# Quark and Lepton Compositeness, Searches for

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

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

| $\Lambda^{+}_{LL}$ (TeV) | $\Lambda^{-}_{LL}$ (TeV) | CL% | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **>1.6** | | 95 | [1,2] | BUSKULIC | 93Q | RVUE | |
| | **>3.6** | 95 | [3] | KROHA | 92 | RVUE | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| >1.6 | >2.0 | 95 | [2] | BUSKULIC | 93Q | ALEP | $E_{cm}$=88.25–94.25 GeV |
| | >2.2 | 95 | | BUSKULIC | 93Q | RVUE | |
| >1.3 | | 95 | [3] | KROHA | 92 | RVUE | |
| >0.7 | >2.8 | 95 | | BEHREND | 91C | CELL | $E_{cm}$=35 GeV |
| >1.3 | >1.3 | 95 | | KIM | 89 | AMY | $E_{cm}$=50–57 GeV |
| >1.4 | >3.3 | 95 | [4] | BRAUNSCH... | 88 | TASS | $E_{cm}$=12–46.8 GeV |
| >1.0 | >0.7 | 95 | [5] | FERNANDEZ | 87B | MAC | $E_{cm}$=29 GeV |
| >1.1 | >1.4 | 95 | [6] | BARTEL | 86C | JADE | $E_{cm}$=12–46.8 GeV |
| >1.17 | >0.87 | 95 | [7] | DERRICK | 86 | HRS | $E_{cm}$=29 GeV |
| >1.1 | >0.76 | 95 | [8] | BERGER | 85B | PLUT | $E_{cm}$=34.7 GeV |

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

[2] 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.

[3] 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 $\eta/\Lambda^2_{LL} = +0.230 \pm 0.206$ TeV$^{-2}$.

[4] BRAUNSCHWEIG 88 assumed $m_Z = 92$ GeV and $\sin^2\theta_W = 0.23$.

[5] FERNANDEZ 87B assumed $\sin^2\theta_W = 0.22$.

[6] BARTEL 86C assumed $m_Z = 93$ GeV and $\sin^2\theta_W = 0.217$.

[7] DERRICK 86 assumed $m_Z = 93$ GeV and $g^2_V = (-1/2+2\sin^2\theta_W)^2 = 0.004$.

[8] 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 $\Lambda^{\pm}_{LL}$ only. For other cases, see each reference.

| $\Lambda^{+}_{LL}$ (TeV) | $\Lambda^{-}_{LL}$ (TeV) | CL% | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **>2.6** | **>1.9** | 95 | [9,10] | BUSKULIC | 93Q | RVUE | |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| >1.7 | >2.2 | 95 | [10] | VELISSARIS | 94 | AMY | $E_{cm}$=57.8 GeV |
| >1.3 | >1.5 | 95 | [10] | BUSKULIC | 93Q | ALEP | $E_{cm}$=88.25–94.25 GeV |
| >2.3 | >2.0 | 95 | | HOWELL | 92 | TOPZ | $E_{cm}$=52–61.4 GeV |
| | >1.7 | 95 | [11] | KROHA | 92 | RVUE | |
| >2.5 | >1.5 | 95 | | BEHREND | 91C | CELL | $E_{cm}$=35–43 GeV |
| >1.6 | >2.0 | 95 | [12] | ABE | 90I | VNS | $E_{cm}$=50–60.8 GeV |
| >1.9 | >1.0 | 95 | | KIM | 89 | AMY | $E_{cm}$=50–57 GeV |
| >2.3 | >1.3 | 95 | | BRAUNSCH... | 88D | TASS | $E_{cm}$=30–46.8 GeV |
| >4.4 | >2.1 | 95 | [13] | BARTEL | 86C | JADE | $E_{cm}$=12–46.8 GeV |
| >2.9 | >0.86 | 95 | [14] | BERGER | 85 | PLUT | $E_{cm}$=34.7 GeV |

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

[10] 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.

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

[12] ABE 90I assumed $m_Z$ =91.163 GeV and $\sin^2\theta_W = 0.231$.

[13] BARTEL 86C assumed $m_Z$ = 93 GeV and $\sin^2\theta_W = 0.217$.

[14] BERGER 85 assumed $m_Z$ = 93 GeV and $\sin^2\theta_W = 0.217$.

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

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

| $\Lambda^+_{LL}$ (TeV) | $\Lambda^-_{LL}$ (TeV) | CL% | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **>1.9** | **>2.9** | 95 | [15] | KROHA | 92 | RVUE | |

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| >1.4 | >2.0 | 95 | [16] | VELISSARIS | 94 | AMY | $E_{cm}$=57.8 GeV |
| >1.0 | >1.5 | 95 | [16] | BUSKULIC | 93Q | ALEP | $E_{cm}$=88.25–94.25 GeV |
| >1.8 | >2.3 | 95 | [16,17] | BUSKULIC | 93Q | RVUE | |
| >1.9 | >1.7 | 95 | | HOWELL | 92 | TOPZ | $E_{cm}$=52–61.4 GeV |
| >1.6 | >2.3 | 95 | | BEHREND | 91C | CELL | $E_{cm}$=35–43 GeV |
| >1.8 | >1.3 | 95 | [18] | ABE | 90I | VNS | $E_{cm}$=50–60.8 GeV |
| >2.2 | >3.2 | 95 | [19] | BARTEL | 86 | JADE | $E_{cm}$=12–46.8 GeV |

[15] KROHA 92 limit is from fit to BARTEL 86C BEHREND 89B, BRAUNSCHWEIG 89C, ABE 90I, and BEHREND 91C. The fit gives $\eta/\Lambda^2_{LL} = +0.095 \pm 0.120$ TeV$^{-2}$.

[16] 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.

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

[18] ABE 90I assumed $m_Z$ =91.163 GeV and $\sin^2\theta_W = 0.231$.

[19] BARTEL 86 assumed $m_Z$ = 93 GeV and $\sin^2\theta_W = 0.217$.

## SCALE LIMITS for Contact Interactions: Λ(ℓℓℓℓ)

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

| $\Lambda^{+}_{LL}$ (TeV) | $\Lambda^{-}_{LL}$ (TeV) | CL% | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **>3.5** | **>2.8** | 95 | [20,21] | BUSKULIC | 93Q | RVUE | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| >3.0 | >2.3 | 95 | [21,22] | BUSKULIC | 93Q | ALEP | $E_{cm}$=88.25–94.25 GeV |
| >2.5 | >2.2 | 95 | [23] | HOWELL | 92 | TOPZ | $E_{cm}$=52–61.4 GeV |
| >3.4 | >2.7 | 95 | [24] | KROHA | 92 | RVUE | |

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

[21] 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.

[22] From $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, and $\tau^+\tau^-$.

[23] HOWELL 92 limit is from $e^+e^- \to \mu^+\mu^-$ and $\tau^+\tau^-$.

[24] KROHA 92 limit is from fit to most PEP/PETRA/TRISTAN data. The fit gives $\eta/\Lambda^2_{LL} = -0.0200 \pm 0.0666$ TeV$^{-2}$.

## SCALE LIMITS for Contact Interactions: Λ(eeqq)

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

| $\Lambda^{+}_{LL}$ (TeV) | $\Lambda^{-}_{LL}$ (TeV) | CL% | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|---|
| **> 2.3** | > 1.0 | 95 | [25] | AID | 95 | H1 | ($eeqq$) ($u$, $d$ quarks) |
| > 1.7 | **> 2.2** | 95 | [26] | ABE | 91D | CDF | ($eeqq$) ($u$, $d$ quarks) |
| >1.2 | | 95 | [27] | ADACHI | 91 | TOPZ | ($eeqq$) (flavor-universal) |
| | >1.7 | 95 | [28] | ABE | 89L | VNS | ($eeqq$) (flavor-universal) |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| | >1.6 | 95 | [27] | ADACHI | 91 | TOPZ | ($eeqq$) (flavor-universal) |
| >0.6 | >1.7 | 95 | [29] | BEHREND | 91C | CELL | ($eecc$) |
| >1.1 | >1.0 | 95 | [29] | BEHREND | 91C | CELL | ($eebb$) |
| >0.9 | | 95 | [28] | ABE | 89L | VNS | ($eeqq$) (flavor-universal) |
| >1.05 | >1.61 | 95 | [30] | HAGIWARA | 89 | RVUE | ($eecc$) |
| >1.21 | >0.53 | 95 | [31] | HAGIWARA | 89 | RVUE | ($eebb$) |

[25] AID 95 limits are from the $Q^2$ spectrum measurement of $ep \to eX$.

[26] ABE 91D limits are from $e^+e^-$ mass distribution in $p\overline{p} \to e^+e^-X$ at $E_{cm} = 1.8$ TeV.

[27] ADACHI 91 limits are from differential jet cross section. Universality of $\Lambda(eeqq)$ for five flavors is assumed.

[28] ABE 89L limits are from jet charge asymmetry. Universality of $\Lambda(eeqq)$ for five flavors is assumed.

[29] BEHREND 91C is from data at $E_{cm} = 35$–43 GeV.

[30] The HAGIWARA 89 limit is derived from forward-backward asymmetry measurements of $D/D^*$ mesons by ALTHOFF 83C, BARTEL 84E, and BARINGER 88.

[31] 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 |
|---|---|---|---|---|---|---|
| **>1.4** | **>1.6** | 95 | ABE | 92B | CDF | $(\mu\mu qq)$ (isosinglet) |

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

| VALUE (TeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **>3.10** | 90 | [32] JODIDIO | 86 | SPEC | $\Lambda^{\pm}_{LR}(\nu_\mu\nu_e\mu e)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >3.8 | | [33] DIAZCRUZ | 94 | RVUE | $\Lambda^{+}_{LL}(\tau\nu_\tau e\nu_e)$ |
| >8.1 | | [33] DIAZCRUZ | 94 | RVUE | $\Lambda^{-}_{LL}(\tau\nu_\tau e\nu_e)$ |
| >4.1 | | [34] DIAZCRUZ | 94 | RVUE | $\Lambda^{+}_{LL}(\tau\nu_\tau \mu\nu_\mu)$ |
| >6.5 | | [34] DIAZCRUZ | 94 | RVUE | $\Lambda^{-}_{LL}(\tau\nu_\tau \mu\nu_\mu)$ |

[32] JODIDIO 86 limit is from $\mu^+ \to \overline{\nu}_\mu e^+ \nu_e$. Chirality invariant interactions $L = (g^2/\Lambda^2)$ $[\eta_{LL}\ (\overline{\nu}_{\mu L}\gamma^\alpha \mu_L)\ (\overline{e}_L\gamma_\alpha \nu_{eL}) + \eta_{LR}\ (\overline{\nu}_{\mu L}\gamma^\alpha \nu_{eL}\ (\overline{e}_R\gamma_\alpha \mu_R)]$ with $g^2/4\pi = 1$ and $(\eta_{LL},\eta_{LR}) = (0,\pm1)$ are taken. No limits are given for $\Lambda^{\pm}_{LL}$ with $(\eta_{LL},\eta_{LR}) = (\pm1,0)$. For more general constraints with right-handed neutrinos and chirality nonconserving contact interactions, see their text.

[33] DIAZCRUZ 94 limits are from $\Gamma(\tau \to\ e\nu\nu)$ and assume flavor-dependent contact interactions with $\Lambda(\tau\nu_\tau e\nu_e) \ll \Lambda(\mu\nu_\mu e\nu_e)$.

[34] DIAZCRUZ 94 limits are from $\Gamma(\tau \to\ \mu\nu\nu)$ 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: $\Lambda(qqqq)$

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

| VALUE (TeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| | | [35] ABE | 96 | CDF | $p\overline{p} \to$ jets inclusive |
| **>1.4** | 95 | [36] ABE | 92D | CDF | $p\overline{p} \to$ jets inclusive |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >1.3 | 95 | [37] ABE | 93G | CDF | $p\overline{p} \to$ dijet mass |
| >1.0 | 99 | [38] ABE | 92M | CDF | $p\overline{p} \to$ dijet angl. |
| >0.825 | 95 | [39] ALITTI | 91B | UA2 | $p\overline{p} \to$ jets inclusive |
| >0.700 | 95 | [36] ABE | 89 | CDF | $p\overline{p} \to$ jets inclusive |
| >0.330 | 95 | [40] ABE | 89H | CDF | $p\overline{p} \to$ dijet angl. |
| >0.400 | 95 | [41] ARNISON | 86C | UA1 | $p\overline{p} \to$ jets inclusive |
| >0.415 | 95 | [42] ARNISON | 86D | UA1 | $p\overline{p} \to$ dijet angl. |
| >0.370 | 95 | [43] APPEL | 85 | UA2 | $p\overline{p} \to$ jets inclusive |
| >0.275 | 95 | [44] BAGNAIA | 84C | UA2 | Repl. by APPEL 85 |

[35] 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.

[36] Limit is from inclusive jet cross-section data in $p\overline{p}$ collisions at $E_{cm} = 1.8$ TeV. The limit takes into account uncertainties in choice of structure functions and in choice of process scale.

[37] ABE 93G limit is from dijet mass distribution in $p\overline{p}$ collisions at $E_{cm} = 1.8$ TeV. The limit is the weakest from several choices of structure functions and renormalization scale.

[38] ABE 92M limit is from dijet angular distribution for $m_{dijet}$ >550 GeV in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV.

[39] ALITTI 91B limit is from inclusive jet cross section in $p\overline{p}$ collisions at $E_{cm} = 630$ GeV. The limit takes into account uncertainties in choice of structure functions and in choice of process scale.

[40] 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.

[41] ARNISON 86C limit is from the study of inclusive high-$p_T$ jet distributions at the CERN $\overline{p}p$ collider ($E_{cm} = 546$ and 630 GeV). The QCD prediction renormalized to the low-$p_T$ region gives a good fit to the data.

[42] ARNISON 86D limit is from the study of dijet angular distribution in the range $240 < m(\text{dijet}) < 300$ GeV at the CERN $\overline{p}p$ 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.

[43] APPEL 85 limit is from the study of inclusive high-$p_T$ jet distributions at the CERN $\overline{p}p$ collider ($E_{cm} = 630$ GeV). The QCD prediction renormalized to the low-$p_T$ region gives a good description of the data.

[44] BAGNAIA 84C limit is from the study of jet $p_T$ and dijet mass distributions at the CERN $\overline{p}p$ collider ($E_{cm} = 540$ GeV). The limit suffers from the uncertainties in comparing the data with the QCD prediction.

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## 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 $e^* \rightarrow e\gamma$ decay except the limits from $\Gamma(Z)$.

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>79.9** | 95 | [45] ACKERSTAFF | 97 | OPAL | $e^+e^- \rightarrow e^*e^*$ |
| >62.5 | 95 | [46] ABREU | 96K | DLPH | $e^+e^- \rightarrow e^*e^*$ |
| >64.7 | 95 | [47] ACCIARRI | 96D | L3 | $e^+e^- \rightarrow e^*e^*$ |
| >65.2 | 95 | [47] BUSKULIC | 96W | ALEP | $e^+e^- \rightarrow e^*e^*$ |

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

| | | | | | |
|---|---|---|---|---|---|
| >66.5 | 95 | [47] ALEXANDER | 96Q | OPAL | $e^+e^- \to e^*e^*$ |
| >45.6 | 95 | ADRIANI | 93M | L3 | $Z \to e^*e^*$ |
| >45.6 | 95 | ABREU | 92C | DLPH | $Z \to e^*e^*$ |
| >29.8 | 95 | [48] BARDADIN-... | 92 | RVUE | $\Gamma(Z)$ |
| >26.1 | 95 | [49] DECAMP | 92 | ALEP | $Z \to e^*e^*$; $\Gamma(Z)$ |
| >46.1 | 95 | DECAMP | 92 | ALEP | $Z \to e^*e^*$ |
| >33 | 95 | [49] ABREU | 91F | DLPH | $Z \to e^*e^*$; $\Gamma(Z)$ |
| >45.0 | 95 | [50] ADEVA | 90F | L3 | $Z \to e^*e^*$ |
| >44.9 | 95 | AKRAWY | 90I | OPAL | $Z \to e^*e^*$ |
| >44.6 | 95 | [51] DECAMP | 90G | ALEP | $e^+e^- \to e^*e^*$ |
| >30.2 | 95 | ADACHI | 89B | TOPZ | $e^+e^- \to e^*e^*$ |
| >28.3 | 95 | KIM | 89 | AMY | $e^+e^- \to e^*e^*$ |
| >27.9 | 95 | [52] ABE | 88B | VNS | $e^+e^- \to e^*e^*$ |

[45] From $e^+e^-$ collisions at $\sqrt{s}$= 161 GeV.
[46] From $e^+e^-$ collisions at $\sqrt{s}$= 130–136 GeV.
[47] From $e^+e^-$ collisions at $\sqrt{s}$= 130–140 GeV.
[48] BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on $\Delta\Gamma(Z)$<36 MeV.
[49] Limit is independent of $e^*$ decay mode.
[50] ADEVA 90F is superseded by ADRIANI 93M.
[51] Superseded by DECAMP 92.
[52] ABE 88B limits assume $e^+e^- \to e^{*+}e^{*-}$ with one photon exchange only and $e^* \to e\gamma$ giving $ee\gamma\gamma$.

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

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

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| >89 | 95 | ADRIANI | 93M L3 | $Z \to ee^*$, $\lambda_Z > 0.5$ |
| >88 | 95 | ABREU | 92C DLPH | $Z \to ee^*$, $\lambda_Z > 0.5$ |
| **>91** | 95 | DECAMP | 92 ALEP | $Z \to ee^*$, $\lambda_Z > 1$ |
| >87 | 95 | AKRAWY | 90I OPAL | $Z \to ee^*$, $\lambda_Z > 0.5$ |

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

| | | | | |
|---|---|---|---|---|
| [53] ACKERSTAFF | 97 | OPAL | $e^+e^- \to ee^*$ |
| [54] ABREU | 96K | DLPH | $e^+e^- \to ee^*$ |
| [55] ACCIARRI | 96D | L3 | $e^+e^- \to ee^*$ |
| [56] ALEXANDER | 96Q | OPAL | $e^+e^- \to ee^*$ |

| | | | | | |
|---|---|---|---|---|---|
| | | [57] BUSKULIC | 96W ALEP | $e^+e^- \to e e^*$ | |
| | | [58] DERRICK | 95B ZEUS | $ep \to e^* X$ | |
| | | [59] ABT | 93 H1 | $ep \to e^* X$ | |
| >86 | 95 | ADRIANI | 93M L3 | $\lambda_\gamma > 0.04$ | |
| | | [60] DERRICK | 93B ZEUS | Superseded by DERRICK 95B | |
| >86 | 95 | ABREU | 92C DLPH | $e^+e^- \to e e^*$, $\lambda_\gamma > 0.1$ | |
| >88 | 95 | [61] ADEVA | 90F L3 | $Z \to e e^*$, $\lambda_Z > 0.5$ | |
| >86 | 95 | [61] ADEVA | 90F L3 | $Z \to e e^*$, $\lambda_Z > 0.04$ | |
| >81 | 95 | [62] DECAMP | 90G ALEP | $Z \to e e^*$, $\lambda_Z > 1$ | |
| >50 | 95 | ADACHI | 89B TOPZ | $e^+e^- \to e e^*$, $\lambda_\gamma > 0.04$ | |
| >56 | 95 | KIM | 89 AMY | $e^+e^- \to e e^*$, $\lambda_\gamma > 0.03$ | |
| none 23–54 | 95 | [63] ABE | 88B VNS | $e^+e^- \to e e^*$ $\lambda_\gamma > 0.04$ | |
| >75 | 95 | [64] ANSARI | 87D UA2 | $W \to e^* \nu$; $\lambda_W > 0.7$ | |
| >63 | 95 | [64] ANSARI | 87D UA2 | $W \to e^* \nu$; $\lambda_W > 0.2$ | |
| >40 | 95 | [64] ANSARI | 87D UA2 | $W \to e^* \nu$; $\lambda_W > 0.09$ | |

[53] 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.

[54] 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.

[55] 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.

[56] 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.

[57] 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.

[58] DERRICK 95B search for single $e^*$ production via $e^* e\gamma$ coupling in $ep$ collisions with the decays $e^* \to e\gamma$, $eZ$, $\nu W$. See their Fig. 13 for the exclusion plot in the $m_{e^*}$–$\lambda\gamma$ plane.

[59] ABT 93 search for single $e^*$ production via $e^* e\gamma$ coupling in $ep$ collisions with the decays $e^* \to e\gamma$, $eZ$, $\nu W$. See their Fig. 4 for exclusion plot in the $m_{e^*}$–$\lambda_\gamma$ plane.

[60] DERRICK 93B search for single $e^*$ production via $e^* e\gamma$ coupling in $ep$ collisions with the decays $e^* \to e\gamma$, $eZ$, $\nu W$. See their Fig. 3 for exclusion plot in the $m_{e^*}$–$\lambda_\gamma$ plane.

[61] Superseded by ADRIANI 93M.

[62] Superseded by DECAMP 92.

[63] ABE 88B limits use $e^+e^- \to e e^*$ where t-channel photon exchange dominates giving $e\gamma(e)$ (quasi-real compton scattering).

[64] ANSARI 87D is at $E_{cm}$ = 546–630 GeV.

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

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

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **>147** | 95 | ALEXANDER 96K | OPAL | |

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

| | | | | | |
|---|---|---|---|---|---|
| >146 | 95 | | ACCIARRI | 95G | L3 |
| | | [65] | BUSKULIC | 93Q | ALEP |
| >127 | 95 | [66] | ADRIANI | 92B | L3 |
| >114 | 95 | [67] | BARDADIN-... | 92 | RVUE |
| > 99 | 95 | | DECAMP | 92 | ALEP |
| | | [68] | 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 | [69] | ABE | 89J | VNS $\eta_L$=1, $\eta_R$=0 |
| > 90.2 | 95 | | ADACHI | 89B | TOPZ |
| > 65 | 95 | | KIM | 89 | AMY |

[65] 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 $m_{e^*}$.

[66] ADRIANI 92B superseded by ACCIARRI 95G.

[67] BARDADIN-OTWINOWSKA 92 limit from fit to the combined data of DECAMP 92, ABREU 91E, ADEVA 90K, AKRAWY 91F.

[68] SHIMOZAWA 92 fit the data to the limiting form of the cross section with $m_{e^*} \gg E_{\rm cm}$ and obtain $m_{e^*}$ >168 GeV at 95%CL. Use of the full form would reduce this limit by a few GeV. The statistically unexpected large value is due to fluctuation in the data.

[69] 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. • • • | | | | |
| | [70] DORENBOS... | 89 | CHRM | $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$ and $\nu_\mu e \to \nu_\mu e$ |
| | [71] GRIFOLS | 86 | THEO | $\nu_\mu e \to \nu_\mu e$ |
| | [72] RENARD | 82 | THEO | $g-2$ of electron |

[70] DORENBOSCH 89 obtain the limit $\lambda_\gamma^2 \Lambda_{\rm cut}^2 / m_{e^*}^2 < 2.6$ (95% CL), where $\Lambda_{\rm cut}$ is the cutoff scale, based on the one-loop calculation by GRIFOLS 86. If one assumes that $\Lambda_{\rm cut}$ = 1 TeV and $\lambda_\gamma = 1$, one obtains $m_{e^*} > 620$ GeV. However, one generally expects $\lambda_\gamma \approx m_{e^*}/\Lambda_{\rm cut}$ in composite models.

[71] GRIFOLS 86 uses $\nu_\mu e \to \nu_\mu e$ and $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$ data from CHARM Collaboration to derive mass limits which depend on the scale of compositeness.

[72] 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 $e^+e^- \to \mu^{*+}\mu^{*-}$ 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 $\mu^* \to \mu\gamma$ decay except for the limits from $\Gamma(Z)$.

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>80.0** | 95 | [73] ACKERSTAFF | 97 | OPAL | $e^+e^- \to \mu^*\mu^*$ |
| >62.6 | 95 | [74] ABREU | 96K | DLPH | $e^+e^- \to \mu^*\mu^*$ |
| >64.9 | 95 | [75] ACCIARRI | 96D | L3 | $e^+e^- \to \mu^*\mu^*$ |
| >65.4 | 95 | [75] BUSKULIC | 96W | ALEP | $e^+e^- \to \mu^*\mu^*$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >66.8 | 95 | [75] ALEXANDER | 96Q | OPAL | $e^+e^- \to \mu^*\mu^*$ |
| >45.6 | 95 | ADRIANI | 93M | L3 | $Z \to \mu^*\mu^*$ |
| >45.6 | 95 | ABREU | 92C | DLPH | $Z \to \mu^*\mu^*$ |
| >29.8 | 95 | [76] BARDADIN-... | 92 | RVUE | $\Gamma(Z)$ |
| >26.1 | 95 | [77] DECAMP | 92 | ALEP | $Z \to \mu^*\mu^*$; $\Gamma(Z)$ |
| >46.1 | 95 | DECAMP | 92 | ALEP | $Z \to \mu^*\mu^*$ |
| >33 | 95 | [77] ABREU | 91F | DLPH | $Z \to \mu^*\mu^*$; $\Gamma(Z)$ |
| >45.3 | 95 | [78] ADEVA | 90F | L3 | $Z \to \mu^*\mu^*$ |
| >44.9 | 95 | AKRAWY | 90I | OPAL | $Z \to \mu^*\mu^*$ |
| >44.6 | 95 | [79] DECAMP | 90G | ALEP | $e^+e^- \to \mu^*\mu^*$ |
| >29.9 | 95 | ADACHI | 89B | TOPZ | $e^+e^- \to \mu^*\mu^*$ |
| >28.3 | 95 | KIM | 89 | AMY | $e^+e^- \to \mu^*\mu^*$ |

[73] From $e^+e^-$ collisions at $\sqrt{s}$= 161 GeV.
[74] From $e^+e^-$ collisions at $\sqrt{s}$= 130–136 GeV.
[75] From $e^+e^-$ collisions at $\sqrt{s}$= 130–140 GeV.
[76] BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on $\Delta\Gamma(Z)$<36 MeV.
[77] Limit is independent of $\mu^*$ decay mode.
[78] Superseded by ADRIANI 93M.
[79] Superseded by DECAMP 92.

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

These limits are from $e^+e^- \to \mu^*\mu$ and depend on transition magnetic coupling between $\mu$ and $\mu^*$. All limits assume $\mu^* \to \mu\gamma$ 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,** 1 June, Part II (1992)).

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >89 | 95 | ADRIANI | 93M | L3 | $Z \to \mu\mu^*, \lambda_Z > 0.5$ |
| >88 | 95 | ABREU | 92C | DLPH | $Z \to \mu\mu^*, \lambda_Z > 0.5$ |
| **>91** | 95 | DECAMP | 92 | ALEP | $Z \to \mu\mu^*, \lambda_Z$ >1 |
| >87 | 95 | AKRAWY | 90I | OPAL | $Z \to \mu\mu^*, \lambda_Z$ >1 |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| | | [80] ACKERSTAFF | 97 | OPAL | $e^+e^- \to \mu\mu^*$ | |
| | | [81] ABREU | 96K | DLPH | $e^+e^- \to \mu\mu^*$ | |
| | | [82] ACCIARRI | 96D | L3 | $e^+e^- \to \mu\mu^*$ | |
| | | [83] ALEXANDER | 96Q | OPAL | $e^+e^- \to \mu\mu^*$ | |
| | | [84] BUSKULIC | 96W | ALEP | $e^+e^- \to \mu\mu^*$ | |
| >85 | 95 | [85] ADEVA | 90F | L3 | $Z \to \mu\mu^*$, $\lambda_Z$ | $>1$ |
| >75 | 95 | [85] ADEVA | 90F | L3 | $Z \to \mu\mu^*$, $\lambda_Z$ | $>0.1$ |
| >80 | 95 | [86] DECAMP | 90G | ALEP | $e^+e^- \to \mu\mu^*$, $\lambda_Z$ | $=1$ |
| >50 | 95 | ADACHI | 89B | TOPZ | $e^+e^- \to \mu\mu^*$, $\lambda_\gamma$ | $=0.7$ |
| >46 | 95 | KIM | 89 | AMY | $e^+e^- \to \mu\mu^*$, $\lambda_\gamma$ | $=0.2$ |

[80] 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.

[81] 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.

[82] 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.

[83] 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.

[84] 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.

[85] Superseded by ADRIANI 93M.

[86] 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.

| *VALUE* (GeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| | [87] RENARD | 82 | THEO | $g-2$ of muon |

[87] 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 $e^+e^- \to \tau^{*+}\tau^{*-}$ 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 $\tau^* \to \tau\gamma$ decay except for the limits from $\Gamma(Z)$.

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>79.1** | 95 | [88] ACKERSTAFF | 97 | OPAL | $e^+e^- \to \tau^*\tau^*$ |
| >62.2 | 95 | [89] ABREU | 96K | DLPH | $e^+e^- \to \tau^*\tau^*$ |
| >64.2 | 95 | [90] ACCIARRI | 96D | L3 | $e^+e^- \to \tau^*\tau^*$ |
| >64.8 | 95 | [90] BUSKULIC | 96W | ALEP | $e^+e^- \to \tau^*\tau^*$ |

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

| | | | | | |
|---|---|---|---|---|---|
| >65.3 | 95 | [90] ALEXANDER | 96Q | OPAL | $e^+e^- \to \tau^*\tau^*$ |
| >45.6 | 95 | ADRIANI | 93M | L3 | $Z \to \tau^*\tau^*$ |
| >45.3 | 95 | ABREU | 92C | DLPH | $Z \to \tau^*\tau^*$ |
| >29.8 | 95 | [91] BARDADIN-... | 92 | RVUE | $\Gamma(Z)$ |
| >26.1 | 95 | [92] DECAMP | 92 | ALEP | $Z \to \tau^*\tau^*$; $\Gamma(Z)$ |
| >46.0 | 95 | DECAMP | 92 | ALEP | $Z \to \tau^*\tau^*$ |
| >33 | 95 | [92] ABREU | 91F | DLPH | $Z \to \tau^*\tau^*$; $\Gamma(Z)$ |
| >45.5 | 95 | [93] ADEVA | 90L | L3 | $Z \to \tau^*\tau^*$ |
| >44.9 | 95 | AKRAWY | 90I | OPAL | $Z \to \tau^*\tau^*$ |
| >41.2 | 95 | [94] DECAMP | 90G | ALEP | $e^+e^- \to \tau^*\tau^*$ |
| >29.0 | 95 | ADACHI | 89B | TOPZ | $e^+e^- \to \tau^*\tau^*$ |

[88] From $e^+e^-$ collisions at $\sqrt{s}$= 161 GeV.
[89] From $e^+e^-$ collisions at $\sqrt{s}$= 130–136 GeV.
[90] From $e^+e^-$ collisions at $\sqrt{s}$= 130–140 GeV.
[91] BARDADIN-OTWINOWSKA 92 limit is independent of decay modes. Based on $\Delta\Gamma(Z)$<36 MeV.
[92] Limit is independent of $\tau^*$ decay mode.
[93] Superseded by ADRIANI 93M.
[94] Superseded by DECAMP 92.

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

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| >88 | 95 | ADRIANI | 93M | L3 | $Z \to \tau\tau^*$, $\lambda_Z > 0.5$ |
| >87 | 95 | ABREU | 92C | DLPH | $Z \to \tau\tau^*$, $\lambda_Z > 0.5$ |
| **>90** | 95 | DECAMP | 92 | ALEP | $Z \to \tau\tau^*$, $\lambda_Z > 0.18$ |
| >86.5 | 95 | AKRAWY | 90I | OPAL | $Z \to \tau\tau^*$, $\lambda_Z > 1$ |

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

| | | | | | |
|---|---|---|---|---|---|
| | | [95] ACKERSTAFF | 97 | OPAL | $e^+e^- \to \tau\tau^*$ |
| | | [96] ABREU | 96K | DLPH | $e^+e^- \to \tau\tau^*$ |
| | | [97] ACCIARRI | 96D | L3 | $e^+e^- \to \tau\tau^*$ |
| | | [98] ALEXANDER | 96Q | OPAL | $e^+e^- \to \tau\tau^*$ |
| | | [99] BUSKULIC | 96W | ALEP | $e^+e^- \to \tau\tau^*$ |
| >88 | 95 | [100] ADEVA | 90L | L3 | $Z \to \tau\tau^*$, $\lambda_Z > 1$ |
| >59 | 95 | [101] DECAMP | 90G | ALEP | $Z \to \tau\tau^*$, $\lambda_Z$=1 |
| >40 | 95 | [102] BARTEL | 86 | JADE | $e^+e^- \to \tau\tau^*$, $\lambda_\gamma$=1 |
| >41.4 | 95 | [103] BEHREND | 86 | CELL | $e^+e^- \to \tau\tau^*$, $\lambda_\gamma$=1 |
| >40.8 | 95 | [103] BEHREND | 86 | CELL | $e^+e^- \to \tau\tau^*$, $\lambda_\gamma$=0.7 |

[95] 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.
[96] 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.
[97] 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.

[98] 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.

[99] 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.

[100] Superseded by ADRIANI 93M.

[101] Superseded by DECAMP 92.

[102] BARTEL 86 is at $E_{cm}$ = 30–46.78 GeV.

[103] BEHREND 86 limit is at $E_{cm}$ = 33–46.8 GeV.

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

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

These limits are obtained from $e^+ e^- \to \nu^* \nu^*$ 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. Limits assume $\nu^* \to \nu\gamma$ decay except for the $\Gamma(Z)$ measurement which makes no assumption about decay mode.

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>77.8** | 95 | [104] ACKERSTAFF | 97 | OPAL | $e^+ e^- \to \nu^* \nu^*$ |
| >61.4 | 95 | [105] ACCIARRI | 96D | L3 | $e^+ e^- \to \nu^* \nu^*$ |
| >63.6 | 95 | [105] BUSKULIC | 96W | ALEP | $e^+ e^- \to \nu^* \nu^*$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >65.0 | 95 | [106] ALEXANDER | 96Q | OPAL | $e^+ e^- \to \nu^* \nu^*$ |
| >43.7 | 95 | [107] BARDADIN-... | 92 | RVUE | $\Gamma(Z)$ |
| >47 | 95 | [108] DECAMP | 92 | ALEP | |
| >42.6 | 95 | [109] DECAMP | 92 | ALEP | $\Gamma(Z)$ |
| >35.4 | 95 | [110,111] DECAMP | 90O | ALEP | $\Gamma(Z)$ |
| >46 | 95 | [111,112] DECAMP | 90O | ALEP | |

[104] ACKERSTAFF 97 result is from $e^+ e^-$ collisions at $\sqrt{s}$= 161 GeV, for homodoublet $\nu^*$. For bounds on the mass of $\nu^*$ with charged decays, see their Table 1.

[105] From $e^+ e^-$ collisions at $\sqrt{s}$= 130–140 GeV.

[106] ALEXANDER 96Q result is from $e^+ e^-$ collisions at $\sqrt{s}$= 130–140 GeV for homedoublet $\nu^*$. For bounds on the mass of $\nu^*$ with charged decays, see their Table 1.

[107] 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 $\nu^*$.

[108] Limit is based on $B(Z \to \nu^* \overline{\nu}^*) \times B(\nu^* \to \nu\gamma)^2 < 5 \times 10^{-5}$ (95%CL) assuming Dirac $\nu^*$, $B(\nu^* \to \nu\gamma) = 1$.

[109] Limit is for Dirac $\nu^*$. The limit is 34.6 GeV for Majorana $\nu^*$, 45.4 GeV for homodoublet $\nu^*$.

[110] DECAMP 90O 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 $\nu^*$.

[111] Superseded by DECAMP 92.

[112] DECAMP 90O limit based on $B(Z \to \nu^* \nu^*) \cdot B(\nu^* \to \nu\gamma)^2 < 7 \times 10^{-5}$ (95%CL), assuming Dirac $\nu^*$, $B(\nu^* \to \nu\gamma) = 1$.

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

These limits are from $Z \to \nu\nu^*$ or $ep \to \nu^* X$ 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* |
|---|---|---|---|---|---|---|
| **>91** | 95 | | ADRIANI | 93M | L3 | $\lambda_Z > 1$, $\nu^* \to \nu\gamma$ |
| >89 | 95 | | ADRIANI | 93M | L3 | $\lambda_Z > 1$, $\nu^*_e \to eW$ |
| **>91** | 95 | [113] | DECAMP | 92 | ALEP | $\lambda_Z > 1$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| | | [114] | ACKERSTAFF | 97 | OPAL | $e^+e^- \to \nu\nu^*$ |
| | | [115] | ACCIARRI | 96D | L3 | $e^+e^- \to \nu\nu^*$ |
| | | [116] | ALEXANDER | 96Q | OPAL | $e^+e^- \to \nu\nu^*$ |
| | | [117] | BUSKULIC | 96W | ALEP | $e^+e^- \to \nu\nu^*$ |
| | | [118] | DERRICK | 95B | ZEUS | $ep \to \nu^* X$ |
| | | [119] | ABT | 93 | H1 | $ep \to \nu^* X$ |
| >87 | 95 | | ADRIANI | 93M | L3 | $\lambda_Z > 0.1$, $\nu^* \to \nu\gamma$ |
| >74 | 95 | | ADRIANI | 93M | L3 | $\lambda_Z > 0.1$, $\nu^*_e \to eW$ |
| | | [120] | BARDADIN-... | 92 | RVUE | |
| >74 | 95 | [113] | DECAMP | 92 | ALEP | $\lambda_Z > 0.034$ |
| >91 | 95 | [121,122] | ADEVA | 90O | L3 | $\lambda_Z > 1$ |
| >83 | 95 | [122] | ADEVA | 90O | L3 | $\lambda_Z > 0.1$, $\nu^* \to \nu\gamma$ |
| >74 | 95 | [122] | ADEVA | 90O | L3 | $\lambda_Z > 0.1$, $\nu^*_e \to eW$ |
| >90 | 95 | [123,124] | DECAMP | 90O | ALEP | $\lambda_Z > 1$ |
| >74.7 | 95 | [123,124] | DECAMP | 90O | ALEP | $\lambda_Z > 0.06$ |

[113] DECAMP 92 limit is based on $B(Z \to \nu^*\overline{\nu}) \times B(\nu^* \to \nu\gamma) < 2.7 \times 10^{-5}$ (95%CL) assuming Dirac $\nu^*$, $B(\nu^* \to \nu\gamma) = 1$.

[114] 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.

[115] 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.

[116] ALEXANDER 96Q result is from $e^+e^-$ collisions at $\sqrt{s}$= 130–140 GeV for homedoublet $\nu^*$. See their Fig. 3b and Fig. 3c for the exclusion limit in the mass-coupling plane.

[117] BUSKULIC 96W result is from $e^+e^-$ collisions at $\sqrt{s}$= 130–140 GeV. See their Fig. 4 for the exclusion limit in the mass-coupling plane.

[118] DERRICK 95B search for single $\nu^*$ production via $\nu^* eW$ coupling in $ep$ collisions with the decays $\nu^* \to \nu\gamma$, $\nu Z$, $eW$. See their Fig. 14 for the exclusion plot in the $m_{\nu^*}$–$\lambda\gamma$ plane.

[119] ABT 93 search for single $\nu^*$ production via $\nu^* eW$ coupling in $ep$ collisions with the decays $\nu^* \to \nu\gamma$, $\nu Z$, $eW$. See their Fig. 4 for exclusion plot in the $m_{\nu^*}$–$\lambda_W$ plane.

[120] See Fig. 5 of BARDADIN-OTWINOWSKA 92 for combined limit of ADEVA 90O, DECAMP 90O, and DECAMP 92.

[121] Limit is either for $\nu^* \to \nu\gamma$ or $\nu^* \to eW$.

[122] Superseded by ADRIANI 93M.

[123] DECAMP 90O limit based on $B(Z \to \nu\nu^*) \cdot B(\nu^* \to \nu\gamma) < 6 \times 10^{-5}$ (95%CL), assuming $B(\nu^* \to \nu\gamma) = 1$.

[124] Superseded by DECAMP 92.

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

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

These limits are obtained from $e^+ e^- \to q^* \overline{q}^*$ 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 | [125] | ADRIANI | 93M | L3 | $u$ or $d$ type, $Z \to q^* q^*$ |
| >45 | 95 | [126] | DECAMP | 92 | ALEP | $u$ or $d$ type, $Z \to q^* q^*$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| | | [127] | ADRIANI | 92F | L3 | $Z \to q^* q^*$ |
| >41.7 | 95 | [128] | BARDADIN-... | 92 | RVUE | $u$-type, $\Gamma(Z)$ |
| >44.7 | 95 | [128] | BARDADIN-... | 92 | RVUE | $d$-type, $\Gamma(Z)$ |
| >40.6 | 95 | [129] | DECAMP | 92 | ALEP | $u$-type, $\Gamma(Z)$ |
| >44.2 | 95 | [129] | DECAMP | 92 | ALEP | $d$-type, $\Gamma(Z)$ |
| >45 | 95 | [129] | ABREU | 91F | DLPH | $u$-type, $\Gamma(Z)$ |
| >45 | 95 | [129] | ABREU | 91F | DLPH | $d$-type, $\Gamma(Z)$ |
| >21.1 | 95 | [130] | BEHREND | 86C | CELL | $e(q^*) = -1/3$, $q^* \to qg$ |
| >22.3 | 95 | [130] | BEHREND | 86C | CELL | $e(q^*) = 2/3$, $q^* \to qg$ |
| >22.5 | 95 | [130] | BEHREND | 86C | CELL | $e(q^*) = -1/3$, $q^* \to q\gamma$ |
| >23.2 | 95 | [130] | BEHREND | 86C | CELL | $e(q^*) = 2/3$, $q^* \to q\gamma$ |

[125] ADRIANI 93M limit is valid for $B(q^* \to qg) > 0.25$ (0.17) for up (down) type.

[126] Limit is for $B(q^* \to qg) + B(q^* \to q\gamma) = 1$.

[127] ADRIANI 92F search for $Z \to q^* \overline{q}^*$ followed with $q^* \to q\gamma$ decays and give the limit $\sigma_Z \cdot B(Z \to q^* \overline{q}^*) \cdot B^2(q^* \to q\gamma) < 2$ pb at 95%CL. Assuming five flavors of degenerate $q^*$ of homodoublet type, $B(q^* \to q\gamma) < 4\%$ is obtained for $m_{q^*} < 45$ GeV.

[128] BARDADIN-OTWINOWSKA 92 limit based on $\Delta\Gamma(Z) < 36$ MeV.

[129] These limits are independent of decay modes.

[130] BEHREND 86C search for $e^+ e^- \to q^* \overline{q}^*$ for $m_{q^*} > 5$ GeV. But $m < 5$ 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 $e^+ e^- \to q^* \overline{q}$ or $p\overline{p} \to q^* X$ 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* |
|---|---|---|---|---|---|---|
| **>570 (CL = 95%) OUR EVALUATION** | | | | | | |
| **none 80–570** | 95 | [131] | ABE | 95N | CDF | $p\overline{p} \to q^* X$, $q^* \to qg$ $q\gamma$, $qW$ |
| >288 | 90 | [132] | ALITTI | 93 | UA2 | $p\overline{p} \to q^* X$, $q^* \to qg$ |
| **> 88** | 95 | [133] | DECAMP | 92 | ALEP | $Z \to q q^*$, $\lambda_Z > 1$ |
| > 86 | 95 | [133] | AKRAWY | 90J | OPAL | $Z \to q q^*$, $\lambda_Z > 1.2$ |

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

| | | | | | |
|---|---|---|---|---|---|
| | | [134] DERRICK | 95B ZEUS | $ep \to q^* X$ | |
| none 80–540 | 95 | [135] ABE | 94 CDF | $p\overline{p} \to q^* X$, $q^* \to q\gamma$, $qW$ | |
| > 79 | 95 | [136] ADRIANI | 93M L3 | $\lambda_Z$(L3)> 0.06 | |
| | | [137] ABREU | 92D DLPH | $Z \to q q^*$ | |
| | | [138] ADRIANI | 92F L3 | $Z \to q q^*$ | |
| > 75 | 95 | [136] DECAMP | 92 ALEP | $Z \to q q^*$, $\lambda_Z$ >1 | |
| | | [139] ALBAJAR | 89 UA1 | $p\overline{p} \to q^* X$, $q^* \to qW$ | |
| > 39 | 95 | [140] BEHREND | 86C CELL | $e^+e^- \to q^*\overline{q}$ ($q^* \to qg, q\gamma$), $\lambda_\gamma$=1 | |

[131] 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.

[132] 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 $m_{d^*} \gg m_{u^*}$ ($m_{u^*} \gg m_{d^*}$).

[133] Assumes B($q^* \to q\gamma$) = 0.1.

[134] DERRICK 95B search for single $q^*$ production via $q^* q\gamma$ coupling in $ep$ collisions with the decays $q^* \to qW$, $qZ$, $qg$, $q\gamma$. See their Fig. 15 for the exclusion plot in the $m_{q^*}$–$\lambda\gamma$ plane.

[135] ABE 94 search for resonances in jet-$\gamma$ and jet-$W$ invariant mass in $p\overline{p}$ 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.

[136] Assumes B($q^* \to qg$) = 1.

[137] ABREU 92D give $\sigma(e^+e^- \to Z \to q^*\overline{q}$ or $q\overline{q}^*) \times$B($q^* \to q\gamma$) <15 pb (95% CL) for $m_{q^*}$ <80 GeV.

[138] ADRIANI 92F search for $Z \to q q^*$ with $q^* \to q\gamma$ and give the limit $\sigma_Z \cdot$ B($Z \to q q^*$) · B($q^* \to q\gamma$) <(2–10) pb (95%CL) for $m_{q^*}$ = (46–82) GeV.

[139] ALBAJAR 89 give $\sigma(q^* \to W+\text{jet})/\sigma(W) < 0.019$ (90% CL) for $m_{q^*} > 220$ GeV.

[140] 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* |
|---|---|---|---|---|
| **>84** | 95 | [141] ABE | 89D CDF | $p\overline{p} \to q_6\overline{q}_6$ |

[141] 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 | [142] ABE | 89D | CDF | Stable $\ell_8$: $p\overline{p} \to \ell_8\overline{\ell}_8$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | | [143] ABT | 93 | H1 | $e_8$: $ep \to e_8 X$ |
| none 3.0–30.3 | 95 | [144] KIM | 90 | AMY | $e_8$: $e^+e^- \to ee +$ jets |
| none 3.5–30.3 | 95 | [144] KIM | 90 | AMY | $\mu_8$: $e^+e^- \to \mu\mu +$ jets |
| | | [145] KIM | 90 | AMY | $e_8$: $e^+e^- \to gg$; $R$ |
| >19.8 | 95 | [146] BARTEL | 87B | JADE | $e_8$, $\mu_8$, $\tau_8$: $e^+e^-$; $R$ |
| none 5–23.2 | 95 | [146] BARTEL | 87B | JADE | $\mu_8$: $e^+e^- \to \mu\mu +$ jets |
| | | [147] BARTEL | 85K | JADE | $e_8$: $e^+e^- \to gg$; $R$ |

[142] 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.

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

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

[145] 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.

[146] 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.

[147] In BARTEL 85K, $R$ can be affected by $e^+e^- \to gg$ 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 ($\nu_8$)

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

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>110** | 90 | [148] BARGER | 89 | RVUE | $\nu_8$: $p\overline{p} \to \nu_8\overline{\nu}_8$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| none 3.8–29.8 | 95 | [149] KIM | 90 | AMY | $\nu_8$: $e^+e^- \to$ acoplanar jets |
| none 9–21.9 | 95 | [150] BARTEL | 87B | JADE | $\nu_8$: $e^+e^- \to$ acoplanar jets |

[148] BARGER 89 used ABE 89B limit for events with large missing transverse momentum. Two-body decay $\nu_8 \to \nu g$ is assumed.

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

[150] BARTEL 87B is at $E_{cm}$ = 46.3–46.78 GeV. The limit assumes the $\nu_8$ 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. • • • | | | | |
| | [151] ALBAJAR | 89 | UA1 | $p\overline{p} \rightarrow W_8 X$, $W_8 \rightarrow W g$ |

[151] ALBAJAR 89 give $\sigma(W_8 \rightarrow W + \text{jet})/\sigma(W) < 0.019$ (90% CL) for $m_{W_8} > 220$ GeV.

## Limits on $ZZ\gamma$ Coupling

Limits are for the electric dipole transition form factor for $Z \rightarrow \gamma Z^*$ parametrized as $f(s') = \beta(s'/m_Z^2 - 1)$, where $s'$ is the virtual $Z$ mass. In the Standard Model $\beta \sim 10^{-5}$.

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| <0.80 | 95 | ADRIANI | 92J | L3 | $Z \rightarrow \gamma \nu \overline{\nu}$ |

## REFERENCES FOR Searches for Quark and Lepton Compositeness


| | | | | |
|---|---|---|---|---|
| ACKERSTAFF | 97 | PL B391 197 | +Alexander, Allison, Altekamp, Ametewee+ | (OPAL Collab.) |
| ABE | 96 | PRL (submitted) | +Akimoto, Akopian, Albrow+ | (CDF Collab.) |
| CDF/ANAL/JET/CDFR/2995 | | | | |
| ABREU | 96K | PL B380 480 | +Adam, Adye, Agasi, Ajinenko+ | (DELPHI Collab.) |
| ACCIARRI | 96D | PL B370 211 | +Adam, Adriani, Aguilar-Benitez, Ahlen+ | (L3 Collab.) |
| ALEXANDER | 96K | PL B377 222 | + | (OPAL Collab.) |
| ALEXANDER | 96Q | PL B386 463 | +Allison, Altekamp, Ametwee+ | (OPAL Collab.) |
| BUSKULIC | 96W | PL B385 445 | +De Bonis, Decamp, Ghez, Goy, Lees+ | (ALEPH Collab.) |
| ABE | 95N | PRL 74 3538 | +Albrow, Amendolia, Amidei, Antos+ | (CDF Collab.) |
| ACCIARRI | 95G | PL B353 136 | +Adam, Adriani, Aguilar-Benitez, Ahlen+ | (L3 Collab.) |
| AID | 95 | PL B353 578 | +Andreev, Andrieu, Appuhn, Arpagaus+ | (H1 Collab.) |
| DERRICK | 95B | ZPHY C65 627 | +Krakauer, Magill, Musgrave, Repond+ | (ZEUS Collab.) |
| ABE | 94 | PRL 72 3004 | +Albrow, Amidei, Anway-Wiese, Apollinari+ | (CDF Collab.) |
| DIAZCRUZ | 94 | PR D49 R2149 | Diaz Cruz, Sampayo | (CINV) |
| VELISSARIS | 94 | PL B331 227 | +Lusin, Chung, Park, Cho, Bodek, Kim+ | (AMY Collab.) |
| ABE | 93G | PRL 71 2542 | +Albrow, Akimoto, Amidei, Anway-Wiese+ | (CDF Collab.) |
| ABT | 93 | NP B396 3 | +Andreev, Andrieu, Appuhn, Arpagaus+ | (H1 Collab.) |
| ADRIANI | 93M | PRPL 236 1 | +Aguilar-Benitez, Ahlen, Alcaraz, Aloisio+ | (L3 Collab.) |
| ALITTI | 93 | NP B400 3 | +Ambrosini, Ansari, Autiero, Bareyre+ | (UA2 Collab.) |
| BUSKULIC | 93Q | ZPHY C59 215 | +Decamp, Goy, Lees, Minard, Mours+ | (ALEPH Collab.) |
| DERRICK | 93B | PL B316 207 | +Krakauer, Magill, Musgrave, Repond+ | (ZEUS Collab.) |
| ABE | 92B | PRL 68 1463 | +Amidei, Apollinari, Atac, Auchincloss+ | (CDF Collab.) |
| ABE | 92D | PRL 68 1104 | +Amidei, Apollinari, Atac, Auchincloss+ | (CDF Collab.) |
| ABE | 92M | PRL 69 2896 | +Amidei, Anway-Wiese, Apollinari, Atac+ | (CDF Collab.) |
| ABREU | 92C | ZPHY C53 41 | +Adam, Adami, Adye, Akesson+ | (DELPHI Collab.) |
| ABREU | 92D | ZPHY C53 555 | +Adam, Adami, Adye, Akesson, Alekseev+ | (DELPHI Collab.) |
| ADRIANI | 92B | PL B288 404 | +Aguilar-Benitez, Ahlen, Akbari, Alcaraz+ | (L3 Collab.) |
| ADRIANI | 92F | PL B292 472 | +Aguilar-Benitez, Ahlen, Akbari, Alcarez+ | (L3 Collab.) |
| ADRIANI | 92J | PL B297 469 | +Aguilar-Benitez, Ahlen, Alcarez, Aloisio+ | (L3 Collab.) |
| BARDADIN-... | 92 | ZPHY C55 163 | Bardadin-Otwinowska | (CLER) |
| DECAMP | 92 | PRPL 216 253 | +Deschizeaux, Goy, Lees, Minard+ | (ALEPH Collab.) |
| HOWELL | 92 | PL B291 206 | +Koltick, Tauchi, Miyamoto, Kichimi+ | (TOPAZ Collab.) |
| KROHA | 92 | PR D46 58 | | (ROCH) |
| PDG | 92 | PR D45, 1 June, Part II | Hikasa, Barnett, Stone+ | (KEK, LBL, BOST+) |
| SHIMOZAWA | 92 | PL B284 144 | +Fujimoto, Abe, Adachi, Doser+ | (TOPAZ Collab.) |
| ABE | 91D | PRL 67 2418 | +Amidei, Apollinari, Atac, Auchincloss+ | (CDF Collab.) |
| ABREU | 91E | PL B268 296 | +Adam, Adami, Adye, Akesson+ | (DELPHI Collab.) |
| ABREU | 91F | NP B367 511 | +Adam, Adami, Adye, Akesson+ | (DELPHI Collab.) |

| | | | | |
|---|---|---|---|---|
| ADACHI | 91 | PL B255 613 | +Anazawa, Doser, Enomoto+ | (TOPAZ Collab.) |
| AKRAWY | 91F | PL B257 531 | +Alexander, Allison, Allport, Anderson+ | (OPAL Collab.) |
| ALITTI | 91B | PL B257 232 | +Ansari, Autiero, Bareyre, Blaylock+ | (UA2 Collab.) |
| BEHREND | 91B | ZPHY C51 143 | +Criegee, Field, Franke, Jung+ | (CELLO Collab.) |
| BEHREND | 91C | ZPHY C51 149 | +Criegee, Field, Franke, Jung, Meyer+ | (CELLO Collab.) |
| Also | 91B | ZPHY C51 143 | Behrend, Criegee, Field, Franke, Jung+ | (CELLO Collab.) |
| ABE | 90I | ZPHY C48 13 | +Amako, Arai, Asano, Chiba+ | (VENUS Collab.) |
| ADEVA | 90F | PL B247 177 | +Adriani, Aguilar-Benitez, Akbari, Alcaraz+ | (L3 Collab.) |
| ADEVA | 90K | PL B250 199 | +Adriani, Aguilar-Benitez, Akbari, Alcarez+ | (L3 Collab.) |
| ADEVA | 90L | PL B250 205 | +Adriani, Aguilar-Benitez, Akbari, Alcaraz+ | (L3 Collab.) |
| ADEVA | 90O | PL B252 525 | +Adriani, Aguilar-Benitez, Akbari, Alcaraz+ | (L3 Collab.) |
| AKRAWY | 90F | PL B241 133 | +Alexander, Allison, Allport+ | (OPAL Collab.) |
| AKRAWY | 90I | PL B244 135 | +Alexander, Allison, Allport, Anderson+ | (OPAL Collab.) |
| AKRAWY | 90J | PL B246 285 | +Alexander, Allison, Allport, Anderson+ | (OPAL Collab.) |
| DECAMP | 90G | PL B236 501 | +Deschizeaux, Lees, Minard+ | (ALEPH Collab.) |
| DECAMP | 90O | PL B250 172 | +Deschizeaux, Goy, Lees+ | (ALEPH Collab.) |
| KIM | 90 | PL B240 243 | +Breedon, Ko, Lander, Maeshima, Malchow+ | (AMY Collab.) |
| ABE | 89 | PRL 62 613 | +Amidei, Apollinari, Ascori, Atac+ | (CDF Collab.) |
| ABE | 89B | PRL 62 1825 | +Amidei, Apollinari, Ascoli, Atac+ | (CDF Collab.) |
| ABE | 89D | PRL 63 1447 | +Amidei, Apollinari, Ascoli, Atac+ | (CDF Collab.) |
| ABE | 89H | PRL 62 3020 | +Amidei, Apollinari, Ascoli, Atac+ | (CDF Collab.) |
| ABE | 89J | ZPHY C45 175 | +Amako, Arai, Fukawa+ | (VENUS Collab.) |
| ABE | 89L | PL B232 425 | +Amako, Arai, Asano, Chiba+ | (VENUS Collab.) |
| ADACHI | 89B | PL B228 553 | +Aihara, Doser, Enomoto, Fujii+ | (TOPAZ Collab.) |
| ALBAJAR | 89 | ZPHY C44 15 | +Albrow, Allkofer, Arnison, Astbury+ | (UA1 Collab.) |
| BARGER | 89 | PL B220 464 | +Hagiwara, Han, Zeppenfeld | (WISC, KEK) |
| BEHREND | 89B | PL B222 163 | +Criegee, Dainton, Field, Franke+ | (CELLO Collab.) |
| BRAUNSCH... | 89C | ZPHY C43 549 | Braunschweig, Gerhards, Kirschfink+ | (TASSO Collab.) |
| DORENBOS... | 89 | ZPHY C41 567 | Dorenbosch, Udo, Allaby, Amaldi+ | (CHARM Collab.) |
| HAGIWARA | 89 | PL B219 369 | +Sakuda, Terunuma | (KEK, DURH, HIRO) |
| KIM | 89 | PL B223 476 | +Kim, Kang, Lee, Myung, Bacala | (AMY Collab.) |
| ABE | 88B | PL B213 400 | +Amako, Arai, Asano, Chiba, Chiba+ | (VENUS Collab.) |
| BARINGER | 88 | PL B206 551 | +Bylsma, De Bonte, Koltick, Low+ | (HRS Collab.) |
| BRAUNSCH... | 88 | ZPHY C37 171 | Braunschweig, Gerhards+ | (TASSO Collab.) |
| BRAUNSCH... | 88D | ZPHY C40 163 | Braunschweig, Gerhards, Kirschfink+ | (TASSO Collab.) |
| ANSARI | 87D | PL B195 613 | +Bagnaia, Banner+ | (UA2 Collab.) |
| BARTEL | 87B | ZPHY C36 15 | +Becker, Felst+ | (JADE Collab.) |
| BEHREND | 87C | PL B191 209 | +Buerger, Criegee, Dainton+ | (CELLO Collab.) |
| FERNANDEZ | 87B | PR D35 10 | +Ford, Qi, Read, Smith, Camporesi+ | (MAC Collab.) |
| ARNISON | 86C | PL B172 461 | +Albrow, Allkofer+ | (UA1 Collab.) |
| ARNISON | 86D | PL B177 244 | +Albajar, Albrow+ | (UA1 Collab.) |
| BARTEL | 86 | ZPHY C31 359 | +Becker, Felst, Haidt+ | (JADE Collab.) |
| BARTEL | 86C | ZPHY C30 371 | +Becker, Cords, Felst, Haidt+ | (JADE Collab.) |
| BEHREND | 86 | PL 168B 420 | +Buerger, Criegee, Fenner+ | (CELLO Collab.) |
| BEHREND | 86C | PL B181 178 | +Buerger, Criegee, Dainton+ | (CELLO Collab.) |
| DERRICK | 86 | PL 166B 463 | +Gan, Kooijman, Loos+ | (HRS Collab.) |
| Also | 86B | PR D34 3286 | Derrick, Gan, Kooijman, Loos, Musgrave+ | (HRS Collab.) |
| DERRICK | 86B | PR D34 3286 | +Gan, Kooijman, Loos, Musgrave+ | (HRS Collab.) |
| GRIFOLS | 86 | PL 168B 264 | +Peris | (BARC) |
| JODIDIO | 86 | PR D34 1967 | +Balke, Carr, Gidal, Shinsky+ | (LBL, NWES, TRIU) |
| Also | 88 | PR D37 237 erratum | Jodidio, Balke, Carr+ | (LBL, NWES, TRIU) |
| APPEL | 85 | PL 160B 349 | +Bagnaia, Banner+ | (UA2 Collab.) |
| BARTEL | 85K | PL 160B 337 | +Becker, Cords, Eichler+ | (JADE Collab.) |
| BERGER | 85 | ZPHY C28 1 | +Genzel, Lackas, Pielorz+ | (PLUTO Collab.) |
| BERGER | 85B | ZPHY C27 341 | +Deuter, Genzel, Lackas, Pielorz+ | (PLUTO Collab.) |
| BAGNAIA | 84C | PL 138B 430 | +Banner, Battiston+ | (UA2 Collab.) |
| BARTEL | 84D | PL 146B 437 | +Becker, Bowdery, Cords+ | (JADE Collab.) |
| BARTEL | 84E | PL 146B 121 | +Becker, Bowdery, Cords, Felst+ | (JADE Collab.) |
| EICHTEN | 84 | RMP 56 579 | +Hinchliffe, Lane, Quigg | (FNAL, LBL, OSU) |
| ALTHOFF | 83C | PL 126B 493 | +Fischer, Burkhardt+ | (TASSO Collab.) |
| RENARD | 82 | PL 116B 264 | | (CERN) |