLPH	$Z \rightarrow e^*e^*$
> 29.8	95	98 BARDADIN-...	92 RVUE	$\Gamma(Z)$

> 26.1	95	99	DECAMP	92	ALEP	$Z \rightarrow e^* e^*$ ; $\Gamma(Z)$
> 46.1	95		DECAMP	92	ALEP	$Z \rightarrow e^* e^*$
> 33	95	99	ABREU	91F	DLPH	$Z \rightarrow e^* e^*$ ; $\Gamma(Z)$
> 45.0	95	100	ADEVA	90F	L3	$Z \rightarrow e^* e^*$
> 44.9	95		AKRAWY	90I	OPAL	$Z \rightarrow e^* e^*$
> 44.6	95	101	DECAMP	90G	ALEP	$e^+ e^- \rightarrow e^* e^*$
> 30.2	95		ADACHI	89B	TOPZ	$e^+ e^- \rightarrow e^* e^*$
> 28.3	95		KIM	89	AMY	$e^+ e^- \rightarrow e^* e^*$
> 27.9	95	102	ABE	88B	VNS	$e^+ e^- \rightarrow e^* e^*$

<sup>84</sup> From  $e^+ e^-$  collisions at  $\sqrt{s} = 183\text{--}209$  GeV.  $f = f'$  is assumed.

<sup>85</sup> From  $e^+ e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV.  $f = f'$  is assumed. ACHARD 03B also obtain limit for  $f = -f'$ :  $m_{e^*} > 96.6$  GeV.

<sup>86</sup> From  $e^+ e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV.  $f=f'$  is assumed. ACCIARRI 01D also obtain limit for  $f=-f'$ :  $m_{e^*} > 93.4$  GeV.

<sup>87</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}=161\text{--}183$  GeV.  $f=f'$  is assumed. ABBIENDI 00I also obtain limit for  $f=-f'$  ( $e^* \rightarrow \nu W$ ):  $m_{e^*} > 86.0$  GeV.

<sup>88</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}=189$  GeV.  $f=f'$  is assumed. ACCIARRI 00E also obtain limit for  $f=-f'$  ( $e^* \rightarrow \nu W$ ):  $m_{e^*} > 92.6$  GeV.

<sup>89</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}= 183$  GeV.  $f=f'$  is assumed. ABREU 990 also obtain limit for  $f=-f'$  ( $e^* \rightarrow \nu W$ ):  $m_{e^*} > 81.3$  GeV.

<sup>90</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}=170\text{--}172$  GeV. ACKERSTAFF 98C also obtain limit from  $e^* \rightarrow \nu W$  decay mode:  $m_{e^*} > 81.3$  GeV.

<sup>91</sup> BARATE 98U obtain limits on the form factor. See their Fig. 14 for limits in mass-form factor plane.

<sup>92</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}= 161$  GeV.

<sup>93</sup> ABREU 97B also obtain limit from charged current decay mode  $e^* \rightarrow \nu W$ ,  $m_{e^*} > 70.9$  GeV.

<sup>94</sup> ABREU 97B also obtain limit from charged current decay mode  $e^* \rightarrow \nu W$ ,  $m_{e^*} > 44.6$  GeV.

<sup>95</sup> ACKERSTAFF 97 also obtain limit from charged current decay mode  $e^* \rightarrow \nu W$ ,  $m_{\nu_e^*} > 77.1$  GeV.

<sup>96</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}= 130\text{--}136$  GeV.

<sup>97</sup> From  $e^+ e^-$  collisions at  $\sqrt{s}= 130\text{--}140$  GeV.

<sup>98</sup> BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on  $\Delta\Gamma(Z)<36$  MeV.

<sup>99</sup> Limit is independent of  $e^*$  decay mode.

<sup>100</sup> ADEVA 90F is superseded by ADRIANI 93M.

<sup>101</sup> Superseded by DECAMP 92.

<sup>102</sup> ABE 88B limits assume  $e^+ e^- \rightarrow e^{*+} e^{*-}$  with one photon exchange only and  $e^* \rightarrow e\gamma$  giving  $e e \gamma \gamma$ .

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

These limits are from  $e^+ e^- \rightarrow e^* e$ ,  $W \rightarrow e^* \nu$ , or  $e p \rightarrow e^* X$  and depend on transition magnetic coupling between  $e$  and  $e^*$ . All limits assume  $e^* \rightarrow e\gamma$  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  $\lambda\text{--}m_{e^*}$  plane. See the original papers.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>255	95	103 ADLOFF	02B H1	$ep \rightarrow e^* X$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>209	95	104 ACOSTA	05B CDF	$p\bar{p} \rightarrow e^* X$
>206	95	105 ACHARD	03B L3	$e^+e^- \rightarrow ee^*$
>208	95	106 ABBIENDI	02G OPAL	$e^+e^- \rightarrow ee^*$
>228	95	107 CHEKANOV	02D ZEUS	$ep \rightarrow e^* X$
>202		108 ACCIARRI	01D L3	$e^+e^- \rightarrow ee^*$
		109 ABBIENDI	00I OPAL	$e^+e^- \rightarrow ee^*$
		110 ACCIARRI	00E L3	$e^+e^- \rightarrow ee^*$
>223	95	111 ADLOFF	00E H1	$ep \rightarrow e^* X$
		112 ABREU	99O DLPH	$e^+e^- \rightarrow ee^*$
none 20–170	95	113 ACCIARRI	98T L3	$e\gamma \rightarrow e^* \rightarrow e\gamma$
		114 ACKERSTAFF	98C OPAL	$e^+e^- \rightarrow ee^*$
		115 BARATE	98U ALEP	$e^+e^- \rightarrow ee^*$
		116,117 ABREU	97B DLPH	$e^+e^- \rightarrow ee^*$
		116,118 ACCIARRI	97G L3	$e^+e^- \rightarrow ee^*$
		119 ACKERSTAFF	97 OPAL	$e^+e^- \rightarrow ee^*$
		120 ADLOFF	97 H1	Lepton-flavor violation
none 30–200	95	121 BREITWEG	97C ZEUS	$ep \rightarrow e^* X$
		122 ABREU	96K DLPH	$e^+e^- \rightarrow ee^*$
		123 ACCIARRI	96D L3	$e^+e^- \rightarrow ee^*$
		124 ALEXANDER	96Q OPAL	$e^+e^- \rightarrow ee^*$
		125 BUSKULIC	96W ALEP	$e^+e^- \rightarrow ee^*$
		126 DERRICK	95B ZEUS	$ep \rightarrow e^* X$
		127 ABT	93 H1	$ep \rightarrow e^* X$
> 86	95	ADRIANI	93M L3	$\lambda_\gamma > 0.04$
> 89	95	ADRIANI	93M L3	$Z \rightarrow ee^*, \lambda_Z > 0.5$
		128 DERRICK	93B ZEUS	Superseded by DERRICK 95B
> 88	95	ABREU	92C DLPH	$Z \rightarrow ee^*, \lambda_Z > 0.5$
> 86	95	ABREU	92C DLPH	$e^+e^- \rightarrow ee^*, \lambda_\gamma > 0.1$
> 91	95	DECAMP	92 ALEP	$Z \rightarrow ee^*, \lambda_Z > 1$
> 88	95	129 ADEVA	90F L3	$Z \rightarrow ee^*, \lambda_Z > 0.5$
> 86	95	129 ADEVA	90F L3	$Z \rightarrow ee^*, \lambda_Z > 0.04$
> 87	95	AKRAWY	90I OPAL	$Z \rightarrow ee^*, \lambda_Z > 0.5$
> 81	95	130 DECAMP	90G ALEP	$Z \rightarrow ee^*, \lambda_Z > 1$
> 50	95	ADACHI	89B TOPZ	$e^+e^- \rightarrow ee^*, \lambda_\gamma > 0.04$
> 56	95	KIM	89 AMY	$e^+e^- \rightarrow ee^*, \lambda_\gamma > 0.03$
none 23–54	95	131 ABE	88B VNS	$e^+e^- \rightarrow ee^*, \lambda_\gamma > 0.04$
> 75	95	132 ANSARI	87D UA2	$W \rightarrow e^* \nu; \lambda_W > 0.7$
> 63	95	132 ANSARI	87D UA2	$W \rightarrow e^* \nu; \lambda_W > 0.2$
> 40	95	132 ANSARI	87D UA2	$W \rightarrow e^* \nu; \lambda_W > 0.09$

<sup>103</sup> ADLOFF 02B search for single  $e^*$  production in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ .  $f = f' = \Lambda/m_{e^*}$  is assumed for the  $e^*$  coupling. See their Fig. 3 for the exclusion plot in the mass-coupling plane.

- 104 ACOSTA 05B search for single  $e^*$  production in  $p\bar{p}$  collisions with the decays  $e^* \rightarrow e\gamma$ .  $f = f' = \Lambda/m_{e^*}$  is assumed for the  $e^*$  coupling. See their Fig.3 for the exclusion limit in the mass-coupling plane.
- 105 ACHARD 03B result is from  $e^+e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV. See their Fig. 4 for the exclusion plot in the mass-coupling plane.
- 106 ABBIENDI 02G result is from  $e^+e^-$  collisions at  $\sqrt{s} = 183\text{--}209$  GeV.  $f = f' = \Lambda/m_{e^*}$  is assumed for  $e^*$  coupling. See their Fig. 4c for the exclusion limit in the mass-coupling plane.
- 107 CHEKANOV 02D search for single  $e^*$  production in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ .  $f = f' = \Lambda/m_{e^*}$  is assumed for the  $e^*$  coupling. See their Fig. 5a for the exclusion plot in the mass-coupling plane.
- 108 ACCIARRI 01D result is from  $e^+e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV.  $f=f'=\Lambda/m_{e^*}$  is assumed for the  $e^*$  coupling. See their Fig. 4 for limits in the mass-coupling plane.
- 109 ABBIENDI 00I result is from  $e^+e^-$  collisions at  $\sqrt{s}=161\text{--}183$  GeV. See their Fig. 7 for limits in mass-coupling plane.
- 110 ACCIARRI 00E result is from  $e^+e^-$  collisions at  $\sqrt{s}=189$  GeV. See their Fig. 3 for limits in mass-coupling plane.
- 111 ADLOFF 00E search for single  $e^*$  production in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ .  $f=f'=\Lambda/m_{e^*}$  is assumed for the  $e^*$  coupling. See their Fig. 9 for the exclusion plot in the mass-coupling plane.
- 112 ABREU 99O result is from  $e^+e^-$  collisions at  $\sqrt{s}= 183$  GeV. See their Figs. 4 and 5 for the exclusion limit in the mass-coupling plane.
- 113 ACCIARRI 98T search for single  $e^*$  production in quasi-real Compton scattering. The limit is for  $|\lambda| > 1.0 \times 10^{-1}$  and non-chiral coupling of  $e^*$ . See their Fig. 7 for the exclusion plot in the mass-coupling plane.
- 114 ACKERSTAFF 98C from  $e^+e^-$  collisions at  $\sqrt{s}=170\text{--}172$  GeV. See their Fig. 11 for the exclusion limit in the mass-coupling plane.
- 115 BARATE 98U is from  $e^+e^-$  collision at  $\sqrt{s}=M_Z$ . See their Fig. 12 for limits in mass-coupling plane
- 116 From  $e^+e^-$  collisions at  $\sqrt{s}= 161$  GeV.
- 117 See Fig. 4a and Fig. 5a of ABREU 97B for the exclusion limit in the mass-coupling plane.
- 118 See Fig. 2 and Fig. 3 of ACCIARRI 97G for the exclusion limit in the mass-coupling plane.
- 119 ACKERSTAFF 97 result is from  $e^+e^-$  collisions at  $\sqrt{s}= 161$  GeV. See their Fig. 3 for the exclusion limit in the mass-coupling plane.
- 120 ADLOFF 97 search for single  $e^*$  production in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ . See their Fig. 4 for the rejection limits on the product of the production cross section and the branching ratio into a specific decay channel.
- 121 BREITWEG 97C search for single  $e^*$  production in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ .  $f=f'=2\Lambda/m_{e^*}$  is assumed for the  $e^*$  coupling. See their Fig. 9 for the exclusion plot in the mass-coupling plane.
- 122 ABREU 96K result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}136$  GeV. See their Fig. 4 for the exclusion limit in the mass-coupling plane.
- 123 ACCIARRI 96D result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}140$  GeV. See their Fig. 2 for the exclusion limit in the mass-coupling plane.
- 124 ALEXANDER 96Q result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}140$  GeV. See their Fig. 3a for the exclusion limit in the mass-coupling plane.
- 125 BUSKULIC 96W result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}140$  GeV. See their Fig. 3 for the exclusion limit in the mass-coupling plane.
- 126 DERRICK 95B search for single  $e^*$  production via  $e^*e\gamma$  coupling in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ . See their Fig. 13 for the exclusion plot in the  $m_{e^*}-\lambda\gamma$  plane.

- 127 ABT 93 search for single  $e^*$  production via  $e^*e\gamma$  coupling in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ . See their Fig. 4 for exclusion plot in the  $m_{e^*}-\lambda_\gamma$  plane.
- 128 DERRICK 93B search for single  $e^*$  production via  $e^*e\gamma$  coupling in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ . See their Fig. 3 for exclusion plot in the  $m_{e^*}-\lambda_\gamma$  plane.
- 129 Superseded by ADRIANI 93M.
- 130 Superseded by DECAMP 92.
- 131 ABE 88B limits use  $e^+e^- \rightarrow ee^*$  where t-channel photon exchange dominates giving  $e\gamma(e)$  (quasi-real compton scattering).
- 132 ANSARI 87D is at  $E_{cm} = 546-630$  GeV.

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

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 and ACHARD 02D are for nonchiral coupling with  $\eta_L = \eta_R = 1$ . We choose the chiral coupling limit as the best limit and list it in the Summary Table.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;310</b>	95	ACHARD 02D	L3	$\sqrt{s}=192-209$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>356	95	<sup>133</sup> ABDALLAH 04N	DLPH	$\sqrt{s}=161-208$ GeV
>311	95	ABREU 00A	DLPH	$\sqrt{s}=189-202$ GeV
>283	95	<sup>134</sup> ACCIARRI 00G	L3	$\sqrt{s}=183-189$ GeV
>306	95	ABBIENDI 99P	OPAL	$\sqrt{s}=189$ GeV
>231	95	ABREU 98J	DLPH	$\sqrt{s}=130-183$ GeV
>194	95	ACKERSTAFF 98	OPAL	$\sqrt{s}=130-172$ GeV
>227	95	ACKER...,K...	98B OPAL	$\sqrt{s}=183$ GeV
>250	95	BARATE 98J	ALEP	$\sqrt{s}=183$ GeV
>160	95	<sup>135</sup> BARATE 98U	ALEP	
>210	95	<sup>136</sup> ACCIARRI 97W	L3	$\sqrt{s}=161, 172$ GeV
>129	95	ACCIARRI 96L	L3	$\sqrt{s}=133$ GeV
>147	95	ALEXANDER 96K	OPAL	
>136	95	BUSKULIC 96Z	ALEP	$\sqrt{s}=130, 136$ GeV
>146	95	ACCIARRI 95G	L3	
		<sup>137</sup> BUSKULIC 93Q	ALEP	
>127	95	<sup>138</sup> ADRIANI 92B	L3	
>114	95	<sup>139</sup> BARDADIN-... 92	RVUE	
> 99	95	DECAMP 92	ALEP	
		<sup>140</sup> 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	<sup>141</sup> ABE 89J	VNS	$\eta_L=1, \eta_R=0$
> 90.2	95	ADACHI 89B	TOPZ	
> 65	95	KIM 89	AMY	

- 133 ABDALLAH 04N also obtain a limit on the excited electron mass with  $e e^*$  chiral coupling,  $m_{e^*} > 295$  GeV at 95% CL.
- 134 ACCIARRI 00G also obtain a limit on  $e^*$  with chiral coupling,  $m_{e^*} > 213$  GeV.
- 135 BARATE 98U is from  $e^+ e^-$  collision at  $\sqrt{s}=M_Z$ . See their Fig. 5 for limits in mass-coupling plane
- 136 ACCIARRI 97W also obtain a limit on  $e^*$  with chiral coupling,  $m_{e^*} > 157$  GeV (95%CL).
- 137 BUSKULIC 93Q obtain  $\Lambda^+ > 121$  GeV (95%CL) from ALEPH experiment and  $\Lambda^+ > 135$  GeV from combined TRISTAN and ALEPH data. These limits roughly correspond to limits on  $m_{e^*}$ .
- 138 ADRIANI 92B superseded by ACCIARRI 95G.
- 139 BARDADIN-OTWINOWSKA 92 limit from fit to the combined data of DECAMP 92, ABREU 91E, ADEVA 90K, AKRAWY 91F.
- 140 SHIMOZAWA 92 fit the data to the limiting form of the cross section with  $m_{e^*} \gg E_{\text{cm}}$  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.
- 141 The ABE 89J limit assumes chiral coupling. This corresponds to  $\lambda_\gamma = 0.7$  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. ● ● ●			
	142 DORENBOS...	89	CHRM $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$ and $\nu_\mu e \rightarrow \nu_\mu e$
	143 GRIFOLS	86	THEO $\nu_\mu e \rightarrow \nu_\mu e$
	144 RENARD	82	THEO $g-2$ of electron
142	DORENBOSCH 89 obtain the limit $\lambda_\gamma^2 \Lambda_{\text{cut}}^2 / m_{e^*}^2 < 2.6$ (95% CL), where $\Lambda_{\text{cut}}$ is the cutoff scale, based on the one-loop calculation by GRIFOLS 86. If one assumes that $\Lambda_{\text{cut}} = 1$ TeV and $\lambda_\gamma = 1$ , one obtains $m_{e^*} > 620$ GeV. However, one generally expects $\lambda_\gamma \approx m_{e^*} / \Lambda_{\text{cut}}$ in composite models.		
143	GRIFOLS 86 uses $\nu_\mu e \rightarrow \nu_\mu e$ and $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$ data from CHARM Collaboration to derive mass limits which depend on the scale of compositeness.		
144	RENARD 82 derived from $g-2$ data limits on mass and couplings of $e^*$ and $\mu^*$ . See figures 2 and 3 of the paper.		

## MASS LIMITS for Excited $\mu$ ( $\mu^*$ )

### Limits for Excited $\mu$ ( $\mu^*$ ) from Pair Production

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

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;103.2</b>	95	145 ABBIENDI	02G OPAL	$e^+ e^- \rightarrow \mu^* \mu^*$ Homodoublet type

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

>102.8	95	146	ACHARD	03B	L3	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
>100.2	95	147	ACCIARRI	01D	L3	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 91.3	95	148	ABBIENDI	00I	OPAL	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 94.2	95	149	ACCIARRI	00E	L3	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 90.7	95	150	ABREU	99O	DLPH	Homodoublet type
> 85.3	95	151	ACKERSTAFF	98C	OPAL	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
		152	BARATE	98U	ALEP	$Z \rightarrow \mu^*\mu^*$
> 79.6	95	153,154	ABREU	97B	DLPH	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 78.4	95	153,155	ABREU	97B	DLPH	$e^+e^- \rightarrow \mu^*\mu^*$ Sequential type
> 79.9	95	153	ACCIARRI	97G	L3	$e^+e^- \rightarrow \mu^*\mu^*$ Sequential type
> 80.0	95	153,156	ACKERSTAFF	97	OPAL	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 62.6	95	157	ABREU	96K	DLPH	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 64.9	95	158	ACCIARRI	96D	L3	$e^+e^- \rightarrow \mu^*\mu^*$ Sequential type
> 66.8	95	158	ALEXANDER	96Q	OPAL	$e^+e^- \rightarrow \mu^*\mu^*$ Homodoublet type
> 65.4	95	158	BUSKULIC	96W	ALEP	$e^+e^- \rightarrow \mu^*\mu^*$ Sequential type
> 45.6	95		ADRIANI	93M	L3	$Z \rightarrow \mu^*\mu^*$
> 45.6	95		ABREU	92C	DLPH	$Z \rightarrow \mu^*\mu^*$
> 29.8	95	159	BARDADIN-...	92	RVUE	$\Gamma(Z)$
> 26.1	95	160	DECAMP	92	ALEP	$Z \rightarrow \mu^*\mu^*$ ; $\Gamma(Z)$
> 46.1	95		DECAMP	92	ALEP	$Z \rightarrow \mu^*\mu^*$
> 33	95	160	ABREU	91F	DLPH	$Z \rightarrow \mu^*\mu^*$ ; $\Gamma(Z)$
> 45.3	95	161	ADEVA	90F	L3	$Z \rightarrow \mu^*\mu^*$
> 44.9	95		AKRAWY	90I	OPAL	$Z \rightarrow \mu^*\mu^*$
> 44.6	95	162	DECAMP	90G	ALEP	$e^+e^- \rightarrow \mu^*\mu^*$
> 29.9	95		ADACHI	89B	TOPZ	$e^+e^- \rightarrow \mu^*\mu^*$
> 28.3	95		KIM	89	AMY	$e^+e^- \rightarrow \mu^*\mu^*$

145 From  $e^+e^-$  collisions at  $\sqrt{s} = 183\text{--}209$  GeV.  $f = f'$  is assumed.

146 From  $e^+e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV.  $f = f'$  is assumed. ACHARD 03B also obtain limit for  $f = -f'$ :  $m_{\mu^*} > 96.6$  GeV.

147 From  $e^+e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV.  $f=f'$  is assumed. ACCIARRI 01D also obtain limit for  $f=-f'$ :  $m_{\mu^*} > 93.4$  GeV.

148 From  $e^+e^-$  collisions at  $\sqrt{s}=161\text{--}183$  GeV.  $f=f'$  is assumed. ABBIENDI 00I also obtain limit for  $f=-f'$  ( $\mu^* \rightarrow \nu W$ ):  $m_{\mu^*} > 86.0$  GeV.

149 From  $e^+e^-$  collisions at  $\sqrt{s}=189$  GeV.  $f=f'$  is assumed. ACCIARRI 00E also obtain limit for  $f=-f'$  ( $\mu^* \rightarrow \nu W$ ):  $m_{\mu^*} > 92.6$  GeV.

150 From  $e^+e^-$  collisions at  $\sqrt{s}= 183$  GeV.  $f=f'$  is assumed. ABREU 99O also obtain limit for  $f=-f'$  ( $\mu^* \rightarrow \nu W$ ):  $m_{\mu^*} > 81.3$  GeV.

151 From  $e^+e^-$  collisions at  $\sqrt{s}=170\text{--}172$  GeV. ACKERSTAFF 98C also obtain limit from  $\mu^* \rightarrow \nu W$  decay mode:  $m_{\mu^*} > 81.3$  GeV.

- 152 BARATE 98U obtain limits on the form factor. See their Fig. 14 for limits in mass-form factor plane.
- 153 From  $e^+e^-$  collisions at  $\sqrt{s}=161$  GeV.
- 154 ABREU 97B also obtain limit from charged current decay mode  $\mu^* \rightarrow \nu W$ ,  $m_{\mu^*} > 70.9$  GeV.
- 155 ABREU 97B also obtain limit from charged current decay mode  $\mu^* \rightarrow \nu W$ ,  $m_{\mu^*} > 44.6$  GeV.
- 156 ACKERSTAFF 97 also obtain limit from charged current decay mode  $\mu^* \rightarrow \nu W$ ,  $m_{\nu_{\mu^*}} > 77.1$  GeV.
- 157 From  $e^+e^-$  collisions at  $\sqrt{s}=130-136$  GeV.
- 158 From  $e^+e^-$  collisions at  $\sqrt{s}=130-140$  GeV.
- 159 BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on  $\Delta\Gamma(Z) < 36$  MeV.
- 160 Limit is independent of  $\mu^*$  decay mode.
- 161 Superseded by ADRIANI 93M.
- 162 Superseded by DECAMP 92.

### Limits for Excited $\mu$ ( $\mu^*$ ) from Single Production

These limits are from  $e^+e^- \rightarrow \mu^*\mu$  and depend on transition magnetic coupling between  $\mu$  and  $\mu^*$ . All limits assume  $\mu^* \rightarrow \mu\gamma$  decay. Limits from LEP 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  $\lambda-m_{\mu^*}$  plane. See the original papers.

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;221</b>	95	163 ABULENCIA,A 06B	CDF	$p\bar{p} \rightarrow \mu\mu^*, \mu^* \rightarrow \mu\gamma$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
	95	164 ABAZOV	06E D0	$p\bar{p} \rightarrow \mu\mu^*$
>180	95	165 ACHARD	03B L3	$e^+e^- \rightarrow \mu\mu^*$
>190	95	166 ABBIENDI	02G OPAL	$e^+e^- \rightarrow \mu\mu^*$
>178	95	167 ACCIARRI	01D L3	$e^+e^- \rightarrow \mu\mu^*$
		168 ABBIENDI	00I OPAL	$e^+e^- \rightarrow \mu\mu^*$
		169 ACCIARRI	00E L3	$e^+e^- \rightarrow \mu\mu^*$
		170 ABREU	99O DLPH	$e^+e^- \rightarrow \mu\mu^*$
		171 ACKERSTAFF	98C OPAL	$e^+e^- \rightarrow \mu\mu^*$
		172 BARATE	98U ALEP	$Z \rightarrow \mu\mu^*$
	173,174	ABREU	97B DLPH	$e^+e^- \rightarrow \mu\mu^*$
	173,175	ACCIARRI	97G L3	$e^+e^- \rightarrow \mu\mu^*$
		176 ACKERSTAFF	97 OPAL	$e^+e^- \rightarrow \mu\mu^*$
		177 ABREU	96K DLPH	$e^+e^- \rightarrow \mu\mu^*$
		178 ACCIARRI	96D L3	$e^+e^- \rightarrow \mu\mu^*$
		179 ALEXANDER	96Q OPAL	$e^+e^- \rightarrow \mu\mu^*$
		180 BUSKULIC	96W ALEP	$e^+e^- \rightarrow \mu\mu^*$
> 89	95	ADRIANI	93M L3	$Z \rightarrow \mu\mu^*, \lambda_Z > 0.5$
> 88	95	ABREU	92C DLPH	$Z \rightarrow \mu\mu^*, \lambda_Z > 0.5$
> 91	95	DECAMP	92 ALEP	$Z \rightarrow \mu\mu^*, \lambda_Z > 1$



> 85	95	181 ADEVA	90F L3	$Z \rightarrow \mu\mu^*, \lambda_Z > 1$
> 75	95	181 ADEVA	90F L3	$Z \rightarrow \mu\mu^*, \lambda_Z > 0.1$
> 87	95	AKRAWY	90I OPAL	$Z \rightarrow \mu\mu^*, \lambda_Z > 1$
> 80	95	182 DECAMP	90G ALEP	$e^+e^- \rightarrow \mu\mu^*, \lambda_Z=1$
> 50	95	ADACHI	89B TOPZ	$e^+e^- \rightarrow \mu\mu^*, \lambda_\gamma=0.7$
> 46	95	KIM	89 AMY	$e^+e^- \rightarrow \mu\mu^*, \lambda_\gamma=0.2$

163  $f = f' = \Lambda/m_{\mu^*}$  is assumed for the  $\mu^*$  coupling. See their Fig.4 for the exclusion limit in the mass-coupling plane. ABULENCIA, A 06B also obtain  $m_{\mu^*}$  limit in the contact interaction model with  $\Lambda = m_{\mu^*}$ ,  $m_{\mu^*} > 696$  GeV.

164 ABAZOV 06E assume  $\mu\mu^*$  production via four-fermion contact interaction  $(4\pi/\Lambda^2)(\bar{q}_L \gamma^\mu q_L)(\bar{\mu}_L^* \gamma_\mu \mu)$ . The obtained limit is  $m_{\mu^*} > 618$  GeV ( $m_{\mu^*} > 688$  GeV) for  $\Lambda = 1$  TeV ( $\Lambda = m_{\mu^*}$ ).

165 ACHARD 03B result is from  $e^+e^-$  collisions at  $\sqrt{s} = 189-209$  GeV.  $f = f' = \Lambda/m_{\mu^*}$  is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

166 ABBIENDI 02G result is from  $e^+e^-$  collisions at  $\sqrt{s} = 183-209$  GeV.  $f = f' = \Lambda/m_{\mu^*}$  is assumed for  $\mu^*$  coupling. See their Fig. 4c for the exclusion limit in the mass-coupling plane.

167 ACCIARRI 01D result is from  $e^+e^-$  collisions at  $\sqrt{s} = 192-202$  GeV.  $f=f'=\Lambda/m_{\mu^*}$  is assumed for the  $\mu^*$  coupling. See their Fig. 4 for limits in the mass-coupling plane.

168 ABBIENDI 00I result is from  $e^+e^-$  collisions at  $\sqrt{s}=161-183$  GeV. See their Fig. 7 for limits in mass-coupling plane.

169 ACCIARRI 00E result is from  $e^+e^-$  collisions at  $\sqrt{s}=189$  GeV. See their Fig. 3 for limits in mass-coupling plane.

170 ABREU 99O result is from  $e^+e^-$  collisions at  $\sqrt{s}= 183$  GeV. See their Figs. 4 and 5 for the exclusion limit in the mass-coupling plane.

171 ACKERSTAFF 98C from  $e^+e^-$  collisions at  $\sqrt{s}=170-172$  GeV. See their Fig. 11 for the exclusion limit in the mass-coupling plane.

172 BARATE 98U obtain limits on the  $Z\mu\mu^*$  coupling. See their Fig. 12 for limits in mass-coupling plane

173 From  $e^+e^-$  collisions at  $\sqrt{s}= 161$  GeV.

174 See Fig. 4a and Fig. 5a of ABREU 97B for the exclusion limit in the mass-coupling plane.

175 See Fig. 2 and Fig. 3 of ACCIARRI 97G for the exclusion limit in the mass-coupling plane.

176 ACKERSTAFF 97 result is from  $e^+e^-$  collisions at  $\sqrt{s}= 161$  GeV. See their Fig. 3 for the exclusion limit in the mass-coupling plane.

177 ABREU 96K result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130-136$  GeV. See their Fig. 4 for the exclusion limit in the mass-coupling plane.

178 ACCIARRI 96D result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130-140$  GeV. See their Fig. 2 for the exclusion limit in the mass-coupling plane.

179 ALEXANDER 96Q result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130-140$  GeV. See their Fig. 3a for the exclusion limit in the mass-coupling plane.

180 BUSKULIC 96W result is from  $e^+e^-$  collisions at  $\sqrt{s}= 130-140$  GeV. See their Fig. 3 for the exclusion limit in the mass-coupling plane.

181 Superseded by ADRIANI 93M.

182 Superseded by DECAMP 92.

## Indirect Limits for Excited $\mu$ ( $\mu^*$ )

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

<u>VALUE (GeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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• • • We do not use the following data for averages, fits, limits, etc. • • •

183	RENARD	82	THEO	$g-2$ of muon
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<sup>183</sup>RENARD 82 derived from  $g-2$  data limits on mass and couplings of  $e^*$  and  $\mu^*$ . See figures 2 and 3 of the paper.

## MASS LIMITS for Excited $\tau$ ( $\tau^*$ )

### Limits for Excited $\tau$ ( $\tau^*$ ) from Pair Production

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

For limits prior to 1987, see our 1992 edition (Physical Review **D45** S1 (1992)).

<u>VALUE (GeV)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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<b>&gt;103.2</b>	95	184	ABBIENDI 02G	OPAL $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
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• • • We do not use the following data for averages, fits, limits, etc. • • •

>102.8	95	185	ACHARD 03B	L3 $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 99.8	95	186	ACCIARRI 01D	L3 $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 91.2	95	187	ABBIENDI 00I	OPAL $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 94.2	95	188	ACCIARRI 00E	L3 $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 89.7	95	189	ABREU 99O	DLPH Homodoublet type
> 84.6	95	190	ACKERSTAFF 98C	OPAL $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 79.4	95	191,193	BARATE 98U ABREU 97B	ALEP $Z \rightarrow \tau^*\tau^*$ DLPH $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 77.4	95	192,194	ABREU 97B	DLPH $e^+e^- \rightarrow \tau^*\tau^*$ Sequential type
> 79.3	95	192	ACCIARRI 97G	L3 $e^+e^- \rightarrow \tau^*\tau^*$ Sequential type
> 79.1	95	192,195	ACKERSTAFF 97	OPAL $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 62.2	95	196	ABREU 96K	DLPH $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 64.2	95	197	ACCIARRI 96D	L3 $e^+e^- \rightarrow \tau^*\tau^*$ Sequential type
> 65.3	95	197	ALEXANDER 96Q	OPAL $e^+e^- \rightarrow \tau^*\tau^*$ Homodoublet type
> 64.8	95	197	BUSKULIC 96W	ALEP $e^+e^- \rightarrow \tau^*\tau^*$ Sequential type
> 45.6	95		ADRIANI 93M	L3 $Z \rightarrow \tau^*\tau^*$
> 45.3	95		ABREU 92C	DLPH $Z \rightarrow \tau^*\tau^*$
> 29.8	95	198	BARDADIN-... 92	RVUE $\Gamma(Z)$

> 26.1	95	199	DECAMP	92	ALEP	$Z \rightarrow \tau^* \tau^*$ ; $\Gamma(Z)$
> 46.0	95		DECAMP	92	ALEP	$Z \rightarrow \tau^* \tau^*$
> 33	95	199	ABREU	91F	DLPH	$Z \rightarrow \tau^* \tau^*$ ; $\Gamma(Z)$
> 45.5	95	200	ADEVA	90L	L3	$Z \rightarrow \tau^* \tau^*$
> 44.9	95		AKRAWY	90I	OPAL	$Z \rightarrow \tau^* \tau^*$
> 41.2	95	201	DECAMP	90G	ALEP	$e^+ e^- \rightarrow \tau^* \tau^*$
> 29.0	95		ADACHI	89B	TOPZ	$e^+ e^- \rightarrow \tau^* \tau^*$

- 184 From  $e^+ e^-$  collisions at  $\sqrt{s} = 183\text{--}209$  GeV.  $f = f'$  is assumed.
- 185 From  $e^+ e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV.  $f = f'$  is assumed. ACHARD 03B also obtain limit for  $f = -f'$ :  $m_{\tau^*} > 96.6$  GeV.
- 186 From  $e^+ e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV.  $f=f'$  is assumed. ACCIARRI 01D also obtain limit for  $f=-f'$ :  $m_{\tau^*} > 93.4$  GeV.
- 187 From  $e^+ e^-$  collisions at  $\sqrt{s}=161\text{--}183$  GeV.  $f=f'$  is assumed. ABBIENDI 00I also obtain limit for  $f=-f'$  ( $\tau^* \rightarrow \nu W$ ):  $m_{\tau^*} > 86.0$  GeV.
- 188 From  $e^+ e^-$  collisions at  $\sqrt{s}=189$  GeV.  $f=f'$  is assumed. ACCIARRI 00E also obtain limit for  $f=-f'$  ( $\tau^* \rightarrow \nu W$ ):  $m_{\tau^*} > 92.6$  GeV.
- 189 From  $e^+ e^-$  collisions at  $\sqrt{s}= 183$  GeV.  $f=f'$  is assumed. ABREU 990 also obtain limit for  $f=-f'$  ( $\tau^* \rightarrow \nu W$ ):  $m_{\tau^*} > 81.3$  GeV.
- 190 From  $e^+ e^-$  collisions at  $\sqrt{s}=170\text{--}172$  GeV. ACKERSTAFF 98C also obtain limit from  $\tau^* \rightarrow \nu W$  decay mode:  $m_{\tau^*} > 81.3$  GeV.
- 191 BARATE 98U obtain limits on the form factor. See their Fig. 14 for limits in mass-form factor plane.
- 192 From  $e^+ e^-$  collisions at  $\sqrt{s}= 161$  GeV.
- 193 ABREU 97B also obtain limit from charged current decay mode  $\tau^* \rightarrow \nu W$ ,  $m_{\tau^*} > 70.9$  GeV.
- 194 ABREU 97B also obtain limit from charged current decay mode  $\tau^* \rightarrow \nu W$ ,  $m_{\tau^*} > 44.6$  GeV.
- 195 ACKERSTAFF 97 also obtain limit from charged current decay mode  $\tau^* \rightarrow \nu W$ ,  $m_{\nu_{\tau^*}} > 77.1$  GeV.
- 196 From  $e^+ e^-$  collisions at  $\sqrt{s}= 130\text{--}136$  GeV.
- 197 From  $e^+ e^-$  collisions at  $\sqrt{s}= 130\text{--}140$  GeV.
- 198 BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on  $\Delta\Gamma(Z)<36$  MeV.
- 199 Limit is independent of  $\tau^*$  decay mode.
- 200 Superseded by ADRIANI 93M.
- 201 Superseded by DECAMP 92.

### Limits for Excited $\tau$ ( $\tau^*$ ) from Single Production

These limits are from  $e^+ e^- \rightarrow \tau^* \tau$  and depend on transition magnetic coupling between  $\tau$  and  $\tau^*$ . All limits assume  $\tau^* \rightarrow \tau \gamma$  decay. Limits from LEP 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  $\lambda\text{--}m_{\tau^*}$  plane. See the original papers.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;185</b>	95	202 ABBIENDI	02G OPAL	$e^+ e^- \rightarrow \tau \tau^*$

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

>180	95	203	ACHARD	03B	L3	$e^+e^- \rightarrow \tau\tau^*$
>173	95	204	ACCIARRI	01D	L3	$e^+e^- \rightarrow \tau\tau^*$
		205	ABBIENDI	00I	OPAL	$e^+e^- \rightarrow \tau\tau^*$
		206	ACCIARRI	00E	L3	$e^+e^- \rightarrow \tau\tau^*$
		207	ABREU	99O	DLPH	$e^+e^- \rightarrow \tau\tau^*$
		208	ACKERSTAFF	98C	OPAL	$e^+e^- \rightarrow \tau\tau^*$
		209	BARATE	98U	ALEP	$Z \rightarrow \tau\tau^*$
	210,211	ABREU	97B	DLPH	$e^+e^- \rightarrow \tau\tau^*$	
	210,212	ACCIARRI	97G	L3	$e^+e^- \rightarrow \tau\tau^*$	
		213	ACKERSTAFF	97	OPAL	$e^+e^- \rightarrow \tau\tau^*$
		214	ABREU	96K	DLPH	$e^+e^- \rightarrow \tau\tau^*$
		215	ACCIARRI	96D	L3	$e^+e^- \rightarrow \tau\tau^*$
		216	ALEXANDER	96Q	OPAL	$e^+e^- \rightarrow \tau\tau^*$
		217	BUSKULIC	96W	ALEP	$e^+e^- \rightarrow \tau\tau^*$
> 88	95		ADRIANI	93M	L3	$Z \rightarrow \tau\tau^*, \lambda_Z > 0.5$
> 87	95		ABREU	92C	DLPH	$Z \rightarrow \tau\tau^*, \lambda_Z > 0.5$
> 90	95		DECAMP	92	ALEP	$Z \rightarrow \tau\tau^*, \lambda_Z > 0.18$
> 88	95	218	ADEVA	90L	L3	$Z \rightarrow \tau\tau^*, \lambda_Z > 1$
> 86.5	95		AKRAWY	90I	OPAL	$Z \rightarrow \tau\tau^*, \lambda_Z > 1$
> 59	95	219	DECAMP	90G	ALEP	$Z \rightarrow \tau\tau^*, \lambda_Z = 1$
> 40	95	220	BARTEL	86	JADE	$e^+e^- \rightarrow \tau\tau^*, \lambda_\gamma = 1$
> 41.4	95	221	BEHREND	86	CELL	$e^+e^- \rightarrow \tau\tau^*, \lambda_\gamma = 1$
> 40.8	95	221	BEHREND	86	CELL	$e^+e^- \rightarrow \tau\tau^*, \lambda_\gamma = 0.7$

202 ABBIENDI 02G result is from  $e^+e^-$  collisions at  $\sqrt{s} = 183\text{--}209$  GeV.  $f = f' = \Lambda/m_{\tau^*}$  is assumed for  $\tau^*$  coupling. See their Fig. 4c for the exclusion limit in the mass-coupling plane.

203 ACHARD 03B result is from  $e^+e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV.  $f = f' = \Lambda/m_{\tau^*}$  is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

204 ACCIARRI 01D result is from  $e^+e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV.  $f = f' = \Lambda/m_{\tau^*}$  is assumed for the  $\tau^*$  coupling. See their Fig. 4 for limits in the mass-coupling plane.

205 ABBIENDI 00I result is from  $e^+e^-$  collisions at  $\sqrt{s} = 161\text{--}183$  GeV. See their Fig. 7 for limits in mass-coupling plane.

206 ACCIARRI 00E result is from  $e^+e^-$  collisions at  $\sqrt{s} = 189$  GeV. See their Fig. 3 for limits in mass-coupling plane.

207 ABREU 99O result is from  $e^+e^-$  collisions at  $\sqrt{s} = 183$  GeV. See their Figs. 4 and 5 for the exclusion limit in the mass-coupling plane.

208 ACKERSTAFF 98C from  $e^+e^-$  collisions at  $\sqrt{s} = 170\text{--}172$  GeV. See their Fig. 11 for the exclusion limit in the mass-coupling plane.

209 BARATE 98U obtain limits on the  $Z\tau\tau^*$  coupling. See their Fig. 12 for limits in mass-coupling plane

210 From  $e^+e^-$  collisions at  $\sqrt{s} = 161$  GeV.

211 See Fig. 4a and Fig. 5a of ABREU 97B for the exclusion limit in the mass-coupling plane.

212 See Fig. 2 and Fig. 3 of ACCIARRI 97G for the exclusion limit in the mass-coupling plane.

213 ACKERSTAFF 97 result is from  $e^+e^-$  collisions at  $\sqrt{s} = 161$  GeV. See their Fig. 3 for the exclusion limit in the mass-coupling plane.

214 ABREU 96K result is from  $e^+e^-$  collisions at  $\sqrt{s} = 130\text{--}136$  GeV. See their Fig. 4 for the exclusion limit in the mass-coupling plane.

- 215 ACCIARRI 96D result is from  $e^+e^-$  collisions at  $\sqrt{s}=130\text{--}140$  GeV. See their Fig. 2 for the exclusion limit in the mass-coupling plane.
- 216 ALEXANDER 96Q result is from  $e^+e^-$  collisions at  $\sqrt{s}=130\text{--}140$  GeV. See their Fig. 3a for the exclusion limit in the mass-coupling plane.
- 217 BUSKULIC 96W result is from  $e^+e^-$  collisions at  $\sqrt{s}=130\text{--}140$  GeV. See their Fig. 3 for the exclusion limit in the mass-coupling plane.
- 218 Superseded by ADRIANI 93M.
- 219 Superseded by DECAMP 92.
- 220 BARTEL 86 is at  $E_{\text{cm}} = 30\text{--}46.78$  GeV.
- 221 BEHREND 86 limit is at  $E_{\text{cm}} = 33\text{--}46.8$  GeV.

## MASS LIMITS for Excited Neutrino ( $\nu^*$ )

### Limits for Excited $\nu$ ( $\nu^*$ ) from Pair Production

These limits are obtained from  $e^+e^- \rightarrow \nu^*\nu^*$  and thus rely only on the (electroweak) charge of  $\nu^*$ . Form factor effects are ignored unless noted. The  $\nu^*$  coupling is assumed to be of sequential type unless otherwise noted. All limits assume a dominant  $\nu^* \rightarrow \nu\gamma$  decay except the limits from  $\Gamma(Z)$ .

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;102.6</b>	95	222 ACHARD	03B L3	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 99.4	95	223 ABBIENDI	04N OPAL	
> 91.2	95	224 ACCIARRI	01D L3	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
> 94.1	95	225 ABBIENDI	00I OPAL	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
		226 ABBIENDI,G	00D OPAL	
> 90.0	95	227 ACCIARRI	00E L3	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
> 84.9	95	228 ABBIENDI	99F OPAL	
		229 ABREU	99O DLPH	Homodoublet type
> 77.6	95	230 ACKERSTAFF	98C OPAL	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
		231 BARATE	98U ALEP	$Z \rightarrow \nu^*\nu^*$
> 64.4	95	232,233 ABREU	97B DLPH	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
> 71.2	95	232,234 ABREU	97B DLPH	$e^+e^- \rightarrow \nu^*\nu^*$ Sequential type
> 77.8	95	232,235 ACCIARRI	97G L3	$e^+e^- \rightarrow \nu^*\nu^*$ Sequential type
> 61.4	95	232,236 ACKERSTAFF	97 OPAL	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
> 65.0	95	237,238 ACCIARRI	96D L3	$e^+e^- \rightarrow \nu^*\nu^*$ Sequential type
> 63.6	95	239,240 ALEXANDER	96Q OPAL	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
> 43.7	95	237 BUSKULIC	96W ALEP	$e^+e^- \rightarrow \nu^*\nu^*$ Sequential type
> 47	95	241 BARDADIN-...	92 RVUE	$\Gamma(Z)$
> 42.6	95	242 DECAMP	92 ALEP	$\Gamma(Z)$
> 35.4	95	243 DECAMP	92 ALEP	$\Gamma(Z)$
> 46	95	244,245 DECAMP	90O ALEP	$\Gamma(Z)$
	95	245,246 DECAMP	90O ALEP	

- 222 From  $e^+e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV.  $f = -f'$  is assumed. ACHARD 03B also obtain limit for  $f = f'$ :  $m_{\nu_e^*} > 101.7$  GeV,  $m_{\nu_\mu^*} > 101.8$  GeV, and  $m_{\nu_\tau^*} > 92.9$  GeV. See their Fig. 4 for the exclusion plot in the mass-coupling plane.
- 223 From  $e^+e^-$  collisions at  $\sqrt{s} = 192\text{--}209$  GeV, ABBIENDI 04N obtain limit on  $\sigma(e^+e^- \rightarrow \nu^*\nu^*) B^2(\nu^* \rightarrow \nu\gamma)$ . See their Fig.2. The limit ranges from 20 to 45fb for  $m_{\nu^*} > 45$  GeV.
- 224 From  $e^+e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV.  $f=f'$  is assumed. ACCIARRI 01D also obtain limit for  $f=-f'$ :  $m_{\nu_e^*} > 99.1$  GeV,  $m_{\nu_\mu^*} > 99.3$  GeV,  $m_{\nu_\tau^*} > 90.5$  GeV.
- 225 From  $e^+e^-$  collisions at  $\sqrt{s}=161\text{--}183$  GeV.  $f=-f'$  (photonic decay) is assumed. ABBIENDI 00I also obtain limit for  $f=f'$  ( $\nu^* \rightarrow \ell W$ ):  $m_{\nu_e^*} > 91.1$  GeV,  $m_{\nu_\mu^*} > 91.1$  GeV,  $m_{\nu_\tau^*} > 83.1$  GeV.
- 226 From  $e^+e^-$  collisions at  $\sqrt{s}= 189$  GeV. ABBIENDI,G 00D obtain limit on  $\sigma(e^+e^- \rightarrow \nu^*\nu^*)B(\nu^* \rightarrow \nu\gamma)^2$ . See their Fig. 14. The limit ranges from 50 to 80 fb for  $\sqrt{s}/2=95$  GeV  $> m_{\nu^*} > 45$  GeV.
- 227 From  $e^+e^-$  collisions at  $\sqrt{s}=189$  GeV.  $f=-f'$  (photonic decay) is assumed. ACCIARRI 00E also obtain limit for  $f=f'$  ( $\nu^* \rightarrow \ell W$ ):  $m_{\nu_e^*} > 93.9$  GeV,  $m_{\nu_\mu^*} > 94.0$  GeV,  $m_{\nu_\tau^*} > 91.5$  GeV.
- 228 From  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}183$  GeV, ABBIENDI 99F obtain limit on  $\sigma(e^+e^- \rightarrow \nu^*\nu^*) B(\nu^* \rightarrow \nu\gamma)^2$ . See their Fig. 13. The limit ranges from 0.094 to 0.14 pb for  $\sqrt{s}/2 > m_{\nu^*} > 45$  GeV.
- 229 From  $e^+e^-$  collisions at  $\sqrt{s}= 183$  GeV.  $f=-f'$  is assumed. ABREU 99O also obtain limit for  $f=f'$ :  $m_{\nu_e^*} > 87.3$  GeV,  $m_{\nu_\mu^*} > 88.0$  GeV,  $m_{\nu_\tau^*} > 81.0$  GeV.
- 230 From  $e^+e^-$  collisions at  $\sqrt{s}=170\text{--}172$  GeV. ACKERSTAFF 98C also obtain limit from charged decay modes:  $m_{\nu_e^*} > 84.1$  GeV,  $m_{\nu_\mu^*} > 83.9$  GeV, and  $m_{\nu_\tau^*} > 79.4$  GeV.
- 231 BARATE 98U obtain limits on the form factor. See their Fig. 14 for limits in mass-form factor plane.
- 232 From  $e^+e^-$  collisions at  $\sqrt{s}= 161$  GeV.
- 233 ABREU 97B also obtain limits from charged current decay modes,  $m_{\nu^*} > 56.4$  GeV.
- 234 ABREU 97B also obtain limits from charged current decay modes,  $m_{\nu^*} > 44.9$  GeV.
- 235 ACCIARRI 97G also obtain limits from charged current decay mode  $\nu_e^* \rightarrow e W$ ,  $m_{\nu^*} > 64.5$  GeV.
- 236 ACKERSTAFF 97 also obtain limits from charged current decay modes  $m_{\nu_e^*} > 78.3$  GeV,  $m_{\nu_\mu^*} > 78.9$  GeV,  $m_{\nu_\tau^*} > 76.2$  GeV.
- 237 From  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}140$  GeV.
- 238 ACCIARRI 96D also obtain limit from  $\nu^* \rightarrow e W$  decay mode:  $m_{\nu^*} > 57.3$  GeV.
- 239 From  $e^+e^-$  collisions at  $\sqrt{s}= 130\text{--}136$  GeV.
- 240 ALEXANDER 96Q also obtain limits from charged current decay modes:  $m_{\nu_e^*} > 66.2$  GeV,  $m_{\nu_\mu^*} > 66.5$  GeV,  $m_{\nu_\tau^*} > 64.7$  GeV.
- 241 BARDADIN-OTWINOWSKA 92 limit is for Dirac  $\nu^*$ . Based on  $\Delta\Gamma(Z) < 36$  MeV. The limit is 36.4 GeV for Majorana  $\nu^*$ , 45.4 GeV for homodoublet  $\nu^*$ .
- 242 Limit is based on  $B(Z \rightarrow \nu^*\bar{\nu}^*) \times B(\nu^* \rightarrow \nu\gamma)^2 < 5 \times 10^{-5}$  (95%CL) assuming Dirac  $\nu^*$ ,  $B(\nu^* \rightarrow \nu\gamma) = 1$ .

- 243 Limit is for Dirac  $\nu^*$ . The limit is 34.6 GeV for Majorana  $\nu^*$ , 45.4 GeV for homodoublet  $\nu^*$ .
- 244 DECAMP 900 limit is from excess  $\Delta\Gamma(Z) < 89$  MeV. The above value is for Dirac  $\nu^*$ ; 26.6 GeV for Majorana  $\nu^*$ ; 44.8 GeV for homodoublet  $\nu^*$ .
- 245 Superseded by DECAMP 92.
- 246 DECAMP 900 limit based on  $B(Z \rightarrow \nu^* \nu^*) \cdot B(\nu^* \rightarrow \nu \gamma)^2 < 7 \times 10^{-5}$  (95%CL), assuming Dirac  $\nu^*$ ,  $B(\nu^* \rightarrow \nu \gamma) = 1$ .

### Limits for Excited $\nu$ ( $\nu^*$ ) from Single Production

These limits are from  $e^+e^- \rightarrow \nu\nu^*$ ,  $Z \rightarrow \nu\nu^*$ , or  $ep \rightarrow \nu^*X$  and depend on transition magnetic coupling between  $\nu/e$  and  $\nu^*$ . Assumptions about  $\nu^*$  decay mode are given in footnotes.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;190</b>	95	247 ACHARD	03B L3	$e^+e^- \rightarrow \nu\nu^*$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
none 50–150	95	248 ADLOFF	02 H1	$ep \rightarrow \nu^*X$
>158	95	249 CHEKANOV	02D ZEUS	$ep \rightarrow \nu^*X$
>171	95	250 ACCIARRI	01D L3	$e^+e^- \rightarrow \nu\nu^*$
		251 ABBIENDI	00I OPAL	$e^+e^- \rightarrow \nu\nu^*$
		252 ABBIENDI,G	00D OPAL	
		253 ACCIARRI	00E L3	$e^+e^- \rightarrow \nu\nu^*$
>114	95	254 ADLOFF	00E H1	$ep \rightarrow \nu^*X$
		255 ABBIENDI	99F OPAL	
		256 ABREU	99O DLPH	$e^+e^- \rightarrow \nu\nu^*$
		257 ACKERSTAFF	98C OPAL	$e^+e^- \rightarrow \nu^*\nu^*$ Homodoublet type
		258 BARATE	98U ALEP	$Z \rightarrow \nu\nu^*$
		259,260 ABREU	97B DLPH	$e^+e^- \rightarrow \nu\nu^*$
		261 ABREU	97I DLPH	$\nu^* \rightarrow \ell W, \nu Z$
		262 ABREU	97J DLPH	$\nu^* \rightarrow \nu\gamma$
		259,263 ACCIARRI	97G L3	$e^+e^- \rightarrow \nu\nu^*$
		264 ACKERSTAFF	97 OPAL	$e^+e^- \rightarrow \nu\nu^*$
		265 ADLOFF	97 H1	Lepton-flavor violation
none 40–96	95	266 BREITWEG	97C ZEUS	$ep \rightarrow \nu^*X$
		267 ACCIARRI	96D L3	$e^+e^- \rightarrow \nu\nu^*$
		268 ALEXANDER	96Q OPAL	$e^+e^- \rightarrow \nu\nu^*$
		269 BUSKULIC	96W ALEP	$e^+e^- \rightarrow \nu\nu^*$
		270 DERRICK	95B ZEUS	$ep \rightarrow \nu^*X$
		271 ABT	93 H1	$ep \rightarrow \nu^*X$
> 91	95	ADRIANI	93M L3	$\lambda_Z > 1, \nu^* \rightarrow \nu\gamma$
> 89	95	ADRIANI	93M L3	$\lambda_Z > 1, \nu_e^* \rightarrow eW$
> 87	95	ADRIANI	93M L3	$\lambda_Z > 0.1, \nu^* \rightarrow \nu\gamma$
> 74	95	ADRIANI	93M L3	$\lambda_Z > 0.1, \nu_e^* \rightarrow eW$
		272 BARDADIN-...	92 RVUE	
> 91	95	273 DECAMP	92 ALEP	$\lambda_Z > 1$
> 74	95	273 DECAMP	92 ALEP	$\lambda_Z > 0.034$
> 91	95	274,275 ADEVA	900 L3	$\lambda_Z > 1$
> 83	95	275 ADEVA	900 L3	$\lambda_Z > 0.1, \nu^* \rightarrow \nu\gamma$

- |        |    |         |        |     |      |   |
|--------|----|---------|--------|-----|------|---|
| > 74   | 95 | 275     | ADEVA  | 900 | L3   | $\lambda_Z > 0.1, \nu_e^* \rightarrow eW$ |
| > 90   | 95 | 276,277 | DECAMP | 900 | ALEP | $\lambda_Z > 1$                           |
| > 74.7 | 95 | 276,277 | DECAMP | 900 | ALEP | $\lambda_Z > 0.06$                        |
- 247 ACHARD 03B result is from  $e^+e^-$  collisions at  $\sqrt{s} = 189\text{--}209$  GeV. The quoted limit is for  $\nu_e^*$ .  $f = -f' = \Lambda/m_{\nu^*}$  is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.
- 248 ADLOFF 02 search for single  $\nu^*$  production in  $ep$  collisions with the decays  $\nu^* \rightarrow \nu\gamma, \nu Z, eW$ . The quoted limit assumes  $f = -f' = \Lambda/m_{\nu^*}$ . See their Fig. 1 for the exclusion plots in the mass-coupling plane.
- 249 CHEKANOV 02D search for single  $\nu^*$  production in  $ep$  collisions with the decays  $\nu^* \rightarrow \nu\gamma, \nu Z, eW$ .  $f = -f' = \Lambda/m_{\nu^*}$  is assumed for the  $e^*$  coupling. CHEKANOV 02D also obtain limit for  $f = f' = \Lambda/m_{\nu^*}$ :  $m_{\nu^*} > 135$  GeV. See their Fig. 5c and Fig. 5d for the exclusion plot in the mass-coupling plane.
- 250 ACCIARRI 01D search for  $\nu\nu^*$  production in  $e^+e^-$  collisions at  $\sqrt{s} = 192\text{--}202$  GeV with decays  $\nu^* \rightarrow \nu\gamma, \nu^* \rightarrow eW$ .  $f = -f' = \Lambda/m_{\nu^*}$  is assumed for the  $\nu^*$  coupling. See their Fig. 4 for limits in the mass-coupling plane.
- 251 ABBIENDI 00i result is from  $e^+e^-$  collisions at  $\sqrt{s} = 161\text{--}183$  GeV. See their Fig. 7 for limits in mass-coupling plane.
- 252 From  $e^+e^-$  collisions at  $\sqrt{s} = 189$  GeV. ABBIENDI, G 00D obtain limit on  $\sigma(e^+e^- \rightarrow \nu^*\nu^*)B(\nu^* \rightarrow \nu\gamma)^2$ . See their Fig. 11.
- 253 ACCIARRI 00E result is from  $e^+e^-$  collisions at  $\sqrt{s} = 189$  GeV. See their Fig. 3 for limits in mass-coupling plane.
- 254 ADLOFF 00E search for single  $\nu^*$  production in  $ep$  collisions with the decays  $\nu^* \rightarrow \nu\gamma, \nu Z, eW$ . The quoted limit assumes  $f = -f' = \Lambda/m_{\nu^*}$ . See their Fig. 10 for the exclusion plot in the mass-coupling plane.
- 255 From  $e^+e^-$  collisions at  $\sqrt{s} = 130\text{--}183$  GeV, ABBIENDI 99F obtain limit on  $\sigma(e^+e^- \rightarrow \nu\nu^*)B(\nu^* \rightarrow \nu\gamma)$ . See their Fig. 8.
- 256 ABREU 99O result is from  $e^+e^-$  collisions at  $\sqrt{s} = 183$  GeV. See their Figs. 4 and 5 for the exclusion limit in the mass-coupling plane.
- 257 ACKERSTAFF 98C from  $e^+e^-$  collisions at  $\sqrt{s} = 170\text{--}172$  GeV. See their Fig. 11 for the exclusion limit in the mass-coupling plane.
- 258 BARATE 98U obtain limits on the  $Z\nu\nu^*$  coupling. See their Fig. 13 for limits in mass-coupling plane
- 259 From  $e^+e^-$  collisions at  $\sqrt{s} = 161$  GeV.
- 260 See Fig. 4b and Fig. 5b of ABREU 97B for the exclusion limit in the mass-coupling plane.
- 261 ABREU 97i limit is from  $Z \rightarrow \nu\nu^*$ . See their Fig. 12 for the exclusion limit in the mass-coupling plane.
- 262 ABREU 97j limit is from  $Z \rightarrow \nu\nu^*$ . See their Fig. 5 for the exclusion limit in the mass-coupling plane.
- 263 See Fig. 2 and Fig. 3 of ACCIARRI 97G for the exclusion limit in the mass-coupling plane.
- 264 ACKERSTAFF 97 result is from  $e^+e^-$  collisions at  $\sqrt{s} = 161$  GeV, for homodoublet  $\nu^*$ . See their Fig. 3 for the exclusion limit in the mass-coupling plane.
- 265 ADLOFF 97 search for single  $e^*$  production in  $ep$  collisions with the decays  $e^* \rightarrow e\gamma, eZ, \nu W$ . See their Fig. 4 for the rejection limits on the product of the production cross section and the branching ratio.
- 266 BREITWEG 97C search for single  $\nu^*$  production in  $ep$  collisions with the decay  $\nu^* \rightarrow \nu\gamma$ .  $f = -f' = 2\Lambda/m_{\nu^*}$  is assumed for the  $\nu^*$  coupling. See their Fig. 10 for the exclusion plot in the mass-coupling plane.
- 267 ACCIARRI 96D result is from  $e^+e^-$  collisions at  $\sqrt{s} = 130\text{--}140$  GeV. See their Fig. 2 for the exclusion limit in the mass-coupling plane.



- 268 ALEXANDER 96Q result is from  $e^+e^-$  collisions at  $\sqrt{s}=130\text{--}140$  GeV for homodoublet  $\nu^*$ . See their Fig. 3b and Fig. 3c for the exclusion limit in the mass-coupling plane.
- 269 BUSKULIC 96W result is from  $e^+e^-$  collisions at  $\sqrt{s}=130\text{--}140$  GeV. See their Fig. 4 for the exclusion limit in the mass-coupling plane.
- 270 DERRICK 95B search for single  $\nu^*$  production via  $\nu^*eW$  coupling in  $ep$  collisions with the decays  $\nu^* \rightarrow \nu\gamma, \nu Z, eW$ . See their Fig. 14 for the exclusion plot in the  $m_{\nu^*}\text{--}\lambda\gamma$  plane.
- 271 ABT 93 search for single  $\nu^*$  production via  $\nu^*eW$  coupling in  $ep$  collisions with the decays  $\nu^* \rightarrow \nu\gamma, \nu Z, eW$ . See their Fig. 4 for exclusion plot in the  $m_{\nu^*}\text{--}\lambda_W$  plane.
- 272 See Fig. 5 of BARDADIN-OTWINOWSKA 92 for combined limit of ADEVA 90o, DECAMP 90o, and DECAMP 92.
- 273 DECAMP 92 limit is based on  $B(Z \rightarrow \nu^*\bar{\nu}) \times B(\nu^* \rightarrow \nu\gamma) < 2.7 \times 10^{-5}$  (95%CL) assuming Dirac  $\nu^*$ ,  $B(\nu^* \rightarrow \nu\gamma) = 1$ .
- 274 Limit is either for  $\nu^* \rightarrow \nu\gamma$  or  $\nu^* \rightarrow eW$ .
- 275 Superseded by ADRIANI 93M.
- 276 DECAMP 90o limit based on  $B(Z \rightarrow \nu\nu^*) \cdot B(\nu^* \rightarrow \nu\gamma) < 6 \times 10^{-5}$  (95%CL), assuming  $B(\nu^* \rightarrow \nu\gamma) = 1$ .
- 277 Superseded by DECAMP 92.

## MASS LIMITS for Excited $q$ ( $q^*$ )

### Limits for Excited $q$ ( $q^*$ ) from Pair Production

These limits are obtained from  $e^+e^- \rightarrow q^*\bar{q}^*$  and thus rely only on the (electroweak) charge of the  $q^*$ . Form factor effects are ignored unless noted. Assumptions about the  $q^*$  decay are given in the comments and footnotes.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>45.6	95	278 ADRIANI 93M	L3	$u$ or $d$ type, $Z \rightarrow q^*q^*$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		279 BARATE 98U	ALEP	$Z \rightarrow q^*q^*$
		280 ADRIANI 92F	L3	$Z \rightarrow q^*q^*$
>41.7	95	281 BARDADIN-... 92	RVUE	$u$ -type, $\Gamma(Z)$
>44.7	95	281 BARDADIN-... 92	RVUE	$d$ -type, $\Gamma(Z)$
>40.6	95	282 DECAMP 92	ALEP	$u$ -type, $\Gamma(Z)$
>44.2	95	282 DECAMP 92	ALEP	$d$ -type, $\Gamma(Z)$
>45	95	283 DECAMP 92	ALEP	$u$ or $d$ type, $Z \rightarrow q^*q^*$
>45	95	282 ABREU 91F	DLPH	$u$ -type, $\Gamma(Z)$
>45	95	282 ABREU 91F	DLPH	$d$ -type, $\Gamma(Z)$
>21.1	95	284 BEHREND 86C	CELL	$e(q^*) = -1/3, q^* \rightarrow qg$
>22.3	95	284 BEHREND 86C	CELL	$e(q^*) = 2/3, q^* \rightarrow qg$
>22.5	95	284 BEHREND 86C	CELL	$e(q^*) = -1/3, q^* \rightarrow q\gamma$
>23.2	95	284 BEHREND 86C	CELL	$e(q^*) = 2/3, q^* \rightarrow q\gamma$

- 278 ADRIANI 93M limit is valid for  $B(q^* \rightarrow qg) > 0.25$  (0.17) for up (down) type.
- 279 BARATE 98U obtain limits on the form factor. See their Fig. 16 for limits in mass-form factor plane.
- 280 ADRIANI 92F search for  $Z \rightarrow q^* \bar{q}^*$  followed with  $q^* \rightarrow q\gamma$  decays and give the limit  $\sigma_Z \cdot B(Z \rightarrow q^* \bar{q}^*) \cdot B^2(q^* \rightarrow q\gamma) < 2 \text{ pb}$  at 95%CL. Assuming five flavors of degenerate  $q^*$  of homodoublet type,  $B(q^* \rightarrow q\gamma) < 4\%$  is obtained for  $m_{q^*} < 45 \text{ GeV}$ .
- 281 BARDADIN-OTWINOWSKA 92 limit based on  $\Delta\Gamma(Z) < 36 \text{ MeV}$ .
- 282 These limits are independent of decay modes.
- 283 Limit is for  $B(q^* \rightarrow qg) + B(q^* \rightarrow q\gamma) = 1$ .
- 284 BEHREND 86C search for  $e^+ e^- \rightarrow q^* \bar{q}^*$  for  $m_{q^*} > 5 \text{ GeV}$ . But  $m < 5 \text{ GeV}$  excluded by total hadronic cross section. The limits are for point-like photon couplings of excited quarks.

### Limits for Excited $q$ ( $q^*$ ) from Single Production

These limits are from  $e^+ e^- \rightarrow q^* \bar{q}$  or  $p\bar{p} \rightarrow q^* X$  and depend on transition magnetic couplings between  $q$  and  $q^*$ . Assumptions about  $q^*$  decay mode are given in the footnotes and comments.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;775</b>	95	285 ABAZOV	04C D0	$p\bar{p} \rightarrow q^* X, q^* \rightarrow qg$
none 200–520 and 580–760	95	286 ABE	97G CDF	$p\bar{p} \rightarrow q^* X, q^* \rightarrow 2 \text{ jets}$
<b>none 80–570</b>	95	287 ABE	95N CDF	$p\bar{p} \rightarrow q^* X, q^* \rightarrow qg, q\gamma, qW$

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

>510	95	288 ABAZOV	06F D0	$p\bar{p} \rightarrow q^* X, q^* \rightarrow qZ$
>205	95	289 CHEKANOV	02D ZEUS	$e p \rightarrow q^* X$
>188	95	290 ADLOFF	00E H1	$e p \rightarrow q^* X$
		291 ABREU	99O DLPH	$e^+ e^- \rightarrow q q^*$
		292 BARATE	98U ALEP	$Z \rightarrow q q^*$
		293 ADLOFF	97 H1	Lepton-flavor violation
none 40–169	95	294 BREITWEG	97C ZEUS	$e p \rightarrow q^* X$
		295 DERRICK	95B ZEUS	$e p \rightarrow q^* X$
none 80–540	95	296 ABE	94 CDF	$p\bar{p} \rightarrow q^* X, q^* \rightarrow q\gamma, qW$
> 79	95	297 ADRIANI	93M L3	$\lambda_Z(L3) > 0.06$
>288	90	298 ALITTI	93 UA2	$p\bar{p} \rightarrow q^* X, q^* \rightarrow qg$
		299 ABREU	92D DLPH	$Z \rightarrow q q^*$
		300 ADRIANI	92F L3	$Z \rightarrow q q^*$
> 75	95	297 DECAMP	92 ALEP	$Z \rightarrow q q^*, \lambda_Z > 1$
> 88	95	301 DECAMP	92 ALEP	$Z \rightarrow q q^*, \lambda_Z > 1$
> 86	95	301 AKRAWY	90J OPAL	$Z \rightarrow q q^*, \lambda_Z > 1.2$
		302 ALBAJAR	89 UA1	$p\bar{p} \rightarrow q^* X, q^* \rightarrow qW$
> 39	95	303 BEHREND	86C CELL	$e^+ e^- \rightarrow q^* \bar{q} (q^* \rightarrow qg, q\gamma), \lambda_\gamma = 1$

285 ABAZOV 04C assume  $f_S = f = f' = \Lambda/m_{q^*}$ .

286 ABE 97G search for new particle decaying to dijets.

287 ABE 95N assume a degenerate  $u^*$  and  $d^*$  with  $f_S = f = f' = \Lambda/m_{q^*}$ . See their Fig. 4 for the excluded region in  $m_{q^*} - f$  plane.

- 288 ABAZOV 06F assume  $q^*$  production via  $qg$  fusion and via contact interactions. The quoted limit is for  $\Lambda = m_{q^*}$ .
- 289 CHEKANOV 02D search for single  $q^*$  production in  $ep$  collisions with the decays  $q^* \rightarrow q\gamma, qZ, qW$ .  $f_s = 0$  and  $f = f' = \Lambda/m_{q^*}$  is assumed for the  $q^*$  coupling. See their Fig. 5b for the exclusion plot in the mass-coupling plane.
- 290 ADLOFF 00E search for single  $q^*$  production in  $ep$  collisions with the decays  $q^* \rightarrow q\gamma, qZ, qW$ .  $f_s=0$  and  $f=f'=\Lambda/m_{q^*}$  is assumed for the  $q^*$  coupling. See their Fig. 11 for the exclusion plot in the mass-coupling plane.
- 291 ABREU 99O result is from  $e^+e^-$  collisions at  $\sqrt{s}=183$  GeV. See their Fig. 6 for the exclusion limit in the mass-coupling plane.
- 292 BARATE 98U obtain limits on the  $Zq^*$  coupling. See their Fig. 16 for limits in mass-coupling plane
- 293 ADLOFF 97 search for single  $q^*$  production in  $ep$  collisions with the decay  $q^* \rightarrow q\gamma$ . See their Fig. 6 for the rejection limits on the product of the production cross section and the branching ratio.
- 294 BREITWEG 97C search for single  $q^*$  production in  $ep$  collisions with the decays  $q^* \rightarrow q\gamma, qW$ .  $f_s=0$ , and  $f=-f'=2\Lambda/m_{q^*}$  is assumed for the  $q^*$  coupling. See their Fig. 11 for the exclusion plot in the mass-coupling plane.
- 295 DERRICK 95B search for single  $q^*$  production via  $q^*q\gamma$  coupling in  $ep$  collisions with the decays  $q^* \rightarrow qW, qZ, qg, q\gamma$ . See their Fig. 15 for the exclusion plot in the  $m_{q^*}-\lambda\gamma$  plane.
- 296 ABE 94 search for resonances in jet- $\gamma$  and jet- $W$  invariant mass in  $p\bar{p}$  collisions at  $E_{cm} = 1.8$  TeV. The limit is for  $f_s = f = f' = \Lambda/m_{q^*}$  and  $u^*$  and  $d^*$  are assumed to be degenerate. See their Fig. 4 for the excluded region in  $m_{q^*}$ - $f$  plane.
- 297 Assumes  $B(q^* \rightarrow qg) = 1$ .
- 298 ALITTI 93 search for resonances in the two-jet invariant mass. The limit is for  $f_s = f = f' = \Lambda/m_{q^*}$ .  $u^*$  and  $d^*$  are assumed to be degenerate. If not, the limit for  $u^*$  ( $d^*$ ) is 277 (247) GeV if  $m_{d^*} \gg m_{u^*}$  ( $m_{u^*} \gg m_{d^*}$ ).
- 299 ABREU 92D give  $\sigma(e^+e^- \rightarrow Z \rightarrow q^*\bar{q} \text{ or } q\bar{q}^*) \times B(q^* \rightarrow q\gamma) < 15$  pb (95% CL) for  $m_{q^*} < 80$  GeV.
- 300 ADRIANI 92F search for  $Z \rightarrow qq^*$  with  $q^* \rightarrow q\gamma$  and give the limit  $\sigma_Z \cdot B(Z \rightarrow qq^*) \cdot B(q^* \rightarrow q\gamma) < (2-10)$  pb (95%CL) for  $m_{q^*} = (46-82)$  GeV.
- 301 Assumes  $B(q^* \rightarrow q\gamma) = 0.1$ .
- 302 ALBAJAR 89 give  $\sigma(q^* \rightarrow W + \text{jet})/\sigma(W) < 0.019$  (90% CL) for  $m_{q^*} > 220$  GeV.
- 303 BEHREND 86C has  $E_{cm} = 42.5-46.8$  GeV. See their Fig. 3 for excluded region in the  $m_{q^*} - (\lambda_\gamma/m_{q^*})^2$  plane. The limit is for  $\lambda_\gamma = 1$  with  $\eta_L = \eta_R = 1$ .

## MASS LIMITS for Color Sextet Quarks ( $q_6$ )

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
<b>&gt;84</b>	95	304 ABE	89D CDF	$p\bar{p} \rightarrow q_6\bar{q}_6$

304 ABE 89D look for pair production of unit-charged particles which leave the detector before decaying. In the above limit the color sextet quark is assumed to fragment into a unit-charged or neutral hadron with equal probability and to have long enough lifetime not to decay within the detector. A limit of 121 GeV is obtained for a color decuplet.

## MASS LIMITS for Color Octet Charged Leptons ( $\ell_8$ )

$$\lambda \equiv m_{\ell_8}/\Lambda$$

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>86	95	305 ABE 89D	CDF	Stable $\ell_8$ : $p\bar{p} \rightarrow \ell_8\bar{\ell}_8$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
none 3.0–30.3	95	306 ABT 93	H1	$e_8$ : $ep \rightarrow e_8 X$
none 3.5–30.3	95	307 KIM 90	AMY	$e_8$ : $e^+e^- \rightarrow ee +$ jets
	95	307 KIM 90	AMY	$\mu_8$ : $e^+e^- \rightarrow \mu\mu +$ jets
>19.8	95	308 KIM 90	AMY	$e_8$ : $e^+e^- \rightarrow gg$ ; $R$
none 5–23.2	95	309 BARTEL 87B	JADE	$e_8, \mu_8, \tau_8$ : $e^+e^-$ ; $R$
	95	309 BARTEL 87B	JADE	$\mu_8$ : $e^+e^- \rightarrow \mu\mu +$ jets
		310 BARTEL 85K	JADE	$e_8$ : $e^+e^- \rightarrow gg$ ; $R$

305 ABE 89D look for pair production of unit-charged particles which leave the detector before decaying. In the above limit the color octet lepton is assumed to fragment into a unit-charged or neutral hadron with equal probability and to have long enough lifetime not to decay within the detector. The limit improves to 99 GeV if it always fragments into a unit-charged hadron.

306 ABT 93 search for  $e_8$  production via  $e$ -gluon fusion in  $ep$  collisions with  $e_8 \rightarrow eg$ . See their Fig. 3 for exclusion plot in the  $m_{e_8}-\Lambda$  plane for  $m_{e_8} = 35-220$  GeV.

307 KIM 90 is at  $E_{cm} = 50-60.8$  GeV. The same assumptions as in BARTEL 87B are used.

308 KIM 90 result  $(m_{e_8}\Lambda_M)^{1/2} > 178.4$  GeV (95%CL,  $\alpha_S = 0.16$  used) is subject to the same restriction as for BARTEL 85K.

309 BARTEL 87B is at  $E_{cm} = 46.3-46.78$  GeV. The limits assume  $\ell_8$  pair production cross sections to be eight times larger than those of the corresponding heavy lepton pair production.

310 In BARTEL 85K,  $R$  can be affected by  $e^+e^- \rightarrow gg$  via  $e_q$  exchange. Their limit  $m_{e_8} > 173$  GeV (CL=95%) at  $\lambda = m_{e_8}/\Lambda_M = 1$  ( $\eta_L = \eta_R = 1$ ) is not listed above because the cross section is sensitive to the product  $\eta_L\eta_R$ , which should be absent in ordinary theory with electronic chiral invariance.

## MASS LIMITS for Color Octet Neutrinos ( $\nu_8$ )

$$\lambda \equiv m_{\nu_8}/\Lambda$$

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>110	90	311 BARGER 89	RVUE	$\nu_8$ : $p\bar{p} \rightarrow \nu_8\bar{\nu}_8$
none 3.8–29.8	95	312 KIM 90	AMY	$\nu_8$ : $e^+e^- \rightarrow$ acoplanar jets
none 9–21.9	95	313 BARTEL 87B	JADE	$\nu_8$ : $e^+e^- \rightarrow$ acoplanar jets

- 311 BARGER 89 used ABE 89B limit for events with large missing transverse momentum. Two-body decay  $\nu_g \rightarrow \nu g$  is assumed.
- 312 KIM 90 is at  $E_{\text{cm}} = 50\text{--}60.8$  GeV. The same assumptions as in BARTEL 87B are used.
- 313 BARTEL 87B is at  $E_{\text{cm}} = 46.3\text{--}46.78$  GeV. The limit assumes the  $\nu_g$  pair production cross section to be eight times larger than that of the corresponding heavy neutrino pair production. This assumption is not valid in general for the weak couplings, and the limit can be sensitive to its  $SU(2)_L \times U(1)_Y$  quantum numbers.

## MASS LIMITS for $W_8$ (Color Octet $W$ Boson)

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
• • •	We do not use the following data for averages, fits, limits, etc. • • •		
	314 ALBAJAR 89	UA1	$p\bar{p} \rightarrow W_8 X,$ $W_8 \rightarrow Wg$
314	ALBAJAR 89		give $\sigma(W_8 \rightarrow W + \text{jet})/\sigma(W) < 0.019$ (90% CL) for $m_{W_8} > 220$ GeV.

## REFERENCES FOR Searches for Quark and Lepton Compositeness

ABAZOV	06E	PR D73 111102R	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	06F	PR D74 011104R	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABDALLAH	06C	EPJ C45 589	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ABULENCIA	06L	PRL 96 211801	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABULENCIA,A	06B	PRL 97 191802	A. Abulencia <i>et al.</i>	(CDF Collab.)
ACOSTA	05B	PRL 94 101802	D. Acosta <i>et al.</i>	(CDF Collab.)
ABAZOV	04C	PR D69 111101R	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABBIENDI	04G	EPJ C33 173	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	04N	PL B602 167	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABDALLAH	04N	EPJ C37 405	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
CHEKANOV	04B	PL B591 23	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
ACHARD	03B	PL B568 23	P. Achard <i>et al.</i>	(L3 Collab.)
ADLOFF	03	PL B568 35	C. Adloff <i>et al.</i>	(H1 Collab.)
BABICH	03	EPJ C29 103	A.A. Babich <i>et al.</i>	
ABBIENDI	02G	PL B544 57	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ACHARD	02D	PL B531 28	P. Achard <i>et al.</i>	(L3 Collab.)
ACHARD	02J	PL B549 290	P. Achard <i>et al.</i>	(L3 Collab.)
ADLOFF	02	PL B525 9	C. Adloff <i>et al.</i>	(H1 Collab.)
ADLOFF	02B	PL B548 35	C. Adloff <i>et al.</i>	(H1 Collab.)
CHEKANOV	02D	PL B549 32	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
ACCIARRI	01D	PL B502 37	M. Acciarri <i>et al.</i>	(L3 Collab.)
AFFOLDER	01I	PRL 87 231803	T. Affolder <i>et al.</i>	(CDF Collab.)
BOURILKOV	01	PR D64 071701	D. Bourilkov	
CHEUNG	01B	PL B517 167	K. Cheung	
ABBIENDI	00I	EPJ C14 73	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	00R	EPJ C13 553	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI,G	00D	EPJ C18 253	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	00E	PR D62 031101	B. Abbott <i>et al.</i>	(D0 Collab.)
ABREU	00A	PL B491 67	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	00S	PL B485 45	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	00E	PL B473 177	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00G	PL B475 198	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00P	PL B489 81	M. Acciarri <i>et al.</i>	(L3 Collab.)
ADLOFF	00	PL B479 358	C. Adloff <i>et al.</i>	(H1 Collab.)
ADLOFF	00E	EPJ C17 567	C. Adloff <i>et al.</i>	(H1 Collab.)
AFFOLDER	00I	PR D62 012004	T. Affolder <i>et al.</i>	(CDF Collab.)
BARATE	00I	EPJ C12 183	R. Barate <i>et al.</i>	(ALEPH Collab.)
BOURILKOV	00	PR D62 076005	D. Bourilkov	
BREITWEG	00B	EPJ C14 239	J. Breitweg <i>et al.</i>	(ZEUS Collab.)
ABBIENDI	99	EPJ C6 1	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	99F	EPJ C8 23	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	99P	PL B465 303	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	99C	PRL 82 2457	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	99D	PRL 82 4769	B. Abbott <i>et al.</i>	(D0 Collab.)

ABREU	99A	EPJ C11 383	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	99O	EPJ C8 41	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ZARNECKI	99	EPJ C11 539	A.F. Zarnecki	
ABBOTT	98G	PRL 80 666	B. Abbott <i>et al.</i>	(D0 Collab.)
ABREU	98J	PL B433 429	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	98J	PL B433 163	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	98T	PL B439 183	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACKERSTAFF	98	EPJ C1 21	K. Akerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	98C	EPJ C1 45	K. Akerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	98V	EPJ C2 441	K. Akerstaff <i>et al.</i>	(OPAL Collab.)
ACKER...K...	98B	PL B438 379	K. Akerstaff <i>et al.</i>	(OPAL Collab.)
BARATE	98J	PL B429 201	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	98U	EPJ C4 571	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARGER	98E	PR D57 391	V. Barger <i>et al.</i>	
BERTRAM	98	PL B443 347	I. Bertram, E.H. Simmons	
McFARLAND	98	EPJ C1 509	K.S. McFarland <i>et al.</i>	(CCFR/NuTeV Collab.)
MIURA	98	PR D57 5345	M. Miura <i>et al.</i>	(VENUS Collab.)
ABE	97G	PR D55 R5263	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	97T	PRL 79 2198	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	97B	PL B393 245	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	97I	ZPHY C74 57	P. Abreu <i>et al.</i>	(DELPHI Collab.)
Also		ZPHY C75 580 (erratum)	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	97J	ZPHY C74 577	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	97G	PL B401 139	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	97W	PL B413 159	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACKERSTAFF	97	PL B391 197	K. Akerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	97C	PL B391 221	K. Akerstaff <i>et al.</i>	(OPAL Collab.)
ADLOFF	97	NP B483 44	C. Adloff <i>et al.</i>	(H1 Collab.)
ARIMA	97	PR D55 19	T. Arima <i>et al.</i>	(VENUS Collab.)
BREITWEG	97C	ZPHY C76 631	J. Breitweg <i>et al.</i>	(ZEUS Collab.)
DEANDREA	97	PL B409 277	A. Deandrea	(MARS)
ABE	96	PRL 77 438	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	96S	PRL 77 5336	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	96K	PL B380 480	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	96D	PL B370 211	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	96L	PL B384 323	M. Acciarri <i>et al.</i>	(L3 Collab.)
ALEXANDER	96K	PL B377 222	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	96Q	PL B386 463	G. Alexander <i>et al.</i>	(OPAL Collab.)
BUSKULIC	96W	PL B385 445	D. Buskalic <i>et al.</i>	(ALEPH Collab.)
BUSKULIC	96Z	PL B384 333	D. Buskalic <i>et al.</i>	(ALEPH Collab.)
ABE	95N	PRL 74 3538	F. Abe <i>et al.</i>	(CDF Collab.)
ACCIARRI	95G	PL B353 136	M. Acciarri <i>et al.</i>	(L3 Collab.)
AID	95	PL B353 578	S. Aid <i>et al.</i>	(H1 Collab.)
DERRICK	95B	ZPHY C65 627	M. Derrick <i>et al.</i>	(ZEUS Collab.)
ABE	94	PRL 72 3004	F. Abe <i>et al.</i>	(CDF Collab.)
DIAZCRUZ	94	PR D49 R2149	J.L. Diaz Cruz, O.A. Sampayo	(CINV)
VELISSARIS	94	PL B331 227	C. Velissaris <i>et al.</i>	(AMY Collab.)
ABE	93G	PRL 71 2542	F. Abe <i>et al.</i>	(CDF Collab.)
ABT	93	NP B396 3	I. Abt <i>et al.</i>	(H1 Collab.)
ADRIANI	93M	PRPL 236 1	O. Adriani <i>et al.</i>	(L3 Collab.)
ALITTI	93	NP B400 3	J. Alitti <i>et al.</i>	(UA2 Collab.)
BUSKULIC	93Q	ZPHY C59 215	D. Buskalic <i>et al.</i>	(ALEPH Collab.)
DERRICK	93B	PL B316 207	M. Derrick <i>et al.</i>	(ZEUS Collab.)
ABE	92B	PRL 68 1463	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	92D	PRL 68 1104	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	92M	PRL 69 2896	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	92C	ZPHY C53 41	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	92D	ZPHY C53 555	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ADRIANI	92B	PL B288 404	O. Adriani <i>et al.</i>	(L3 Collab.)
ADRIANI	92F	PL B292 472	O. Adriani <i>et al.</i>	(L3 Collab.)
BARDADIN....	92	ZPHY C55 163	M. Bardadin-Otwinowska	(CLER)
DECAMP	92	PRPL 216 253	D. Decamp <i>et al.</i>	(ALEPH Collab.)
HOWELL	92	PL B291 206	B. Howell <i>et al.</i>	(TOPAZ Collab.)
KROHA	92	PR D46 58	H. Kroha	(ROCH)
PDG	92	PR D45 S1	K. Hikasa <i>et al.</i>	(KEK, LBL, BOST+)
SHIMOZAWA	92	PL B284 144	K. Shimosawa <i>et al.</i>	(TOPAZ Collab.)
ABE	91D	PRL 67 2418	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	91E	PL B268 296	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	91F	NP B367 511	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ADACHI	91	PL B255 613	I. Adachi <i>et al.</i>	(TOPAZ Collab.)
AKRAWY	91F	PL B257 531	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)

ALITTI	91B	PL B257 232	J. Alitti <i>et al.</i>	(UA2 Collab.)
BEHREND	91B	ZPHY C51 143	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
BEHREND	91C	ZPHY C51 149	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
Also		ZPHY C51 143	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
ABE	90I	ZPHY C48 13	K. Abe <i>et al.</i>	(VENUS Collab.)
ADEVA	90F	PL B247 177	B. Adeva <i>et al.</i>	(L3 Collab.)
ADEVA	90K	PL B250 199	B. Adeva <i>et al.</i>	(L3 Collab.)
ADEVA	90L	PL B250 205	B. Adeva <i>et al.</i>	(L3 Collab.)
ADEVA	90O	PL B252 525	B. Adeva <i>et al.</i>	(L3 Collab.)
AKRAWY	90F	PL B241 133	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
AKRAWY	90I	PL B244 135	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
AKRAWY	90J	PL B246 285	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
DECAMP	90G	PL B236 501	D. Decamp <i>et al.</i>	(ALEPH Collab.)
DECAMP	90O	PL B250 172	D. Decamp <i>et al.</i>	(ALEPH Collab.)
KIM	90	PL B240 243	G.N. Kim <i>et al.</i>	(AMY Collab.)
ABE	89	PRL 62 613	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	89B	PRL 62 1825	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	89D	PRL 63 1447	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	89H	PRL 62 3020	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	89J	ZPHY C45 175	K. Abe <i>et al.</i>	(VENUS Collab.)
ABE	89L	PL B232 425	K. Abe <i>et al.</i>	(VENUS Collab.)
ADACHI	89B	PL B228 553	I. Adachi <i>et al.</i>	(TOPAZ Collab.)
ALBAJAR	89	ZPHY C44 15	C. Albajar <i>et al.</i>	(UA1 Collab.)
BARGER	89	PL B220 464	V. Barger <i>et al.</i>	(WISC, KEK)
BEHREND	89B	PL B222 163	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
BRAUNSCH...	89C	ZPHY C43 549	W. Braunschweig <i>et al.</i>	(TASSO Collab.)
DORENBOS...	89	ZPHY C41 567	J. Dorenbosch <i>et al.</i>	(CHARM Collab.)
HAGIWARA	89	PL B219 369	K. Hagiwara, M. Sakuda, N. Terunuma	(KEK, DURH+)
KIM	89	PL B223 476	S.K. Kim <i>et al.</i>	(AMY Collab.)
ABE	88B	PL B213 400	K. Abe <i>et al.</i>	(VENUS Collab.)
BARINGER	88	PL B206 551	P. Baringer <i>et al.</i>	(HRS Collab.)
BRAUNSCH...	88	ZPHY C37 171	W. Braunschweig <i>et al.</i>	(TASSO Collab.)
BRAUNSCH...	88D	ZPHY C40 163	W. Braunschweig <i>et al.</i>	(TASSO Collab.)
ANSARI	87D	PL B195 613	R. Ansari <i>et al.</i>	(UA2 Collab.)
BARTEL	87B	ZPHY C36 15	W. Bartel <i>et al.</i>	(JADE Collab.)
BEHREND	87C	PL B191 209	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
FERNANDEZ	87B	PR D35 10	E. Fernandez <i>et al.</i>	(MAC Collab.)
ARNISON	86C	PL B172 461	G.T.J. Arnison <i>et al.</i>	(UA1 Collab.)
ARNISON	86D	PL B177 244	G.T.J. Arnison <i>et al.</i>	(UA1 Collab.)
BARTEL	86	ZPHY C31 359	W. Bartel <i>et al.</i>	(JADE Collab.)
BARTEL	86C	ZPHY C30 371	W. Bartel <i>et al.</i>	(JADE Collab.)
BEHREND	86	PL 168B 420	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
BEHREND	86C	PL B181 178	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
DERRICK	86	PL 166B 463	M. Derrick <i>et al.</i>	(HRS Collab.)
Also		PR D34 3286	M. Derrick <i>et al.</i>	(HRS Collab.)
DERRICK	86B	PR D34 3286	M. Derrick <i>et al.</i>	(HRS Collab.)
GRIFOLS	86	PL 168B 264	J.A. Grifols, S. Peris	(BARC)
JODIDIO	86	PR D34 1967	A. Jodidio <i>et al.</i>	(LBL, NWES, TRIU)
Also		PR D37 237 (erratum)	A. Jodidio <i>et al.</i>	(LBL, NWES, TRIU)
APPEL	85	PL 160B 349	J.A. Appel <i>et al.</i>	(UA2 Collab.)
BARTEL	85K	PL 160B 337	W. Bartel <i>et al.</i>	(JADE Collab.)
BERGER	85	ZPHY C28 1	C. Berger <i>et al.</i>	(PLUTO Collab.)
BERGER	85B	ZPHY C27 341	C. Berger <i>et al.</i>	(PLUTO Collab.)
BAGNAIA	84C	PL 138B 430	P. Bagnaia <i>et al.</i>	(UA2 Collab.)
BARTEL	84D	PL 146B 437	W. Bartel <i>et al.</i>	(JADE Collab.)
BARTEL	84E	PL 146B 121	W. Bartel <i>et al.</i>	(JADE Collab.)
EICHTEN	84	RMP 56 579	E. Eichten <i>et al.</i>	(FNAL, LBL, OSU)
ALTHOFF	83C	PL 126B 493	M. Althoff <i>et al.</i>	(TASSO Collab.)
RENARD	82	PL 116B 264	F.M. Renard	(CERN)