# Heavy Bosons Other Than Higgs Bosons, Searches for

NODE=S056

NODE=S056

We list here various limits on charged and neutral heavy vector bosons (other than $W$'s and $Z$'s), heavy scalar bosons (other than Higgs bosons), vector or scalar leptoquarks, and axigluons.

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NODE=S056210

### MASS LIMITS for $W'$ (Heavy Charged Vector Boson Other Than $W$) in Hadron Collider Experiments

NODE=S056W1C

Couplings of $W'$ to quarks and leptons are taken to be identical with those of $W$. The following limits are obtained from $p\overline{p} \to W' X$ with $W'$ decaying to the mode indicated in the comments. New decay channels (*e.g.*, $W' \to WZ$) are assumed to be suppressed. UA1 and UA2 experiments assume that the $t\overline{b}$ channel is not open.

NODE=S056W1C

NODE=S056W1C

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>1000** | 95 | ABAZOV | 08C | D0 | $W' \to e\nu$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| > 788 | 95 | ABULENCIA | 07K | CDF | $W' \to e\nu$ |
| none 200–610 | 95 | [1] ABAZOV | 06N | D0 | $W' \to tb$ |
| > 800 | 95 | ABAZOV | 04C | D0 | $W' \to q\overline{q}$ |
| 225–536 | 95 | [2] ACOSTA | 03B | CDF | $W' \to tb$ |
| none 200–480 | 95 | [3] AFFOLDER | 02C | CDF | $W' \to WZ$ |
| > 786 | 95 | [4] AFFOLDER | 01I | CDF | $W' \to e\nu, \mu\nu$ |
| > 660 | 95 | [5] ABE | 00 | CDF | $W' \to \mu\nu$ |
| none 300–420 | 95 | [6] ABE | 97G | CDF | $W' \to q\overline{q}$ |
| > 720 | 95 | [7] ABACHI | 96C | D0 | $W' \to e\nu$ |
| > 610 | 95 | [8] ABACHI | 95E | D0 | $W' \to e\nu, \tau\nu$ |
| > 652 | 95 | [9] ABE | 95M | CDF | $W' \to e\nu$ |
| > 251 | 90 | [10] ALITTI | 93 | UA2 | $W' \to q\overline{q}$ |
| none 260–600 | 95 | [11] RIZZO | 93 | RVUE | $W' \to q\overline{q}$ |
| > 220 | 90 | [12] ALBAJAR | 89 | UA1 | $W' \to e\nu$ |
| > 209 | 90 | [13] ANSARI | 87D | UA2 | $W' \to e\nu$ |

[1] The ABAZOV 06N quoted limit is for $W'$ with SM-like coupling which interferes with the SM $W$ boson. For $W'$ with right-handed coupling, $M_{W'}$ between 200 and 630 (670) GeV is excluded for $M_{\nu_R} \ll M_{W'}$ ($M_{\nu_R} > M_{W'}$). NODE=S056W1C;LINKAGE=BZ

[2] The ACOSTA 03B quoted limit is for $M_{W'} \gg M_{\nu_R}$. For $M_{W'} < M_{\nu_R}$, $M_{W'}$ between 225 and 566 GeV is excluded. NODE=S056W1C;LINKAGE=CT

[3] The quoted limit is obtained assuming $W'WZ$ coupling strength is the same as the ordinary $WWZ$ coupling strength in the Standard Model. See their Fig. 2 for the limits on the production cross sections as a function of the $W'$ width. NODE=S056W1C;LINKAGE=FC

[4] AFFOLDER 01I combine a new bound on $W' \to e\nu$ of 754 GeV with the bound of ABE 00 on $W' \to \mu\nu$ to obtain quoted bound. NODE=S056W1C;LINKAGE=FK

[5] ABE 00 assume that the neutrino from $W'$ decay is stable and has a mass significantly less than $m_{W'}$. NODE=S056W1C;LINKAGE=BK

[6] ABE 97G search for new particle decaying to dijets. NODE=S056W1C;LINKAGE=SZ

[7] For bounds on $W_R$ with nonzero right-handed mass, see Fig. 5 from ABACHI 96C. NODE=S056W1C;LINKAGE=J

[8] ABACHI 95E assume that the decay $W' \to WZ$ is suppressed and that the neutrino from $W'$ decay is stable and has a mass significantly less $m_{W'}$. NODE=S056W1C;LINKAGE=I

[9] ABE 95M assume that the decay $W' \to WZ$ is suppressed and the (right-handed) neutrino is light, noninteracting, and stable. If $m_\nu$=60 GeV, for example, the effect on the mass limit is negligible. NODE=S056W1C;LINKAGE=H

[10] ALITTI 93 search for resonances in the two-jet invariant mass. The limit assumes $\Gamma(W')/m_{W'} = \Gamma(W)/m_W$ and $B(W' \to jj) = 2/3$. This corresponds to $W_R$ with $m_{\nu_R} > m_{W_R}$ (no leptonic decay) and $W_R \to t\overline{b}$ allowed. See their Fig. 4 for limits in the $m_{W'}$–$B(q\overline{q})$ plane. NODE=S056W1C;LINKAGE=G

[11] RIZZO 93 analyses CDF limit on possible two-jet resonances. The limit is sensitive to the inclusion of the assumed $K$ factor. NODE=S056W1C;LINKAGE=RZ

[12] ALBAJAR 89 cross section limit at 630 GeV is $\sigma(W')\, B(e\nu) <$ 4.1 pb (90% CL). NODE=S056W1C;LINKAGE=D

[13] See Fig. 5 of ANSARI 87D for the excluded region in the $m_{W'}$–$[(g_{W'q})^2\, B(W' \to e\overline{\nu})]$ plane. Note that the quantity $(g_{W'q})^2\, B(W' \to e\overline{\nu})$ is normalized to unity for the standard $W$ couplings. NODE=S056W1C;LINKAGE=C

## $W_R$ (Right-Handed $W$ Boson) MASS LIMITS

NODE=S056MR

Assuming a light right-handed neutrino, except for BEALL 82, LANGACKER 89B, and COLANGELO 91. $g_R = g_L$ assumed. [Limits in the section MASS LIMITS for $W'$ below are also valid for $W_R$ if $m_{\nu_R} \ll m_{W_R}$.] Some limits assume manifest left-right symmetry, *i.e.*, the equality of left- and right Cabibbo-Kobayashi-Maskawa matrices. For a comprehensive review, see LANGACKER 89B. Limits on the $W_L$-$W_R$ mixing angle $\zeta$ are found in the next section. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

NODE=S056MR

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* | |
|---|---|---|---|---|---|---|
| **> 715** | 90 | [14] CZAKON | 99 | RVUE | Electroweak | NODE=S056MR |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| > 180 | 90 | [15] MELCONIAN | 07 | CNTR | $^{37}$K $\beta^+$ decay | |
| > 290.7 | 90 | [16] SCHUMANN | 07 | CNTR | Polarized neutron decay | |
| [> 3300] | 95 | [17] CYBURT | 05 | COSM | Nucleosynthesis; light $\nu_R$ | |
| > 310 | 90 | [18] THOMAS | 01 | CNTR | $\beta^+$ decay | |
| > 137 | 95 | [19] ACKERSTAFF | 99D | OPAL | $\tau$ decay | |
| >1400 | 68 | [20] BARENBOIM | 98 | RVUE | Electroweak, $Z$-$Z'$ mixing | |
| > 549 | 68 | [21] BARENBOIM | 97 | RVUE | $\mu$ decay | |
| > 220 | 95 | [22] STAHL | 97 | RVUE | $\tau$ decay | |
| > 220 | 90 | [23] ALLET | 96 | CNTR | $\beta^+$ decay | |
| > 281 | 90 | [24] KUZNETSOV | 95 | CNTR | Polarized neutron decay | |
| > 282 | 90 | [25] KUZNETSOV | 94B | CNTR | Polarized neutron decay | |
| > 439 | 90 | [26] BHATTACH... | 93 | RVUE | $Z$-$Z'$ mixing | |
| > 250 | 90 | [27] SEVERIJNS | 93 | CNTR | $\beta^+$ decay | |
| | | [28] IMAZATO | 92 | CNTR | $K^+$ decay | |
| > 475 | 90 | [29] POLAK | 92B | RVUE | $\mu$ decay | |
| > 240 | 90 | [30] AQUINO | 91 | RVUE | Neutron decay | |
| > 496 | 90 | [30] AQUINO | 91 | RVUE | Neutron and muon decay | OCCUR=2 |
| > 700 | | [31] COLANGELO | 91 | THEO | $m_{K^0_L} - m_{K^0_S}$ | |
| > 477 | 90 | [32] POLAK | 91 | RVUE | $\mu$ decay | |
| [none 540–23000] | | [33] BARBIERI | 89B | ASTR | SN 1987A; light $\nu_R$ | |
| > 300 | 90 | [34] LANGACKER | 89B | RVUE | General | |
| > 160 | 90 | [35] BALKE | 88 | CNTR | $\mu \rightarrow e \nu \overline{\nu}$ | |
| > 406 | 90 | [36] JODIDIO | 86 | ELEC | Any $\zeta$ | |
| > 482 | 90 | [36] JODIDIO | 86 | ELEC | $\zeta = 0$ | OCCUR=2 |
| > 800 | | MOHAPATRA | 86 | RVUE | SU(2)$_L$×SU(2)$_R$×U(1) | |
| > 400 | 95 | [37] STOKER | 85 | ELEC | Any $\zeta$ | |
| > 475 | 95 | [37] STOKER | 85 | ELEC | $\zeta$ <0.041 | OCCUR=2 |
| | | [38] BERGSMA | 83 | CHRM | $\nu_\mu e \rightarrow \mu \nu_e$ | |
| > 380 | 90 | [39] CARR | 83 | ELEC | $\mu^+$ decay | |
| >1600 | | [40] BEALL | 82 | THEO | $m_{K^0_L} - m_{K^0_S}$ | |

[14] CZAKON 99 perform a simultaneous fit to charged and neutral sectors. NODE=S056MR;LINKAGE=ZP

[15] MELCONIAN 07 measure the neutrino angular asymmetry in $\beta^+$-decays of polarized $^{37}$K, stored in a magneto-optical trap. Result is consistent with SM prediction and does not constrain the $W_L - W_R$ mixing angle appreciably. NODE=S056MR;LINKAGE=ME

[16] SCHUMANN 07 limit is from measurements of the asymmetry $\langle \vec{p}_\nu \cdot \sigma_n \rangle$ in the $\beta$ decay of polarized neutrons. Zero mixing is assumed. NODE=S056MR;LINKAGE=SC

[17] CYBURT 05 limit follows by requiring that three light $\nu_R$'s decouple when $T_{dec} > 140$ MeV. For different $T_{dec}$, the bound becomes $M_{W_R} > 3.3$ TeV ($T_{dec}$ / 140 MeV)$^{3/4}$. NODE=S056MR;LINKAGE=CB

[18] THOMAS 01 limit is from measurement of $\beta^+$ polarization in decay of polarized $^{12}$N. The listed limit assumes no mixing. NODE=S056MR;LINKAGE=TH

[19] ACKERSTAFF 99D limit is from $\tau$ decay parameters. Limit increase to 145 GeV for zero mixing. NODE=S056MR;LINKAGE=RD

[20] BARENBOIM 98 assumes minimal left-right model with Higgs of SU(2)$_R$ in SU(2)$_L$ doublet. For Higgs in SU(2)$_L$ triplet, $m_{W_R}$ >1100 GeV. Bound calculated from effect of corresponding $Z_{LR}$ on electroweak data through $Z$–$Z_{LR}$ mixing. NODE=S056MR;LINKAGE=B6

[21] The quoted limit is from $\mu$ decay parameters. BARENBOIM 97 also evaluate limit from $K_L$-$K_S$ mass difference. NODE=S056MR;LINKAGE=MW

[22] STAHL 97 limit is from fit to $\tau$-decay parameters. NODE=S056MR;LINKAGE=S

[23] ALLET 96 measured polarization-asymmetry correlation in $^{12}$N$\beta^+$ decay. The listed limit assumes zero $L$-$R$ mixing. NODE=S056MR;LINKAGE=R

[24] KUZNETSOV 95 limit is from measurements of the asymmetry $\langle \vec{p}_\nu \cdot \sigma_n \rangle$ in the $\beta$ decay of polarized neutrons. Zero mixing assumed. See also KUZNETSOV 94B. NODE=S056MR;LINKAGE=N

[25] KUZNETSOV 94B limit is from measurements of the asymmetry $\langle \vec{p}_\nu \cdot \sigma_n \rangle$ in the $\beta$ decay of polarized neutrons. Zero mixing assumed. NODE=S056MR;LINKAGE=L

[26] BHATTACHARYYA 93 uses $Z$-$Z'$ mixing limit from LEP '90 data, assuming a specific Higgs sector of SU(2)$_L$×SU(2)$_R$×U(1) gauge model. The limit is for $m_t$=200 GeV and slightly improves for smaller $m_t$. NODE=S056MR;LINKAGE=K

[27] SEVERIJNS 93 measured polarization-asymmetry correlation in $^{107}\text{In}\,\beta^+$ decay. The listed limit assumes zero $L$-$R$ mixing. Value quoted here is from SEVERIJNS 94 erratum. NODE=S056MR;LINKAGE=IS

[28] IMAZATO 92 measure positron asymmetry in $K^+ \to \mu^+ \nu_\mu$ decay and obtain $\xi P_\mu > 0.990$ (90% CL). If $W_R$ couples to $u\overline{s}$ with full weak strength ($V^R_{us}$=1), the result corresponds to $m_{W_R} >$653 GeV. See their Fig. 4 for $m_{W_R}$ limits for general $|V^R_{us}|^2=1-|V^R_{ud}|^2$. NODE=S056MR;LINKAGE=IM

[29] POLAK 92B limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming $\zeta$=0. Supersedes POLAK 91. NODE=S056MR;LINKAGE=PK

[30] AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right symmetry assumed. Stronger of the two limits also includes muon decay results. NODE=S056MR;LINKAGE=F

[31] COLANGELO 91 limit uses hadronic matrix elements evaluated by QCD sum rule and is less restrictive than BEALL 82 limit which uses vacuum saturation approximation. Manifest left-right symmetry assumed. NODE=S056MR;LINKAGE=H

[32] POLAK 91 limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming $\zeta$=0. Superseded by POLAK 92B. NODE=S056MR;LINKAGE=PZ

[33] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV. NODE=S056MR;LINKAGE=BB

[34] LANGACKER 89B limit is for any $\nu_R$ mass (either Dirac or Majorana) and for a general class of right-handed quark mixing matrices. NODE=S056MR;LINKAGE=I

[35] BALKE 88 limit is for $m_{\nu_{eR}} = 0$ and $m_{\nu_{\mu R}} \leq 50$ MeV. Limits come from precise measurements of the muon decay asymmetry as a function of the positron energy. NODE=S056MR;LINKAGE=Q

[36] JODIDIO 86 is the same TRIUMF experiment as STOKER 85 (and CARR 83); however, it uses a different technique. The results given here are combined results of the two techniques. The technique here involves precise measurement of the end-point $e^+$ spectrum in the decay of the highly polarized $\mu^+$. NODE=S056MR;LINKAGE=J

[37] STOKER 85 is same TRIUMF experiment as CARR 83. Here they measure the decay $e^+$ spectrum asymmetry above 46 MeV/$c$ using a muon-spin-rotation technique. Assumed a light right-handed neutrino. Quoted limits are from combining with CARR 83. NODE=S056MR;LINKAGE=C

[38] BERGSMA 83 set limit $m_{W_2}/m_{W_1} >$1.9 at CL = 90%. NODE=S056MR;LINKAGE=A

[39] CARR 83 is TRIUMF experiment with a highly polarized $\mu^+$ beam. Looked for deviation from $V-A$ at the high momentum end of the decay $e^+$ energy spectrum. Limit from previous world-average muon polarization parameter is $m_{W_R} >$240 GeV. Assumes a light right-handed neutrino. NODE=S056MR;LINKAGE=B

[40] BEALL 82 limit is obtained assuming that $W_R$ contribution to $K^0_L$–$K^0_S$ mass difference is smaller than the standard one, neglecting the top quark contributions. Manifest left-right symmetry assumed. NODE=S056MR;LINKAGE=E

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## Limit on $W_L$-$W_R$ Mixing Angle $\zeta$

NODE=S056WRZ

Lighter mass eigenstate $W_1 = W_L\cos\zeta - W_R\sin\zeta$. Light $\nu_R$ assumed unless noted. Values in brackets are from cosmological and astrophysical considerations. NODE=S056WRZ

NODE=S056WRZ

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| < 0.12 | 95 | [41] ACKERSTAFF | 99D | OPAL | $\tau$ decay |
| < 0.013 | 90 | [42] CZAKON | 99 | RVUE | Electroweak |
| < 0.0333 | | [43] BARENBOIM | 97 | RVUE | $\mu$ decay |
| < 0.04 | 90 | [44] MISHRA | 92 | CCFR | $\nu N$ scattering |
| −0.0006 to 0.0028 | 90 | [45] AQUINO | 91 | RVUE | |
| [none 0.00001–0.02] | | [46] BARBIERI | 89B | ASTR | SN 1987A |
| < 0.040 | 90 | [47] JODIDIO | 86 | ELEC | $\mu$ decay |
| −0.056 to 0.040 | 90 | [47] JODIDIO | 86 | ELEC | $\mu$ decay |

OCCUR=2

[41] ACKERSTAFF 99D limit is from $\tau$ decay parameters. NODE=S056WRZ;LINKAGE=RD

[42] CZAKON 99 perform a simultaneous fit to charged and neutral sectors. NODE=S056WRZ;LINKAGE=ZP

[43] The quoted limit is from $\mu$ decay parameters. BARENBOIM 97 also evaluate limit from $K_L$-$K_S$ mass difference. NODE=S056WRZ;LINKAGE=MW

[44] MISHRA 92 limit is from the absence of extra large-$x$, large-$y$ $\overline{\nu}_\mu N \to \overline{\nu}_\mu X$ events at Tevatron, assuming left-handed $\nu$ and right-handed $\overline{\nu}$ in the neutrino beam. The result gives $\zeta^2(1-2m^2_{W_1}/m^2_{W_2}) < 0.0015$. The limit is independent of $\nu_R$ mass. NODE=S056WRZ;LINKAGE=A

[45] AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right asymmetry is assumed. NODE=S056WRZ;LINKAGE=C

[46] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV. NODE=S056WRZ;LINKAGE=BB

[47] First JODIDIO 86 result assumes $m_{W_R}=\infty$, second is for unconstrained $m_{W_R}$. NODE=S056WRZ;LINKAGE=B

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NODE=S056215

## MASS LIMITS for $Z'$ (Heavy Neutral Vector Boson Other Than $Z$)

NODE=S056216

### Limits for $Z'_{SM}$

NODE=S056Z1C

$Z'_{SM}$ is assumed to have couplings with quarks and leptons which are identical to those of $Z$, and decays only to known fermions.

NODE=S056Z1C

NODE=S056Z1C;CHECK LIMITS

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **> 923** | 95 | [48] AALTONEN | 07H | CDF | $p\overline{p}$, $Z'_{SM} \rightarrow e^+e^-$ |
| **>1305** | 95 | [49] ABDALLAH | 06C | DLPH | $e^+e^-$ |
| **>1500** | 95 | [50] CHEUNG | 01B | RVUE | Electroweak |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| > 850 | | [51] ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| > 825 | 95 | [52] ABULENCIA | 05A | CDF | $p\overline{p}$; $Z'_{SM} \rightarrow e^+e^-$, $\mu^+\mu^-$ |
| > 399 | 95 | [53] ACOSTA | 05R | CDF | $\overline{p}p$: $Z'_{SM} \rightarrow \tau^+\tau^-$ |
| none 400–640 | 95 | ABAZOV | 04C | D0 | $p\overline{p}$: $Z'_{SM} \rightarrow q\overline{q}$ |
| >1018 | 95 | [54] ABBIENDI | 04G | OPAL | $e^+e^-$ |
| > 670 | 95 | [55] ABAZOV | 01B | D0 | $p\overline{p}$, $Z'_{SM} \rightarrow e^+e^-$ |
| > 710 | 95 | [56] ABREU | 00S | DLPH | $e^+e^-$ |
| > 898 | 95 | [57] BARATE | 00I | ALEP | $e^+e^-$ |
| > 809 | 95 | [58] ERLER | 99 | RVUE | Electroweak |
| > 690 | 95 | [59] ABE | 97S | CDF | $p\overline{p}$; $Z'_{SM} \rightarrow e^+e^-$, $\mu^+\mu^-$ |
| > 490 | 95 | ABACHI | 96D | D0 | $p\overline{p}$; $Z'_{SM} \rightarrow e^+e^-$ |
| > 398 | 95 | [60] VILAIN | 94B | CHM2 | $\nu_\mu e \rightarrow \nu_\mu e$ and $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$ |
| > 237 | 90 | [61] ALITTI | 93 | UA2 | $p\overline{p}$; $Z'_{SM} \rightarrow q\overline{q}$ |
| none 260–600 | 95 | [62] RIZZO | 93 | RVUE | $p\overline{p}$; $Z'_{SM} \rightarrow q\overline{q}$ |
| > 426 | 90 | [63] ABE | 90F | VNS | $e^+e^-$ |

OCCUR=4

[48] AALTONEN 07H search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.

NODE=S056Z1C;LINKAGE=AA

[49] ABDALLAH 06C use data $\sqrt{s}$ = 130–207 GeV.

NODE=S056Z1C;LINKAGE=HL

[50] CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.

NODE=S056Z1C;LINKAGE=QK

[51] ABULENCIA 06L search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.

NODE=S056Z1C;LINKAGE=BU

[52] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.

NODE=S056Z1C;LINKAGE=AU

[53] ACOSTA 05R search for resonances decaying to tau lepton pairs in $\overline{p}p$ collisions at $\sqrt{s}$ = 1.96 TeV.

NODE=S056Z1C;LINKAGE=AC

[54] ABBIENDI 04G give 95% CL limit on $Z$-$Z'$ mixing $-0.00422 < \theta < 0.00091$. $\sqrt{s}$ = 91 to 207 GeV.

NODE=S056Z1C;LINKAGE=AB

[55] ABAZOV 01B search for resonances in $p\overline{p} \rightarrow e^+e^-$ at $\sqrt{s}$=1.8 TeV. They find $\sigma \cdot$ B($Z' \rightarrow ee$)< 0.06 pb for $M_{Z'} > 500$ GeV.

NODE=S056Z1C;LINKAGE=ZB

[56] ABREU 00S uses LEP data at $\sqrt{s}$=90 to 189 GeV.

NODE=S056Z1C;LINKAGE=TG

[57] BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume $\theta$=0. Bounds in the mass-mixing plane are shown in their Figure 18.

NODE=S056Z1C;LINKAGE=BI

[58] ERLER 99 give 90%CL limit on the $Z$-$Z'$ mixing $-0.0041 < \theta < 0.0003$. $\rho_0$=1 is assumed.

NODE=S056Z1C;LINKAGE=JE

[59] ABE 97S find $\sigma(Z')\times$B($e^+e^-$,$\mu^+\mu^-$)< 40 fb for $m_{Z'} > 600$ GeV at $\sqrt{s}$= 1.8 TeV.

NODE=S056Z1C;LINKAGE=AS

[60] VILAIN 94B assume $m_t$ = 150 GeV.

NODE=S056Z1C;LINKAGE=ZV

[61] ALITTI 93 search for resonances in the two-jet invariant mass. The limit assumes B($Z' \rightarrow q\overline{q}$)=0.7. See their Fig. 5 for limits in the $m_{Z'}$−B($q\overline{q}$) plane.

NODE=S056Z1C;LINKAGE=GG

[62] RIZZO 93 analyses CDF limit on possible two-jet resonances.

NODE=S056Z1C;LINKAGE=RZ

[63] ABE 90F use data for $R$, $R_{\ell\ell}$, and $A_{\ell\ell}$. They fix $m_W$ = 80.49 ± 0.43 ± 0.24 GeV and $m_Z$ = 91.13 ± 0.03 GeV.

NODE=S056Z1C;LINKAGE=I

### Limits for $Z_{LR}$

NODE=S056ZLR

$Z_{LR}$ is the extra neutral boson in left-right symmetric models. $g_L = g_R$ is assumed unless noted. Values in parentheses assume stronger constraint on the Higgs sector, usually motivated by specific left-right symmetric models (see the Note on the $W'$). Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino. Direct search bounds assume decays to Standard Model fermions only, unless noted.

NODE=S056ZLR

NODE=S056ZLR;CHECK LIMITS

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **>600** | 95 | SCHAEL | 07A | ALEP | $e^+e^-$ |
| **>860** | 95 | [64] CHEUNG | 01B | RVUE | Electroweak |
| **>630** | 95 | [65] ABE | 97S | CDF | $p\overline{p}$; $Z'_{LR} \rightarrow e^+e^-$, $\mu^+\mu^-$ |

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

| | | | | | |
|---|---|---|---|---|---|
| >455 | 95 | [66] ABDALLAH | 06C | DLPH | $e^+ e^-$ |
| >518 | 95 | [67] ABBIENDI | 04G | OPAL | $e^+ e^-$ |
| >380 | 95 | [68] ABREU | 00S | DLPH | $e^+ e^-$ |
| >436 | 95 | [69] BARATE | 00I | ALEP | Repl. by SCHAEL 07A |
| >550 | 95 | [70] CHAY | 00 | RVUE | Electroweak |
| | | [71] ERLER | 00 | RVUE | Cs |
| | | [72] CASALBUONI | 99 | RVUE | Cs |
| (> 1205) | 90 | [73] CZAKON | 99 | RVUE | Electroweak |
| >564 | 95 | [74] ERLER | 99 | RVUE | Electroweak |
| (> 1673) | 95 | [75] ERLER | 99 | RVUE | Electroweak |
| (> 1700) | 68 | [76] BARENBOIM | 98 | RVUE | Electroweak |
| >244 | 95 | [77] CONRAD | 98 | RVUE | $\nu_\mu N$ scattering |
| >253 | 95 | [78] VILAIN | 94B | CHM2 | $\nu_\mu e \rightarrow \nu_\mu e$ and $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$ |
| none 200–600 | 95 | [79] RIZZO | 93 | RVUE | $p\overline{p}$; $Z_{LR} \rightarrow q\overline{q}$ |
| [> 2000] | | WALKER | 91 | COSM | Nucleosynthesis; light $\nu_R$ |
| none 200–500 | | [80] GRIFOLS | 90 | ASTR | SN 1987A; light $\nu_R$ |
| none 350–2400 | | [81] BARBIERI | 89B | ASTR | SN 1987A; light $\nu_R$ |

OCCUR=2

OCCUR=2

[64] CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.

NODE=S056ZLR;LINKAGE=QK

[65] ABE 97S find $\sigma(Z') \times B(e^+ e^-, \mu^+ \mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s} = 1.8$ TeV.

NODE=S056ZLR;LINKAGE=AS

[66] ABDALLAH 06C give 95% CL limit $|\theta| < 0.0028$. See their Fig. 14 for limit contours in the mass-mixing plane.

NODE=S056ZLR;LINKAGE=HL

[67] ABBIENDI 04G give 95% CL limit on $Z$-$Z'$ mixing $-0.00098 < \theta < 0.00190$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s} = 91$ to 207 GeV.

NODE=S056ZLR;LINKAGE=AB

[68] ABREU 00S give 95% CL limit on $Z$-$Z'$ mixing $|\theta| < 0.0018$. See their Fig. 6 for the limit contour in the mass-mixing plane. $\sqrt{s}$=90 to 189 GeV.

NODE=S056ZLR;LINKAGE=TG

[69] BARATE 00I search for deviations in cross section and asymmetries in $e^+ e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume $\theta$=0. Bounds in the mass-mixing plane are shown in their Figure 18.

NODE=S056ZLR;LINKAGE=BI

[70] CHAY 00 also find $-0.0003 < \theta < 0.0019$. For $g_R$ free, $m_{Z'} > 430$ GeV.

NODE=S056ZLR;LINKAGE=CY

[71] ERLER 00 discuss the possibility that a discrepancy between the observed and predicted values of $Q_W$(Cs) is due to the exchange of $Z'$. The data are better described in a certain class of the $Z'$ models including $Z_{LR}$ and $Z_\chi$.

NODE=S056ZLR;LINKAGE=LE

[72] CASALBUONI 99 discuss the discrepancy between the observed and predicted values of $Q_W$(Cs). It is shown that the data are better described in a class of models including the $Z_{LR}$ model.

NODE=S056ZLR;LINKAGE=CS

[73] CZAKON 99 perform a simultaneous fit to charged and neutral sectors. Assumes manifest left-right symmetric model. Finds $|\theta| < 0.0042$.

NODE=S056ZLR;LINKAGE=ZP

[74] ERLER 99 give 90% CL limit on the $Z$-$Z'$ mixing $-0.0009 < \theta < 0.0017$.

NODE=S056ZLR;LINKAGE=JE

[75] ERLER 99 assumes 2 Higgs doublets, transforming as 10 of SO(10), embedded in $E_6$.

NODE=S056ZLR;LINKAGE=EJ

[76] BARENBOIM 98 also gives 68% CL limits on the $Z$-$Z'$ mixing $-0.0005 < \theta < 0.0033$. Assumes Higgs sector of minimal left-right model.

NODE=S056ZLR;LINKAGE=H

[77] CONRAD 98 limit is from measurements at CCFR, assuming no $Z$-$Z'$ mixing.

NODE=S056ZLR;LINKAGE=ZC

[78] VILAIN 94B assume $m_t = 150$ GeV and $\theta$=0. See Fig. 2 for limit contours in the mass-mixing plane.

NODE=S056ZLR;LINKAGE=ZV

[79] RIZZO 93 analyses CDF limit on possible two-jet resonances.

NODE=S056ZLR;LINKAGE=RZ

[80] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. A specific Higgs sector is assumed. See also GRIFOLS 90D, RIZZO 91.

NODE=S056ZLR;LINKAGE=Z2

[81] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV. Bounds depend on assumed supernova core temperature.

NODE=S056ZLR;LINKAGE=BB

## Limits for $Z_\chi$

NODE=S056ZCH

$Z_\chi$ is the extra neutral boson in SO(10) $\rightarrow$ SU(5) $\times$ U(1)$_\chi$. $g_\chi = e/\cos\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho = 1$ but with no further constraints on the Higgs sector. Values in parentheses assume stronger constraint on the Higgs sector motivated by superstring models. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

NODE=S056ZCH

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **> 822** | 95 | [82] AALTONEN | 07H | CDF | $p\overline{p}$, $Z'_\chi \rightarrow e^+ e^-$ |
| **> 781** | 95 | [83] ABBIENDI | 04G | OPAL | $e^+ e^-$ |

NODE=S056ZCH

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

| | | | | | | |
|---|---|---|---|---|---|---|
| $>$ 680 | 95 | SCHAEL | 07A | ALEP | $e^+e^-$ | |
| $>$ 545 | 95 | [84] ABDALLAH | 06C | DLPH | $e^+e^-$ | |
| $>$ 740 | | [85] ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H | |
| $>$ 690 | 95 | [86] ABULENCIA | 05A | CDF | $p\overline{p}$; $Z'_\chi \rightarrow e^+e^-$, $\mu^+\mu^-$ | |
| $>$2100 | | [87] BARGER | 03B | COSM | Nucleosynthesis; light $\nu_R$ | |
| $>$ 680 | 95 | [88] CHEUNG | 01B | RVUE | Electroweak | |
| $>$ 440 | 95 | [89] ABREU | 00S | DLPH | $e^+e^-$ | |
| $>$ 533 | 95 | [90] BARATE | 00I | ALEP | Repl. by SCHAEL 07A | |
| $>$ 554 | 95 | [91] CHO | 00 | RVUE | Electroweak | |
| | | [92] ERLER | 00 | RVUE | Cs | |
| | | [93] ROSNER | 00 | RVUE | Cs | |
| $>$ 545 | 95 | [94] ERLER | 99 | RVUE | Electroweak | |
| ($>$ 1368) | 95 | [95] ERLER | 99 | RVUE | Electroweak | OCCUR=2 |
| $>$ 215 | 95 | [96] CONRAD | 98 | RVUE | $\nu_\mu N$ scattering | |
| $>$ 595 | 95 | [97] ABE | 97S | CDF | $p\overline{p}$; $Z'_\chi \rightarrow e^+e^-$, $\mu^+\mu^-$ | |
| $>$ 190 | 95 | [98] ARIMA | 97 | VNS | Bhabha scattering | |
| $>$ 262 | 95 | [99] VILAIN | 94B | CHM2 | $\nu_\mu e \rightarrow \nu_\mu e$; $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$ | |
| [$>$1470] | | [100] FARAGGI | 91 | COSM | Nucleosynthesis; light $\nu_R$ | |
| $>$ 231 | 90 | [101] ABE | 90F | VNS | $e^+e^-$ | OCCUR=3 |
| [$>$ 1140] | | [102] GONZALEZ-G..90D | | COSM | Nucleosynthesis; light $\nu_R$ | |
| [$>$ 2100] | | [103] GRIFOLS | 90 | ASTR | SN 1987A; light $\nu_R$ | |

[82] AALTONEN 07H search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZCH;LINKAGE=AA

[83] ABBIENDI 04G give 95% CL limit on $Z$-$Z'$ mixing $-0.00099 < \theta < 0.00194$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s}$ = 91 to 207 GeV. NODE=S056ZCH;LINKAGE=AB

[84] ABDALLAH 06C give 95% CL limit $|\theta| < 0.0031$. See their Fig. 14 for limit contours in the mass-mixing plane. NODE=S056ZCH;LINKAGE=HL

[85] ABULENCIA 06L search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZCH;LINKAGE=BU

[86] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZCH;LINKAGE=AU

[87] BARGER 03B limit is from the nucleosynthesis bound on the effective number of light neutrino $\delta N_\nu$ <1. The quark-hadron transition temperature $T_c$=150 MeV is assumed. The limit with $T_c$=400 MeV is >4300 GeV. NODE=S056ZCH;LINKAGE=GR

[88] CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis. NODE=S056ZCH;LINKAGE=QK

[89] ABREU 00S give 95% CL limit on $Z$-$Z'$ mixing $|\theta| < 0.0017$. See their Fig. 6 for the limit contour in the mass-mixing plane. $\sqrt{s}$=90 to 189 GeV. NODE=S056ZCH;LINKAGE=TG

[90] BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume $\theta$=0. Bounds in the mass-mixing plane are shown in their Figure 18. NODE=S056ZCH;LINKAGE=BI

[91] CHO 00 use various electroweak data to constrain $Z'$ models assuming $m_H$=100 GeV. See Fig. 3 for limits in the mass-mixing plane. NODE=S056ZCH;LINKAGE=6Z

[92] ERLER 00 discuss the possibility that a discrepancy between the observed and predicted values of $Q_W$(Cs) is due to the exchange of $Z'$. The data are better described in a certain class of the $Z'$ models including $Z_{LR}$ and $Z_\chi$. NODE=S056ZCH;LINKAGE=LE

[93] ROSNER 00 discusses the possibility that a discrepancy between the observed and predicted values of $Q_W$(Cs) is due to the exchange of $Z'$. The data are better described in a certain class of the $Z'$ models including $Z_\chi$. NODE=S056ZCH;LINKAGE=RC

[94] ERLER 99 give 90% CL limit on the $Z$-$Z'$ mixing $-0.0020 < \theta < 0.0015$. NODE=S056ZCH;LINKAGE=JE

[95] ERLER 99 assumes 2 Higgs doublets, transforming as 10 of SO(10), embedded in $E_6$. NODE=S056ZCH;LINKAGE=EJ

[96] CONRAD 98 limit is from measurements at CCFR, assuming no $Z$-$Z'$ mixing. NODE=S056ZCH;LINKAGE=ZC

[97] ABE 97S find $\sigma(Z')\times$B($e^+e^-$,$\mu^+\mu^-$)< 40 fb for $m_{Z'}$ > 600 GeV at $\sqrt{s}$= 1.8 TeV. NODE=S056ZCH;LINKAGE=AS

[98] $Z$-$Z'$ mixing is assumed to be zero. $\sqrt{s}$= 57.77 GeV. NODE=S056ZCH;LINKAGE=Q

[99] VILAIN 94B assume $m_t$ = 150 GeV and $\theta$=0. See Fig. 2 for limit contours in the mass-mixing plane. NODE=S056ZCH;LINKAGE=ZV

[100] FARAGGI 91 limit assumes the nucleosynthesis bound on the effective number of neutrinos $\Delta N_\nu$ < 0.5 and is valid for $m_{\nu_R}$ < 1 MeV. NODE=S056ZCH;LINKAGE=M

[101] ABE 90F use data for $R$, $R_{\ell\ell}$, and $A_{\ell\ell}$. ABE 90F fix $m_W$ = 80.49 ± 0.43 ± 0.24 GeV and $m_Z$ = 91.13 ± 0.03 GeV. NODE=S056ZCH;LINKAGE=I

[102] Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu$ < 1) and that $\nu_R$ is light ( $\lesssim$ 1 MeV). NODE=S056ZCH;LINKAGE=Z1

[103] GRIFOLS 90 limit holds for $m_{\nu_R}$ $\lesssim$ 1 MeV. See also GRIFOLS 90D, RIZZO 91. NODE=S056ZCH;LINKAGE=Z2

## Limits for $Z_\psi$

NODE=S056ZPS

$Z_\psi$ is the extra neutral boson in $E_6 \to SO(10) \times U(1)_\psi$. $g_\psi = e/\cos\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho=1$ but with no further constraints on the Higgs sector. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

NODE=S056ZPS

NODE=S056ZPS

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>822** | 95 | [104] AALTONEN | 07H | CDF | $p\overline{p}$, $Z'_\psi \to e^+e^-$ |
| **>475** | 95 | [105] ABDALLAH | 06C | DLPH | $e^+e^-$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >410 | 95 | SCHAEL | 07A | ALEP | $e^+e^-$ |
| >725 | | [106] ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| >675 | 95 | [107] ABULENCIA | 05A | CDF | $p\overline{p}$; $Z'_\psi \to e^+e^-$, $\mu^+\mu^-$ |
| >366 | 95 | [108] ABBIENDI | 04G | OPAL | $e^+e^-$ |
| >600 | | [109] BARGER | 03B | COSM | Nucleosynthesis; light $\nu_R$ |
| >350 | 95 | [110] ABREU | 00S | DLPH | $e^+e^-$ |
| >294 | 95 | [111] BARATE | 00I | ALEP | Repl. by SCHAEL 07A |
| >137 | 95 | [112] CHO | 00 | RVUE | Electroweak |
| >146 | 95 | [113] ERLER | 99 | RVUE | Electroweak |
| > 54 | 95 | [114] CONRAD | 98 | RVUE | $\nu_\mu N$ scattering |
| >590 | 95 | [115] ABE | 97S | CDF | $p\overline{p}$; $Z'_\psi \to e^+e^-$, $\mu^+\mu^-$ |
| >135 | 95 | [116] VILAIN | 94B | CHM2 | $\nu_\mu e \to \nu_\mu e$; $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$ |
| >105 | 90 | [117] ABE | 90F | VNS | $e^+e^-$ |
| [> 160] | | [118] GONZALEZ-G.. | 90D | COSM | Nucleosynthesis; light $\nu_R$ |
| [> 2000] | | [119] GRIFOLS | 90D | ASTR | SN 1987A; light $\nu_R$ |

[104] AALTONEN 07H search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZPS;LINKAGE=AA

[105] ABDALLAH 06C give 95% CL limit $|\theta| < 0.0027$. See their Fig. 14 for limit contours in the mass-mixing plane. NODE=S056ZPS;LINKAGE=HL

[106] ABULENCIA 06L search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZPS;LINKAGE=BU

[107] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZPS;LINKAGE=AU

[108] ABBIENDI 04G give 95% CL limit on $Z$-$Z'$ mixing $-0.00129 < \theta < 0.00258$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s}$ = 91 to 207 GeV. NODE=S056ZPS;LINKAGE=AB

[109] BARGER 03B limit is from the nucleosynthesis bound on the effective number of light neutrino $\delta N_\nu$ <1. The quark-hadron transition temperature $T_c$=150 MeV is assumed. The limit with $T_c$=400 MeV is >1100 GeV. NODE=S056ZPS;LINKAGE=GR

[110] ABREU 00S give 95% CL limit on $Z$-$Z'$ mixing $|\theta| < 0.0018$. See their Fig. 6 for the limit contour in the mass-mixing plane. $\sqrt{s}$=90 to 189 GeV. NODE=S056ZPS;LINKAGE=TG

[111] BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \to$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume $\theta$=0. Bounds in the mass-mixing plane are shown in their Figure 18. NODE=S056ZPS;LINKAGE=BI

[112] CHO 00 use various electroweak data to constrain $Z'$ models assuming $m_H$=100 GeV. See Fig. 3 for limits in the mass-mixing plane. NODE=S056ZPS;LINKAGE=6Z

[113] ERLER 99 give 90% CL limit on the $Z$-$Z'$ mixing $-0.0013 < \theta < 0.0024$. NODE=S056ZPS;LINKAGE=JE

[114] CONRAD 98 limit is from measurements at CCFR, assuming no $Z$-$Z'$ mixing. NODE=S056ZPS;LINKAGE=ZC

[115] ABE 97S find $\sigma(Z')\times B(e^+e^-,\mu^+\mu^-) <$ 40 fb for $m_{Z'} >$ 600 GeV at $\sqrt{s}$= 1.8 TeV. NODE=S056ZPS;LINKAGE=AS

[116] VILAIN 94B assume $m_t$ = 150 GeV and $\theta$=0. See Fig. 2 for limit contours in the mass-mixing plane. NODE=S056ZPS;LINKAGE=ZV

[117] ABE 90F use data for $R$, $R_{\ell\ell}$, and $A_{\ell\ell}$. ABE 90F fix $m_W$ = 80.49 ± 0.43 ± 0.24 GeV and $m_Z$ = 91.13 ± 0.03 GeV. NODE=S056ZPS;LINKAGE=I

[118] Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that $\nu_R$ is light ( $\lesssim$ 1 MeV). NODE=S056ZPS;LINKAGE=Z1

[119] GRIFOLS 90D limit holds for $m_{\nu_R} \lesssim$ 1 MeV. See also RIZZO 91. NODE=S056ZPS;LINKAGE=Z2

## Limits for $Z_\eta$

NODE=S056ZET

$Z_\eta$ is the extra neutral boson in $E_6$ models, corresponding to $Q_\eta = \sqrt{3/8}\ Q_\chi - \sqrt{5/8}\ Q_\psi$. $g_\eta = e/\cos\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho=1$ but with no further constraints on the Higgs sector. Values in parentheses assume stronger constraint on the Higgs sector motivated by superstring models. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

NODE=S056ZET

NODE=S056ZET

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **> 891** | 95 | [120] AALTONEN | 07H | CDF | $p\overline{p}$, $Z'_\eta \to e^+e^-$ |
| **> 515** | 95 | [121] ABBIENDI | 04G | OPAL | $e^+e^-$ |
| **> 619** | 95 | [122] CHO | 00 | RVUE | Electroweak |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| $>$ 350 | 95 | | SCHAEL | 07A | ALEP | $e^+e^-$ |
| $>$ 360 | 95 | [123] | ABDALLAH | 06C | DLPH | $e^+e^-$ |
| $>$ 745 | | [124] | ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| $>$ 720 | 95 | [125] | ABULENCIA | 05A | CDF | $p\overline{p}$; $Z'_\eta \rightarrow e^+e^-$, $\mu^+\mu^-$ |
| $>$1600 | | [126] | BARGER | 03B | COSM | Nucleosynthesis; light $\nu_R$ |
| $>$ 310 | 95 | [127] | ABREU | 00S | DLPH | $e^+e^-$ |
| $>$ 329 | 95 | [128] | BARATE | 00I | ALEP | Repl. by SCHAEL 07A |
| $>$ 365 | 95 | [129] | ERLER | 99 | RVUE | Electroweak |
| $>$ 87 | 95 | [130] | CONRAD | 98 | RVUE | $\nu_\mu N$ scattering |
| $>$ 620 | 95 | [131] | ABE | 97S | CDF | $p\overline{p}$; $Z'_\eta \rightarrow e^+e^-$, $\mu^+\mu^-$ |
| $>$ 100 | 95 | [132] | VILAIN | 94B | CHM2 | $\nu_\mu e \rightarrow \nu_\mu e$; $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$ |
| $>$ 125 | 90 | [133] | ABE | 90F | VNS | $e^+e^-$ |
| [$>$ 820] | | [134] | GONZALEZ-G.. | 90D | COSM | Nucleosynthesis; light $\nu_R$ |
| [$>$ 3300] | | [135] | GRIFOLS | 90 | ASTR | SN 1987A; light $\nu_R$ |
| [$>$ 1040] | | [134] | LOPEZ | 90 | COSM | Nucleosynthesis; light $\nu_R$ |

OCCUR=2

[120] AALTONEN 07H search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZET;LINKAGE=AA

[121] ABBIENDI 04G give 95% CL limit on $Z$-$Z'$ mixing $-0.00447 < \theta < 0.00331$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s}$ = 91 to 207 GeV. NODE=S056ZET;LINKAGE=AB

[122] CHO 00 use various electroweak data to constrain $Z'$ models assuming $m_H$=100 GeV. See Fig. 3 for limits in the mass-mixing plane. NODE=S056ZET;LINKAGE=6Z

[123] ABDALLAH 06C give 95% CL limit $|\theta| < 0.0092$. See their Fig. 14 for limit contours in the mass-mixing plane. NODE=S056ZET;LINKAGE=HL

[124] ABULENCIA 06L search for resonances decaying to $e^+e^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZET;LINKAGE=BU

[125] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. NODE=S056ZET;LINKAGE=AU

[126] BARGER 03B limit is from the nucleosynthesis bound on the effective number of light neutrino $\delta N_\nu$ <1. The quark-hadron transition temperature $T_c$=150 MeV is assumed. The limit with $T_c$=400 MeV is >3300 GeV. NODE=S056ZET;LINKAGE=GR

[127] ABREU 00S give 95% CL limit on $Z$-$Z'$ mixing $|\theta| < 0.0024$. See their Fig. 6 for the limit contour in the mass-mixing plane. $\sqrt{s}$=90 to 189 GeV. NODE=S056ZET;LINKAGE=TG

[128] BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume $\theta$=0. Bounds in the mass-mixing plane are shown in their Figure 18. NODE=S056ZET;LINKAGE=BI

[129] ERLER 99 give 90% CL limit on the $Z$-$Z'$ mixing $-0.0062 < \theta < 0.0011$. NODE=S056ZET;LINKAGE=JE

[130] CONRAD 98 limit is from measurements at CCFR, assuming no $Z$-$Z'$ mixing. NODE=S056ZET;LINKAGE=ZC

[131] ABE 97S find $\sigma(Z')\times$B($e^+e^-$,$\mu^+\mu^-$)< 40 fb for $m_{Z'}$ > 600 GeV at $\sqrt{s}$= 1.8 TeV. NODE=S056ZET;LINKAGE=AS

[132] VILAIN 94B assume $m_t$ = 150 GeV and $\theta$=0. See Fig. 2 for limit contours in the mass-mixing plane. NODE=S056ZET;LINKAGE=ZV

[133] ABE 90F use data for $R$, $R_{\ell\ell}$, and $A_{\ell\ell}$. ABE 90F fix $m_W = 80.49 \pm 0.43 \pm 0.24$ GeV and $m_Z = 91.13 \pm 0.03$ GeV. NODE=S056ZET;LINKAGE=I

[134] These authors claim that the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu$ < 1) constrains $Z'$ masses if $\nu_R$ is light ( $\lesssim$ 1 MeV). NODE=S056ZET;LINKAGE=Z1

[135] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim$ 1 MeV. See also GRIFOLS 90D, RIZZO 91. NODE=S056ZET;LINKAGE=Z2

## Limits for other $Z'$

NODE=S056ZOT
NODE=S056ZOT

| *VALUE* (GeV) | | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | [136] | ABULENCIA | 06M | CDF | $Z' \rightarrow e\mu$ |
| | [137] | ABAZOV | 04A | D0 | $Z' \rightarrow t\overline{t}$ |
| | [138] | BARGER | 03B | COSM | Nucleosynthesis; light $\nu_R$ |
| | [139] | CHO | 00 | RVUE | $E_6$-motivated |
| | [140] | CHO | 98 | RVUE | $E_6$-motivated |
| | [141] | ABE | 97G | CDF | $Z' \rightarrow \overline{q}q$ |

[136] ABULENCIA 06M search for new particle with lepton flavor violating decay at $\sqrt{s}$ = 1.96 TeV. See their Fig. 4 for an exclusion plot on a mass-coupling plane. NODE=S056ZOT;LINKAGE=UL

[137] Search for narrow resonance decaying to $t\overline{t}$. See their Fig.2 for limit on $\sigma B$. NODE=S056ZOT;LINKAGE=AB

[138] BARGER 03B use the nucleosynthesis bound on the effective number of light neutrino $\delta N_\nu$. See their Figs. 4–5 for limits in general $E_6$ motivated models. NODE=S056ZOT;LINKAGE=GR

[139] CHO 00 use various electroweak data to constrain $Z'$ models assuming $m_H$=100 GeV. See Fig. 2 for limits in general $E_6$-motivated models. NODE=S056ZOT;LINKAGE=6Z

[140] CHO 98 study constraints on four-Fermi contact interactions obtained from low-energy electroweak experiments, assuming no $Z$-$Z'$ mixing. NODE=S056ZOT;LINKAGE=CH

[141] Search for $Z'$ decaying to dijets at $\sqrt{s}$=1.8 TeV. For $Z'$ with electromagnetic strength coupling, no bound is obtained. NODE=S056ZOT;LINKAGE=BK

## Indirect Constraints on Kaluza-Klein Gauge Bosons

NODE=S056KKI

Bounds on a Kaluza-Klein excitation of the $Z$ boson or photon in $d$=1 extra dimension. These bounds can also be interpreted as a lower bound on $1/R$, the size of the extra dimension. Unless otherwise stated, bounds assume all fermions live on a single brane and all gauge fields occupy the 4+$d$-dimensional bulk. See also the section on "Extra Dimensions" in the "Searches" Listings in this *Review*.

NODE=S056KKI

NODE=S056KKI

| *VALUE* (TeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* | |
|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| > 4.7 | | [142] MUECK | 02 | RVUE | Electroweak | |
| > 3.3 | 95 | [143] CORNET | 00 | RVUE | $e \nu q q'$ | |
| >5000 | | [144] DELGADO | 00 | RVUE | $\epsilon_K$ | |
| > 2.6 | 95 | [145] DELGADO | 00 | RVUE | Electroweak | OCCUR=2 |
| > 3.3 | 95 | [146] RIZZO | 00 | RVUE | Electroweak | |
| > 2.9 | 95 | [147] MARCIANO | 99 | RVUE | Electroweak | |
| > 2.5 | 95 | [148] MASIP | 99 | RVUE | Electroweak | |
| > 1.6 | 90 | [149] NATH | 99 | RVUE | Electroweak | |
| > 3.4 | 95 | [150] STRUMIA | 99 | RVUE | Electroweak | |

[142] MUECK 02 limit is $2\sigma$ and is from global electroweak fit ignoring correlations among observables. Higgs is assumed to be confined on the brane and its mass is fixed. For scenarios of bulk Higgs, of brane-SU(2)$_L$, bulk-U(1)$_Y$, and of bulk-SU(2)$_L$, brane-U(1)$_Y$, the corresponding limits are > 4.6 TeV, > 4.3 TeV and > 3.0 TeV, respectively. NODE=S056KKI;LINKAGE=MK

[143] Bound is derived from limits on $e \nu q q'$ contact interaction, using data from HERA and the Tevatron. NODE=S056KKI;LINKAGE=G

[144] Bound holds only if first two generations of quarks lives on separate branes. If quark mixing is not complex, then bound lowers to 400 TeV from $\Delta m_K$. NODE=S056KKI;LINKAGE=B1

[145] See Figs. 1 and 2 of DELGADO 00 for several model variations. Special boundary conditions can be found which permit KK states down to 950 GeV and that agree with the measurement of $Q_W$(Cs). Quoted bound assumes all Higgs bosons confined to brane; placing one Higgs doublet in the bulk lowers bound to 2.3 TeV. NODE=S056KKI;LINKAGE=B2

[146] Bound is derived from global electroweak analysis assuming the Higgs field is trapped on the matter brane. If the Higgs propagates in the bulk, the bound increases to 3.8 TeV. NODE=S056KKI;LINKAGE=H

[147] Bound is derived from global electroweak analysis but considering only presence of the KK $W$ bosons. NODE=S056KKI;LINKAGE=F

[148] Global electroweak analysis used to obtain bound independent of position of Higgs on brane or in bulk. NODE=S056KKI;LINKAGE=E

[149] Bounds from effect of KK states on $G_F$, $\alpha$, $M_W$, and $M_Z$. Hard cutoff at string scale determined using gauge coupling unification. Limits for $d$=2,3,4 rise to 3.5, 5.7, and 7.8 TeV. NODE=S056KKI;LINKAGE=A

[150] Bound obtained for Higgs confined to the matter brane with $m_H$=500 GeV. For Higgs in the bulk, the bound increases to 3.5 TeV. NODE=S056KKI;LINKAGE=D

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NODE=S056230

## MASS LIMITS for Leptoquarks from Pair Production

NODE=S056EGT

These limits rely only on the color or electroweak charge of the leptoquark.

NODE=S056EGT

NODE=S056EGT

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* | |
|---|---|---|---|---|---|---|
| **>229** | 95 | [151] ABAZOV | 07J | D0 | Third generation | |
| **>251** | 95 | [152] ABAZOV | 06A | D0 | Second generation | |
| >226 | 95 | [153] ABULENCIA | 06T | CDF | Second generation | |
| **>256** | 95 | [154] ABAZOV | 05H | D0 | First generation | |
| >236 | 95 | [155] ACOSTA | 05P | CDF | First generation | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| >136 | 95 | [156] ABAZOV | 06L | D0 | All generations | |
| >117 | 95 | [157] ACOSTA | 05I | CDF | First generation | |
| > 99 | 95 | [158] ABBIENDI | 03R | OPAL | First generation | |
| >100 | 95 | [158] ABBIENDI | 03R | OPAL | Second generation | OCCUR=2 |
| > 98 | 95 | [158] ABBIENDI | 03R | OPAL | Third generation | OCCUR=3 |
| > 98 | 95 | [159] ABAZOV | 02 | D0 | All generations | |
| >225 | 95 | [160] ABAZOV | 01D | D0 | First generation | |
| > 85.8 | 95 | [161] ABBIENDI | 00M | OPAL | Superseded by ABBIENDI 03R | |
| > 85.5 | 95 | [161] ABBIENDI | 00M | OPAL | Superseded by ABBIENDI 03R | OCCUR=2 |
| > 82.7 | 95 | [161] ABBIENDI | 00M | OPAL | Superseded by ABBIENDI 03R | OCCUR=3 |
| >200 | 95 | [162] ABBOTT | 00C | D0 | Second generation | |
| >123 | 95 | [163] AFFOLDER | 00K | CDF | Second generation | |
| >148 | 95 | [164] AFFOLDER | 00K | CDF | Third generation | OCCUR=2 |
| >160 | 95 | [165] ABBOTT | 99J | D0 | Second generation | |

| | | | | | | |
|---|---|---|---|---|---|---|
| >225 | 95 | [166] ABBOTT | 98E | D0 | First generation | |
| > 94 | 95 | [167] ABBOTT | 98J | D0 | Third generation | |
| >202 | 95 | [168] ABE | 98S | CDF | Second generation | |
| >242 | 95 | [169] GROSS-PILCH... | 98 | | First generation | |
| > 99 | 95 | [170] ABE | 97F | CDF | Third generation | |
| >213 | 95 | [171] ABE | 97X | CDF | First generation | |
| > 45.5 | 95 | [172,173] ABREU | 93J | DLPH | First + second generation | |
| > 44.4 | 95 | [174] ADRIANI | 93M | L3 | First generation | |
| > 44.5 | 95 | [174] ADRIANI | 93M | L3 | Second generation | OCCUR=2 |
| > 45 | 95 | [174] DECAMP | 92 | ALEP | Third generation | OCCUR=2 |
| none 8.9–22.6 | 95 | [175] KIM | 90 | AMY | First generation | |
| none 10.2–23.2 | 95 | [175] KIM | 90 | AMY | Second generation | OCCUR=2 |
| none 5–20.8 | 95 | [176] BARTEL | 87B | JADE | | |
| none 7–20.5 | 95 | [177] BEHREND | 86B | CELL | | |

[151] ABAZOV 07J search for pair productions of scalar leptoquark state decaying to $\nu b$ in $p\overline{p}$ collisions at $E_{cm}$ = 1.96 TeV. The limit above assumes B($\nu b$) = 1. NODE=S056EGT;LINKAGE=BA

[152] ABAZOV 06A search for scalar leptoquarks using $\mu\mu jj$ events in $p\overline{p}$ collisions at $E_{cm}$ = 1.8 TeV and at 1.96 TeV. The limit above assumes B($\mu q$) = 1. For B($\mu q$) = 0.5, the limit becomes 204 GeV. NODE=S056EGT;LINKAGE=AV

[153] ABULENCIA 06T search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}$ = 1.96 TeV. The quoted limit assumes B($\mu q$) = 1. For B($\mu q$) = 0.5 or 0.1, the bound becomes 208 GeV or 143 GeV, respectively. See their Fig. 4 for the exclusion limit as a function of B($\mu q$). NODE=S056EGT;LINKAGE=UL

[154] ABAZOV 05H search for scalar leptoquarks using $eejj$ and $e\nu jj$ events in $\overline{p}p$ collisions at $E_{cm}$ = 1.8 TeV and 1.96 TeV. The limit above assumes B($eq$) = 1. For B($eq$) = 0.5 the bound becomes 234 GeV. NODE=S056EGT;LINKAGE=AZ

[155] ACOSTA 05P search for scalar leptoquarks using $eejj$, $e\nu jj$ events in $\overline{p}p$ collisions at $E_{cm}$ = 1.96TeV. The limit above assumes B($eq$) = 1. For B($eq$) = 0.5 and 0.1, the bound becomes 205 GeV and 145 GeV, respectively. NODE=S056EGT;LINKAGE=AO

[156] ABAZOV 06L search for scalar leptoquarks using $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}$ = 1.8 TeV and at 1.96 TeV. The limit above assumes B($\nu q$) = 1. NODE=S056EGT;LINKAGE=VA

[157] ACOSTA 05I search for scalar leptoquarks using $\nu\nu jj$ events in $\overline{p}p$ collisions at $E_{cm}$ = 1.96 TeV. The limit above assumes B($\nu q$) = 1. NODE=S056EGT;LINKAGE=AC

[158] ABBIENDI 03R search for scalar/vector leptoquarks in $e^+e^-$ collisions at $\sqrt{s}$ = 189–209 GeV. The quoted limits are for charge −4/3 isospin 0 scalar-leptoquark with B($\ell q$) = 1. See their table 12 for other cases. NODE=S056EGT;LINKAGE=AB

[159] ABAZOV 02 search for scalar leptoquarks using $\nu\nu jj$ events in $\overline{p}p$ collisions at $E_{cm}$=1.8 TeV. The bound holds for all leptoquark generations. Vector leptoquarks are likewise constrained to lie above 200 GeV. NODE=S056EGT;LINKAGE=BK

[160] ABAZOV 01D search for scalar leptoquarks using $e\nu jj$, $eejj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The limit above assumes B($eq$)=1. For B($eq$)=0.5 and 0, the bound becomes 204 and 79 GeV, respectively. Bounds for vector leptoquarks are also given. Supersedes ABBOTT 98E. NODE=S056EGT;LINKAGE=ZE

[161] ABBIENDI 00M search for scalar/vector leptoquarks in $e^+e^-$ collisions at $\sqrt{s}$=183 GeV. The quoted limits are for charge −4/3 isospin 0 scalar-leptoquarks with B($\ell q$)=1. See their Table 8 and Figs. 6–9 for other cases. NODE=S056EGT;LINKAGE=TM

[162] ABBOTT 00C search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The limit above assumes B($\mu q$)=1. For B($\mu q$)=0.5 and 0, the bound becomes 180 and 79 GeV respectively. Bounds for vector leptoquarks are also given. NODE=S056EGT;LINKAGE=GC

[163] AFFOLDER 00K search for scalar leptoquark using $\nu\nu cc$ events in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The quoted limit assumes B($\nu c$)=1. Bounds for vector leptoquarks are also given. NODE=S056EGT;LINKAGE=KI

[164] AFFOLDER 00K search for scalar leptoquark using $\nu\nu bb$ events in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The quoted limit assumes B($\nu b$)=1. Bounds for vector leptoquarks are also given. NODE=S056EGT;LINKAGE=KL

[165] ABBOTT 99J search for leptoquarks using $\mu\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}$= 1.8TeV. The quoted limit is for a scalar leptoquark with B($\mu q$) = B($\nu q$) = 0.5. Limits on vector leptoquarks range from 240 to 290 GeV. NODE=S056EGT;LINKAGE=JB

[166] ABBOTT 98E search for scalar leptoquarks using $e\nu jj$, $eejj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The limit above assumes B($eq$)=1. For B($eq$)=0.5 and 0, the bound becomes 204 and 79 GeV, respectively. NODE=S056EGT;LINKAGE=LB

[167] ABBOTT 98J search for charge −1/3 third generation scalar and vector leptoquarks in $p\overline{p}$ collisions at $E_{cm}$= 1.8 TeV. The quoted limit is for scalar leptoquark with B($\nu b$)=1. NODE=S056EGT;LINKAGE=AJ

[168] ABE 98S search for scalar leptoquarks using $\mu\mu jj$ events in $p\overline{p}$ collisions at $E_{cm}$= 1.8 TeV. The limit is for B($\mu q$)= 1. For B($\mu q$)=B($\nu q$)=0.5, the limit is > 160 GeV. NODE=S056EGT;LINKAGE=TG

[169] GROSS-PILCHER 98 is the combined limit of the CDF and DØ Collaborations as determined by a joint CDF/DØ working group and reported in this FNAL Technical Memo. Original data published in ABE 97X and ABBOTT 98E. NODE=S056EGT;LINKAGE=GP

[170] ABE 97F search for third generation scalar and vector leptoquarks in $p\overline{p}$ collisions at $E_{cm}$ = 1.8 TeV. The quoted limit is for scalar leptoquark with B($\tau b$) = 1. NODE=S056EGT;LINKAGE=GH

[171] ABE 97X search for scalar leptoquarks using $eejj$ events in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The limit is for B($eq$)=1. NODE=S056EGT;LINKAGE=L

[172] Limit is for charge −1/3 isospin-0 leptoquark with B($\ell q$) = 2/3. NODE=S056EGT;LINKAGE=TA

[173] First and second generation leptoquarks are assumed to be degenerate. The limit is slightly lower for each generation.

NODE=S056EGT;LINKAGE=TB

[174] Limits are for charge $-1/3$, isospin-0 scalar leptoquarks decaying to $\ell^- q$ or $\nu q$ with any branching ratio. See paper for limits for other charge-isospin assignments of leptoquarks.

NODE=S056EGT;LINKAGE=F

[175] KIM 90 assume pair production of charge 2/3 scalar-leptoquark via photon exchange. The decay of the first (second) generation leptoquark is assumed to be any mixture of $d e^+$ and $u \overline{\nu}$ ($s \mu^+$ and $c \overline{\nu}$). See paper for limits for specific branching ratios.

NODE=S056EGT;LINKAGE=E

[176] BARTEL 87B limit is valid when a pair of charge 2/3 spinless leptoquarks X is produced with point coupling, and when they decay under the constraint $\mathrm{B}(\mathrm{X} \to c \overline{\nu}_\mu) + \mathrm{B}(\mathrm{X} \to s \mu^+) = 1$.

NODE=S056EGT;LINKAGE=C

[177] BEHREND 86B assumed that a charge 2/3 spinless leptoquark, $\chi$, decays either into $s\mu^+$ or $c\overline{\nu}$: $\mathrm{B}(\chi \to s\mu^+) + \mathrm{B}(\chi \to c\overline{\nu}) = 1$.

NODE=S056EGT;LINKAGE=D

## MASS LIMITS for Leptoquarks from Single Production

NODE=S056ESP

These limits depend on the $q$-$\ell$-leptoquark coupling $g_{LQ}$. It is often assumed that $g^2_{LQ}/4\pi$=1/137. Limits shown are for a scalar, weak isoscalar, charge $-1/3$ leptoquark.

NODE=S056ESP

NODE=S056ESP

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **>298** | 95 | [178] CHEKANOV | 03B | ZEUS | First generation |
| **> 73** | 95 | [179] ABREU | 93J | DLPH | Second generation |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | | [180] ABAZOV | 07E | D0 | Second generation |
| >295 | 95 | [181] AKTAS | 05B | H1 | First generation |
| | | [182] CHEKANOV | 05A | ZEUS | Lepton-flavor violation |
| >197 | 95 | [183] ABBIENDI | 02B | OPAL | First generation |
| | | [184] CHEKANOV | 02 | ZEUS | Repl. by CHEKANOV 05A |
| >290 | 95 | [185] ADLOFF | 01C | H1 | First generation |
| >204 | 95 | [186] BREITWEG | 01 | ZEUS | First generation |
| | | [187] BREITWEG | 00E | ZEUS | First generation |
| >161 | 95 | [188] ABREU | 99G | DLPH | First generation |
| >200 | 95 | [189] ADLOFF | 99 | H1 | First generation |
| | | [190] DERRICK | 97 | ZEUS | Lepton-flavor violation |
| >168 | 95 | [191] DERRICK | 93 | ZEUS | First generation |

OCCUR=3

[178] CHEKANOV 03B limit is for a scalar, weak isoscalar, charge $-1/3$ leptoquark coupled with $e_R$. See their Figs. 11–12 and Table 5 for limits on states with different quantum numbers.

NODE=S056ESP;LINKAGE=PS

[179] Limit from single production in $Z$ decay. The limit is for a leptoquark coupling of electromagnetic strength and assumes $\mathrm{B}(\ell q) = 2/3$. The limit is 77 GeV if first and second leptoquarks are degenerate.

NODE=S056ESP;LINKAGE=TC

[180] ABAZOV 07E search for leptoquark single production through $qg$ fusion process in $p\overline{p}$ collisions. See their Fig. 4 for exclusion plot in mass-coupling plane.

NODE=S056ESP;LINKAGE=AB

[181] AKTAS 05B limit is for a scalar, weak isoscalar, charge $-1/3$ leptoquark coupled with $e_R$. See their Fig. 3 for limits on states with different quantum numbers.

NODE=S056ESP;LINKAGE=AK

[182] CHEKANOV 05 search for various leptoquarks with lepton-flavor violating couplings. See their Figs.6–10 and Tables 1–8 for detailed limits.

NODE=S056ESP;LINKAGE=CH

[183] For limits on states with different quantum numbers and the limits in the mass-coupling plane, see their Fig. 4 and Fig. 5.

NODE=S056ESP;LINKAGE=B6

[184] CHEKANOV 02 search for various leptoquarks with lepton-flavor violating couplings. See their Figs. 6–7 and Tables 5–6 for detailed limits.

NODE=S056ESP;LINKAGE=SE

[185] For limits on states with different quantum numbers and the limits in the mass-coupling plane, see their Fig. 3.

NODE=S056ESP;LINKAGE=FE

[186] See their Fig. 14 for limits in the mass-coupling plane.

NODE=S056ESP;LINKAGE=WB

[187] BREITWEG 00E search for $F$=0 leptoquarks in $e^+ p$ collisions. For limits in mass-coupling plane, see their Fig. 11.

NODE=S056ESP;LINKAGE=FP

[188] ABREU 99G limit obtained from process $e\gamma \to LQ+q$. For limits on vector and scalar states with different quantum numbers and the limits in the coupling-mass plane, see their Fig. 4 and Table 2.

NODE=S056ESP;LINKAGE=GS

[189] For limits on states with different quantum numbers and the limits in the mass-coupling plane, see their Fig. 13 and Fig. 14. ADLOFF 99 also search for leptoquarks with lepton-flavor violating couplings. ADLOFF 99 supersedes AID 96B.

NODE=S056ESP;LINKAGE=DF

[190] DERRICK 97 search for various leptoquarks with lepton-flavor violating couplings. See their Figs. 5–8 and Table 1 for detailed limits.

NODE=S056ESP;LINKAGE=Z1

[191] DERRICK 93 search for single leptoquark production in $ep$ collisions with the decay $eq$ and $\nu q$. The limit is for leptoquark coupling of electromagnetic strength and assumes $\mathrm{B}(eq) = \mathrm{B}(\nu q) = 1/2$. The limit for $\mathrm{B}(eq) = 1$ is 176 GeV. For limits on states with different quantum numbers, see their Table 3.

NODE=S056ESP;LINKAGE=K3

## Indirect Limits for Leptoquarks

NODE=S056LQI
NODE=S056LQI

| *VALUE* (TeV) | *CL%* | *DOCUMENT ID* | *TECN* | *COMMENT* |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | | [192] AKTAS | 07A | H1 | Lepton-flavor vilation |
| $>$ 0.49 | 95 | [193] SCHAEL | 07A | ALEP | $e^+ e^- \rightarrow q\overline{q}$ |
| | | [194] SMIRNOV | 07 | RVUE | $K \rightarrow e\mu$, $B \rightarrow e\tau$ |
| | | [195] CHEKANOV | 05A | ZEUS | Lepton-flavor violation |
| $>$ 1.7 | 96 | [196] ADLOFF | 03 | H1 | First generation |
| $>$ 46 | 90 | [197] CHANG | 03 | BELL | Pati-Salam type |
| | | [198] CHEKANOV | 02 | ZEUS | Repl. by CHEKANOV 05A |
| $>$ 1.7 | 95 | [199] CHEUNG | 01B | RVUE | First generation |
| $>$ 0.39 | 95 | [200] ACCIARRI | 00P | L3 | $e^+ e^- \rightarrow q q$ |
| $>$ 1.5 | 95 | [201] ADLOFF | 00 | H1 | First generation |
| $>$ 0.2 | 95 | [202] BARATE | 00I | ALEP | Repl. by SCHAEL 07A |
| | | [203] BARGER | 00 | RVUE | Cs |
| | | [204] GABRIELLI | 00 | RVUE | Lepton flavor violation |
| $>$ 0.74 | 95 | [205] ZARNECKI | 00 | RVUE | $S_1$ leptoquark |
| | | [206] ABBIENDI | 99 | OPAL | |
| $>$ 19.3 | 95 | [207] ABE | 98V | CDF | $B_s \rightarrow e^\pm \mu^\mp$, Pati-Salam type |
| | | [208] ACCIARRI | 98J | L3 | $e^+ e^- \rightarrow q\overline{q}$ |
| | | [209] ACKERSTAFF | 98V | OPAL | $e^+ e^- \rightarrow q\overline{q}$, $e^+ e^- \rightarrow b\overline{b}$ |
| $>$ 0.76 | 95 | [210] DEANDREA | 97 | RVUE | $\widetilde{R}_2$ leptoquark |
| | | [211] DERRICK | 97 | ZEUS | Lepton-flavor violation |
| | | [212] GROSSMAN | 97 | RVUE | $B \rightarrow \tau^+ \tau^-$ (X) |
| | | [213] JADACH | 97 | RVUE | $e^+ e^- \rightarrow q\overline{q}$ |
| $>$1200 | | [214] KUZNETSOV | 95B | RVUE | Pati-Salam type |
| | | [215] MIZUKOSHI | 95 | RVUE | Third generation scalar leptoquark |
| $>$ 0.3 | 95 | [216] BHATTACH... | 94 | RVUE | Spin-0 leptoquark coupled to $\overline{e}_R t_L$ |
| | | [217] DAVIDSON | 94 | RVUE | |
| $>$ 18 | | [218] KUZNETSOV | 94 | RVUE | Pati-Salam type |
| $>$ 0.43 | 95 | [219] LEURER | 94 | RVUE | First generation spin-1 leptoquark |
| $>$ 0.44 | 95 | [219] LEURER | 94B | RVUE | First generation spin-0 leptoquark |
| | | [220] MAHANTA | 94 | RVUE | $P$ and $T$ violation |
| $>$ 1 | | [221] SHANKER | 82 | RVUE | Nonchiral spin-0 leptoquark OCCUR=2 |
| $>$ 125 | | [221] SHANKER | 82 | RVUE | Nonchiral spin-1 leptoquark OCCUR=3 |

[192] AKTAS 07A search for lepton-flavor violation in $ep$ collision. See their Tables 4–7 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks. NODE=S056LQI;LINKAGE=AK

[193] SCHAEL 07A limit is for the weak-isoscalar spin-0 left-handed leptoquark with the coupling of electromagnetic strength. For the limits of leptoquarks with different quantum numbers, see their Table 35. NODE=S056LQI;LINKAGE=SC

[194] SMIRNOV 07 obtains mass limits for the vector and scalar chiral leptoquark states from $K \rightarrow e\mu$, $B \rightarrow e\tau$ decays. NODE=S056LQI;LINKAGE=SM

[195] CHEKANOV 05 search for various leptoquarks with lepton-flavor violating couplings. See their Figs.6–10 and Tables 1–8 for detailed limits. NODE=S056LQI;LINKAGE=CH

[196] ADLOFF 03 limit is for the weak isotriplet spin-0 leptoquark at strong coupling $\lambda=\sqrt{4\pi}$. For the limits of leptoquarks with different quantum numbers, see their Table 3. Limits are derived from bounds on $e^\pm q$ contact interactions. NODE=S056LQI;LINKAGE=QL

[197] The bound is derived from B($B^0 \rightarrow e^\pm \mu^\mp$) $<$ $1.7 \times 10^{-7}$. NODE=S056LQI;LINKAGE=CA

[198] CHEKANOV 02 search for lepton-flavor violation in $ep$ collisions. See their Tables 1–4 for limits on lepton-flavor violating and four-fermion interactions induced by various leptoquarks. NODE=S056LQI;LINKAGE=SE

[199] CHEUNG 01B quoted limit is for a scalar, weak isoscalar, charge $-1/3$ leptoquark with a coupling of electromagnetic strength. The limit is derived from bounds on contact interactions in a global electroweak analysis. For the limits of leptoquarks with different quantum numbers, see Table 5. NODE=S056LQI;LINKAGE=QK

[200] ACCIARRI 00P limit is for the weak isoscalar spin-0 leptoquark with the coupling of electromagnetic strength. For the limits of leptoquarks with different quantum numbers, see their Table 4. NODE=S056LQI;LINKAGE=QQ

[201] ADLOFF 00 limit is for the weak isotriplet spin-0 leptoquark at strong coupling, $\lambda=\sqrt{4\pi}$. For the limits of leptoquarks with different quantum numbers, see their Table 2. ADLOFF 00 limits are from the $Q^2$ spectrum measurement of $e^+ p \rightarrow e^+ X$. NODE=S056LQI;LINKAGE=QI

[202] BARATE 00I search for deviations in cross section and jet-charge asymmetry in $e^+ e^- \rightarrow \overline{q} q$ due to $t$-channel exchange of a leptoquark at $\sqrt{s}$=130 to 183 GeV. Limits for other scalar and vector leptoquarks are also given in their Table 22. NODE=S056LQI;LINKAGE=BI

[203] BARGER 00 explain the deviation of atomic parity violation in cesium atoms from prediction is explained by scalar leptoquark exchange. NODE=S056LQI;LINKAGE=CS

[204] GABRIELLI 00 calculate various process with lepton flavor violation in leptoquark models. NODE=S056LQI;LINKAGE=QS

[205] ZARNECKI 00 limit is derived from data of HERA, LEP, and Tevatron and from various low-energy data including atomic parity violation. Leptoquark coupling with electromagnetic strength is assumed. NODE=S056LQI;LINKAGE=RK

[206] ABBIENDI 99 limits are from $e^+ e^- \rightarrow q\overline{q}$ cross section at 130–136, 161–172, 183 GeV. See their Fig. 8 and Fig. 9 for limits in mass-coupling plane. NODE=S056LQI;LINKAGE=BL

[207] ABE 98V quoted limit is from B($B_s \rightarrow e^\pm \mu^\mp$)$<$ $8.2 \times 10^{-6}$. ABE 98V also obtain a similar limit on $M_{LQ} >$ 20.4 TeV from B($B_d \rightarrow e^\pm \mu^\mp$)$<$ $4.5 \times 10^{-6}$. Both NODE=S056LQI;LINKAGE=LV

bounds assume the non-canonical association of the $b$ quark with electrons or muons under SU(4).

[208] ACCIARRI 98J limit is from $e^+ e^- \rightarrow q\overline{q}$ cross section at $\sqrt{s}$= 130–172 GeV which can be affected by the $t$- and $u$-channel exchanges of leptoquarks. See their Fig. 4 and Fig. 5 for limits in the mass-coupling plane. NODE=S056LQI;LINKAGE=M

[209] ACKERSTAFF 98V limits are from $e^+ e^- \rightarrow q\overline{q}$ and $e^+ e^- \rightarrow b\overline{b}$ cross sections at $\sqrt{s}$ = 130–172 GeV, which can be affected by the $t$- and $u$-channel exchanges of leptoquarks. See their Fig. 21 and Fig. 22 for limits of leptoquarks in mass-coupling plane. NODE=S056LQI;LINKAGE=VA

[210] DEANDREA 97 limit is for $\widetilde{R}_2$ leptoquark obtained from atomic parity violation (APV). The coupling of leptoquark is assumed to be electromagnetic strength. See Table 2 for limits of the four-fermion interactions induced by various scalar leptoquark exchange. DEANDREA 97 combines APV limit and limits from Tevatron and HERA. See Fig. 1–4 for combined limits of leptoquark in mass-coupling plane. NODE=S056LQI;LINKAGE=LD

[211] DERRICK 97 search for lepton-flavor violation in $e p$ collision. See their Tables 2–5 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks. NODE=S056LQI;LINKAGE=Z1

[212] GROSSMAN 97 estimate the upper bounds on the branching fraction $B \rightarrow \tau^+ \tau^-$ (X) from the absence of the $B$ decay with large missing energy. These bounds can be used to constrain leptoquark induced four-fermion interactions. NODE=S056LQI;LINKAGE=K

[213] JADACH 97 limit is from $e^+ e^- \rightarrow q\overline{q}$ cross section at $\sqrt{s}$=172.3 GeV which can be affected by the $t$- and $u$-channel exchanges of leptoquarks. See their Fig. 1 for limits on vector leptoquarks in mass-coupling plane. NODE=S056LQI;LINKAGE=L

[214] KUZNETSOV 95B use $\pi$, $K$, $B$, $\tau$ decays and $\mu e$ conversion and give a list of bounds on the leptoquark mass and the fermion mixing matrix in the Pati-Salam model. The quoted limit is from $K_L \rightarrow \mu e$ decay assuming zero mixing. NODE=S056LQI;LINKAGE=J

[215] MIZUKOSHI 95 calculate the one-loop radiative correction to the $Z$-physics parameters in various scalar leptoquark models. See their Fig. 4 for the exclusion plot of third generation leptoquark models in mass-coupling plane. NODE=S056LQI;LINKAGE=I

[216] BHATTACHARYYA 94 limit is from one-loop radiative correction to the leptonic decay width of the $Z$. $m_H$=250 GeV, $\alpha_s(m_Z)$=0.12, $m_t$=180 GeV, and the electroweak strength of leptoquark coupling are assumed. For leptoquark coupled to $\overline{e}_L t_R$, $\overline{\mu} t$, and $\overline{\tau} t$, see Fig. 2 in BHATTACHARYYA 94B erratum and Fig. 3. NODE=S056LQI;LINKAGE=G

[217] DAVIDSON 94 gives an extensive list of the bounds on leptoquark-induced four-fermion interactions from $\pi$, $K$, $D$, $B$, $\mu$, $\tau$ decays and meson mixings, *etc.* See Table 15 of DAVIDSON 94 for detail. NODE=S056LQI;LINKAGE=E

[218] KUZNETSOV 94 gives mixing independent bound of the Pati-Salam leptoquark from the cosmological limit on $\pi^0 \rightarrow \overline{\nu}\nu$. NODE=S056LQI;LINKAGE=F

[219] LEURER 94, LEURER 94B limits are obtained from atomic parity violation and apply to any chiral leptoquark which couples to the first generation with electromagnetic strength. For a nonchiral leptoquark, universality in $\pi_{\ell 2}$ decay provides a much more stringent bound. NODE=S056LQI;LINKAGE=D

[220] MAHANTA 94 gives bounds of $P$- and $T$-violating scalar-leptoquark couplings from atomic and molecular experiments. NODE=S056LQI;LINKAGE=H

[221] From $(\pi \rightarrow e\nu)/(\pi \rightarrow \mu\nu)$ ratio. SHANKER 82 assumes the leptoquark induced four-fermion coupling $4g^2/M^2$ $(\overline{\nu}_{eL}\ u_R)$ $(\overline{d}_L\ e_R)$with $g$=0.004 for spin-0 leptoquark and $g^2/M^2$ $(\overline{\nu}_{eL}\ \gamma_\mu u_L)$ $(\overline{d}_R\ \gamma^\mu e_R)$ with $g\simeq$ 0.6 for spin-1 leptoquark. NODE=S056LQI;LINKAGE=A

## MASS LIMITS for Diquarks

NODE=S056DQ
NODE=S056DQ

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| none 290–420 | 95 | [222] ABE | 97G | CDF | $E_6$ diquark |
| none 15–31.7 | 95 | [223] ABREU | 94O | DLPH | SUSY $E_6$ diquark |

[222] ABE 97G search for new particle decaying to dijets. NODE=S056DQ;LINKAGE=SZ

[223] ABREU 94O limit is from $e^+ e^- \rightarrow \overline{c}\overline{s}cs$. Range extends up to 43 GeV if diquarks are degenerate in mass. NODE=S056DQ;LINKAGE=A

## MASS LIMITS for $g_A$ (axigluon)

NODE=S056AXG

Axigluons are massive color-octet gauge bosons in chiral color models and have axial-vector coupling to quarks with the same coupling strength as gluons. NODE=S056AXG

NODE=S056AXG

| *VALUE* (GeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $>$910 | 95 | [224] CHOUDHURY | 07 | RVUE | $p\overline{p} \rightarrow t\overline{t}X$ |
| $>$365 | 95 | [225] DONCHESKI | 98 | RVUE | $\Gamma(Z \rightarrow$ hadron) |
| none 200–980 | 95 | [226] ABE | 97G | CDF | $p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2 jets |
| none 200–870 | 95 | [227] ABE | 95N | CDF | $p\overline{p} \rightarrow g_A X$, $g_A \rightarrow q\overline{q}$ |
| none 240–640 | 95 | [228] ABE | 93G | CDF | $p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2jets |
| $>$ 50 | 95 | [229] CUYPERS | 91 | RVUE | $\sigma(e^+ e^- \rightarrow$ hadrons) |
| none 120–210 | 95 | [230] ABE | 90H | CDF | $p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2jets |
| $>$ 29 | | [231] ROBINETT | 89 | THEO | Partial-wave unitarity |
| none 150–310 | 95 | [232] ALBAJAR | 88B | UA1 | $p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2jets |
| $>$ 20 | | BERGSTROM | 88 | RVUE | $p\overline{p} \rightarrow \Upsilon X$ via $g_A g$ |
| $>$ 9 | | [233] CUYPERS | 88 | RVUE | $\Upsilon$ decay |
| $>$ 25 | | [234] DONCHESKI | 88B | RVUE | $\Upsilon$ decay |

[224] CHOUDHURY 07 limit is from the $t\overline{t}$ production cross section measured at CDF. NODE=S056AXG;LINKAGE=CH

[225] DONCHESKI 98 compare $\alpha_s$ derived from low-energy data and that from $\Gamma(Z \rightarrow \text{hadrons})/\Gamma(Z \rightarrow \text{leptons})$. NODE=S056AXG;LINKAGE=GD

[226] ABE 97G search for new particle decaying to dijets. NODE=S056AXG;LINKAGE=SZ

[227] ABE 95N assume axigluons decaying to quarks in the Standard Model only. NODE=S056AXG;LINKAGE=N

[228] ABE 93G assume $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 10$. NODE=S056AXG;LINKAGE=AG

[229] CUYPERS 91 compare $\alpha_s$ measured in $\Upsilon$ decay and that from $R$ at PEP/PETRA energies. NODE=S056AXG;LINKAGE=H

[230] ABE 90H assumes $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 5$ ($\Gamma(g_A) = 0.09 m_{g_A}$). For $N = 10$, the excluded region is reduced to 120–150 GeV. NODE=S056AXG;LINKAGE=G

[231] ROBINETT 89 result demands partial-wave unitarity of $J = 0$ $t\overline{t} \rightarrow t\overline{t}$ scattering amplitude and derives a limit $m_{g_A} > 0.5\ m_t$. Assumes $m_t > 56$ GeV. NODE=S056AXG;LINKAGE=B

[232] ALBAJAR 88B result is from the nonobservation of a peak in two-jet invariant mass distribution. $\Gamma(g_A) < 0.4\ m_{g_A}$ assumed. See also BAGGER 88. NODE=S056AXG;LINKAGE=A

[233] CUYPERS 88 requires $\Gamma(\Upsilon \rightarrow g g_A) < \Gamma(\Upsilon \rightarrow g g g)$. A similar result is obtained by DONCHESKI 88. NODE=S056AXG;LINKAGE=D

[234] DONCHESKI 88B requires $\Gamma(\Upsilon \rightarrow g q\overline{q})/\Gamma(\Upsilon \rightarrow g g g) < 0.25$, where the former decay proceeds via axigluon exchange. A more conservative estimate of $< 0.5$ leads to $m_{g_A} > 21$ GeV. NODE=S056AXG;LINKAGE=C

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## $X^0$ (Heavy Boson) Searches in $Z$ Decays

NODE=S056ZXG

Searches for radiative transition of $Z$ to a lighter spin-0 state $X^0$ decaying to hadrons, a lepton pair, a photon pair, or invisible particles as shown in the comments. The limits are for the product of branching ratios. NODE=S056ZXG

NODE=S056ZXG

| *VALUE* | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* | |
|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| | | [235] BARATE | 98U | ALEP | $X^0 \rightarrow \ell\overline{\ell}, q\overline{q}, g g, \gamma\gamma, \nu\overline{\nu}$ | |
| | | [236] ACCIARRI | 97Q | L3 | $X^0 \rightarrow$ invisible particle(s) | |
| | | [237] ACTON | 93E | OPAL | $X^0 \rightarrow \gamma\gamma$ | |
| | | [238] ABREU | 92D | DLPH | $X^0 \rightarrow$ hadrons | |
| | | [239] ADRIANI | 92F | L3 | $X^0 \rightarrow$ hadrons | |
| | | [240] ACTON | 91 | OPAL | $X^0 \rightarrow$ anything | |
| $<1.1 \times 10^{-4}$ | 95 | [241] ACTON | 91B | OPAL | $X^0 \rightarrow e^+e^-$ | |
| $<9 \times 10^{-5}$ | 95 | [241] ACTON | 91B | OPAL | $X^0 \rightarrow \mu^+\mu^-$ | OCCUR=2 |
| $<1.1 \times 10^{-4}$ | 95 | [241] ACTON | 91B | OPAL | $X^0 \rightarrow \tau^+\tau^-$ | OCCUR=3 |
| $<2.8 \times 10^{-4}$ | 95 | [242] ADEVA | 91D | L3 | $X^0 \rightarrow e^+e^-$ | |
| $<2.3 \times 10^{-4}$ | 95 | [242] ADEVA | 91D | L3 | $X^0 \rightarrow \mu^+\mu^-$ | OCCUR=2 |
| $<4.7 \times 10^{-4}$ | 95 | [243] ADEVA | 91D | L3 | $X^0 \rightarrow$ hadrons | OCCUR=3 |
| $<8 \times 10^{-4}$ | 95 | [244] AKRAWY | 90J | OPAL | $X^0 \rightarrow$ hadrons | |

[235] BARATE 98U obtain limits on $B(Z \rightarrow \gamma X^0)B(X^0 \rightarrow \ell\overline{\ell}, q\overline{q}, g g, \gamma\gamma, \nu\overline{\nu})$. See their Fig. 17. NODE=S056ZXG;LINKAGE=BU

[236] See Fig. 4 of ACCIARRI 97Q for the upper limit on $B(Z \rightarrow \gamma X^0;\ E_\gamma > E_{\text{min}})$ as a function of $E_{\text{min}}$. NODE=S056ZXG;LINKAGE=L

[237] ACTON 93E give $\sigma(e^+e^- \rightarrow X^0\gamma)\cdot B(X^0 \rightarrow \gamma\gamma) < 0.4$ pb (95%CL) for $m_{X^0} = 60 \pm 2.5$ GeV. If the process occurs via $s$-channel $\gamma$ exchange, the limit translates to $\Gamma(X^0)\cdot B(X^0 \rightarrow \gamma\gamma)^2 < 20$ MeV for $m_{X^0} = 60 \pm 1$ GeV. NODE=S056ZXG;LINKAGE=E

[238] ABREU 92D give $\sigma_Z \cdot B(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow \text{hadrons}) <$(3–10) pb for $m_{X^0} =$ 10–78 GeV. A very similar limit is obtained for spin-1 $X^0$. NODE=S056ZXG;LINKAGE=X

[239] ADRIANI 92F search for isolated $\gamma$ in hadronic $Z$ decays. The limit $\sigma_Z \cdot B(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow \text{hadrons}) <$(2–10) pb (95%CL) is given for $m_{X^0} =$ 25–85 GeV. NODE=S056ZXG;LINKAGE=F2

[240] ACTON 91 searches for $Z \rightarrow Z^* X^0$, $Z^* \rightarrow e^+e^-, \mu^+\mu^-$, or $\nu\overline{\nu}$. Excludes any new scalar $X^0$ with $m_{X^0} < 9.5$ GeV/$c$ if it has the same coupling to $ZZ^*$ as the MSM Higgs boson. NODE=S056ZXG;LINKAGE=F

[241] ACTON 91B limits are for $m_{X^0} =$ 60–85 GeV. NODE=S056ZXG;LINKAGE=D

[242] ADEVA 91D limits are for $m_{X^0} =$ 30–89 GeV. NODE=S056ZXG;LINKAGE=B

[243] ADEVA 91D limits are for $m_{X^0} =$ 30–86 GeV. NODE=S056ZXG;LINKAGE=C

[244] AKRAWY 90J give $\Gamma(Z \rightarrow \gamma X^0)\cdot B(X^0 \rightarrow \text{hadrons}) < 1.9$ MeV (95%CL) for $m_{X^0} =$ 32–80 GeV. We divide by $\Gamma(Z) = 2.5$ GeV to get product of branching ratios. For nonresonant transitions, the limit is $B(Z \rightarrow \gamma q\overline{q}) < 8.2$ MeV assuming three-body phase space distribution. NODE=S056ZXG;LINKAGE=A

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## MASS LIMITS for a Heavy Neutral Boson Coupling to $e^+e^-$

NODE=S056HEE
NODE=S056HEE

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

| | | | | | | |
|---|---|---|---|---|---|---|
| none 55–61 | | [245] ODAKA | 89 | VNS | $\Gamma(X^0 \to e^+e^-) \cdot B(X^0 \to \text{had.}) \gtrsim 0.2$ MeV | |
| >45 | 95 | [246] DERRICK | 86 | HRS | $\Gamma(X^0 \to e^+e^-)$=6 MeV | |
| >46.6 | 95 | [247] ADEVA | 85 | MRKJ | $\Gamma(X^0 \to e^+e^-)$=10 keV | |
| >48 | 95 | [247] ADEVA | 85 | MRKJ | $\Gamma(X^0 \to e^+e^-)$=4 MeV | OCCUR=2 |
| | | [248] BERGER | 85B | PLUT | | |
| none 39.8–45.5 | | [249] ADEVA | 84 | MRKJ | $\Gamma(X^0 \to e^+e^-)$=10 keV | |
| >47.8 | 95 | [249] ADEVA | 84 | MRKJ | $\Gamma(X^0 \to e^+e^-)$=4 MeV | OCCUR=2 |
| none 39.8–45.2 | | [249] BEHREND | 84C | CELL | | |
| >47 | 95 | [249] BEHREND | 84C | CELL | $\Gamma(X^0 \to e^+e^-)$=4 MeV | OCCUR=2 |

[245] ODAKA 89 looked for a narrow or wide scalar resonance in $e^+e^- \to$ hadrons at $E_{\text{cm}}$ = 55.0–60.8 GeV. NODE=S056HEE;LINKAGE=C

[246] DERRICK 86 found no deviation from the Standard Model Bhabha scattering at $E_{\text{cm}}$= 29 GeV and set limits on the possible scalar boson $e^+e^-$ coupling. See their figure 4 for excluded region in the $\Gamma(X^0 \to e^+e^-)$-$m_{X^0}$ plane. Electronic chiral invariance requires a parity doublet of $X^0$, in which case the limit applies for $\Gamma(X^0 \to e^+e^-)$ = 3 MeV. NODE=S056HEE;LINKAGE=A2

[247] ADEVA 85 first limit is from $2\gamma$, $\mu^+\mu^-$, hadrons assuming $X^0$ is a scalar. Second limit is from $e^+e^-$ channel. $E_{\text{cm}}$ = 40–47 GeV. Supersedes ADEVA 84. NODE=S056HEE;LINKAGE=B

[248] BERGER 85B looked for effect of spin-0 boson exchange in $e^+e^- \to e^+e^-$ and $\mu^+\mu^-$ at $E_{\text{cm}}$ = 34.7 GeV. See Fig. 5 for excluded region in the $m_{X^0} - \Gamma(X^0)$ plane. NODE=S056HEE;LINKAGE=D

[249] ADEVA 84 and BEHREND 84C have $E_{\text{cm}}$ = 39.8–45.5 GeV. MARK-J searched $X^0$ in $e^+e^- \to$ hadrons, $2\gamma$, $\mu^+\mu^-$, $e^+e^-$ and CELLO in the same channels plus $\tau$ pair. No narrow or broad $X^0$ is found in the energy range. They also searched for the effect of $X^0$ with $m_X > E_{\text{cm}}$. The second limits are from Bhabha data and for spin-0 singlet. The same limits apply for $\Gamma(X^0 \to e^+e^-)$ = 2 MeV if $X^0$ is a spin-0 doublet. The second limit of BEHREND 84C was read off from their figure 2. The original papers also list limits in other channels. NODE=S056HEE;LINKAGE=A

## Search for $X^0$ Resonance in $e^+e^-$ Collisions

NODE=S056REE

The limit is for $\Gamma(X^0 \to e^+e^-) \cdot B(X^0 \to f)$, where $f$ is the specified final state. Spin 0 is assumed for $X^0$. NODE=S056REE

| *VALUE* (keV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* | NODE=S056REE |
|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $<10^3$ | 95 | [250] ABE | 93C | VNS | $\Gamma(ee)$ | |
| <(0.4–10) | 95 | [251] ABE | 93C | VNS | $f = \gamma\gamma$ | OCCUR=2 |
| <(0.3–5) | 95 | [252,253] ABE | 93D | TOPZ | $f = \gamma\gamma$ | |
| <(2–12) | 95 | [252,253] ABE | 93D | TOPZ | $f$ = hadrons | OCCUR=2 |
| <(4–200) | 95 | [253,254] ABE | 93D | TOPZ | $f = ee$ | OCCUR=3 |
| <(0.1–6) | 95 | [253,254] ABE | 93D | TOPZ | $f = \mu\mu$ | OCCUR=4 |
| <(0.5–8) | 90 | [255] STERNER | 93 | AMY | $f = \gamma\gamma$ | |

[250] Limit is for $\Gamma(X^0 \to e^+e^-)$ $m_{X^0}$ = 56–63.5 GeV for $\Gamma(X^0)$ = 0.5 GeV. NODE=S056REE;LINKAGE=A

[251] Limit is for $m_{X^0}$ = 56–61.5 GeV and is valid for $\Gamma(X^0) \ll 100$ MeV. See their Fig. 5 for limits for $\Gamma$ = 1,2 GeV. NODE=S056REE;LINKAGE=B

[252] Limit is for $m_{X^0}$ = 57.2–60 GeV. NODE=S056REE;LINKAGE=D

[253] Limit is valid for $\Gamma(X^0) \ll 100$ MeV. See paper for limits for $\Gamma$ = 1 GeV and those for $J$ = 2 resonances. NODE=S056REE;LINKAGE=F

[254] Limit is for $m_{X^0}$ = 56.6–60 GeV. NODE=S056REE;LINKAGE=E

[255] STERNER 93 limit is for $m_{X^0}$ = 57–59.6 GeV and is valid for $\Gamma(X^0)$<100 MeV. See their Fig. 2 for limits for $\Gamma$ = 1,3 GeV. NODE=S056REE;LINKAGE=C

## Search for $X^0$ Resonance in $ep$ Collisions

NODE=S056EPX

| *VALUE* | *DOCUMENT ID* | | *TECN* | *COMMENT* | NODE=S056EPX |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | [256] CHEKANOV | 02B | ZEUS | $X \to jj$ | |

[256] CHEKANOV 02B search for photoproduction of $X$ decaying into dijets in $ep$ collisions. See their Fig. 5 for the limit on the photoproduction cross section. NODE=S056EPX;LINKAGE=A

## Search for $X^0$ Resonance in Two-Photon Process

NODE=S056RGG

The limit is for $\Gamma(X^0) \cdot B(X^0 \to \gamma\gamma)^2$. Spin 0 is assumed for $X^0$. NODE=S056RGG

| *VALUE* (MeV) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* | NODE=S056RGG |
|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| <2.6 | 95 | [257] ACTON | 93E | OPAL | $m_{X^0}$=60 ± 1 GeV | |
| <2.9 | 95 | BUSKULIC | 93F | ALEP | $m_{X^0} \sim 60$ GeV | |

[257] ACTON 93E limit for a $J = 2$ resonance is 0.8 MeV. NODE=S056RGG;LINKAGE=A

## Search for $X^0$ Resonance in $e^+e^- \rightarrow X^0\gamma$

NODE=S056REG
NODE=S056REG

| VALUE (GeV) | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| | [258] ABBIENDI | 03D | OPAL | $X^0 \rightarrow \gamma\gamma$ |
| | [259] ABREU | 00Z | DLPH | $X^0$ decaying invisibly |
| | [260] ADAM | 96C | DLPH | $X^0$ decaying invisibly |

[258] ABBIENDI 03D measure the $e^+e^- \rightarrow \gamma\gamma\gamma$ cross section at $\sqrt{s}$=181–209 GeV. The upper bound on the production cross section, $\sigma(e^+e^- \rightarrow X^0\gamma)$ times the branching ratio for $X^0 \rightarrow \gamma\gamma$, is less than 0.03 pb at 95%CL for $X^0$ masses between 20 and 180 GeV. See their Fig. 9b for the limits in the mass-cross section plane. NODE=S056REG;LINKAGE=C

[259] ABREU 00Z is from the single photon cross section at $\sqrt{s}$=183, 189 GeV. The production cross section upper limit is less than 0.3 pb for $X^0$ mass between 40 and 160 GeV. See their Fig. 4 for the limit in mass-cross section plane. NODE=S056REG;LINKAGE=B

[260] ADAM 96C is from the single photon production cross at $\sqrt{s}$=130, 136 GeV. The upper bound is less than 3 pb for $X^0$ masses between 60 and 130 GeV. See their Fig. 5 for the exact bound on the cross section $\sigma(e^+e^- \rightarrow \gamma X^0)$. NODE=S056REG;LINKAGE=A

## Search for $X^0$ Resonance in $Z \rightarrow f\overline{f}X^0$

NODE=S056ZFR

The limit is for $B(Z \rightarrow f\overline{f}X^0) \cdot B(X^0 \rightarrow F)$ where $f$ is a fermion and $F$ is the specified final state. Spin 0 is assumed for $X^0$. NODE=S056ZFR

NODE=S056ZFR

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT | |
|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| | | [261] ABREU | 96T | DLPH | $f$=$e$,$\mu$,$\tau$; $F$=$\gamma\gamma$ | |
| $<3.7 \times 10^{-6}$ | 95 | [262] ABREU | 96T | DLPH | $f$=$\nu$; $F$=$\gamma\gamma$ | OCCUR=2 |
| | | [263] ABREU | 96T | DLPH | $f$=$q$; $F$=$\gamma\gamma$ | OCCUR=3 |
| $<6.8 \times 10^{-6}$ | 95 | [262] ACTON | 93E | OPAL | $f$=$e$,$\mu$,$\tau$; $F$=$\gamma\gamma$ | |
| $<5.5 \times 10^{-6}$ | 95 | [262] ACTON | 93E | OPAL | $f$=$q$; $F$=$\gamma\gamma$ | OCCUR=2 |
| $<3.1 \times 10^{-6}$ | 95 | [262] ACTON | 93E | OPAL | $f$=$\nu$; $F$=$\gamma\gamma$ | OCCUR=3 |
| $<6.5 \times 10^{-6}$ | 95 | [262] ACTON | 93E | OPAL | $f$=$e$,$\mu$; $F$=$\ell\overline{\ell}$, $q\overline{q}$, $\nu\overline{\nu}$ | OCCUR=4 |
| $<7.1 \times 10^{-6}$ | 95 | [262] BUSKULIC | 93F | ALEP | $f$=$e$,$\mu$; $F$=$\ell\overline{\ell}$, $q\overline{q}$, $\nu\overline{\nu}$ | |
| | | [264] ADRIANI | 92F | L3 | $f$=$q$; $F$=$\gamma\gamma$ | |

[261] ABREU 96T obtain limit as a function of $m_{X^0}$. See their Fig. 6. NODE=S056ZFR;LINKAGE=B1

[262] Limit is for $m_{X^0}$ around 60 GeV. NODE=S056ZFR;LINKAGE=B

[263] ABREU 96T obtain limit as a function of $m_{X^0}$. See their Fig. 15. NODE=S056ZFR;LINKAGE=B2

[264] ADRIANI 92F give $\sigma_Z \cdot B(Z \rightarrow q\overline{q}X^0) \cdot B(X^0 \rightarrow \gamma\gamma)$<(0.75–1.5) pb (95%CL) for $m_{X^0}$ = 10–70 GeV. The limit is 1 pb at 60 GeV. NODE=S056ZFR;LINKAGE=A

## Search for $X^0$ Resonance in $p\overline{p} \rightarrow WX^0$

NODE=S056PPW
NODE=S056PPW

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| | [265] ABE | 97W | CDF | $X^0 \rightarrow b\overline{b}$ |

[265] ABE 97W search for $X^0$ production associated with $W$ in $p\overline{p}$ collisions at $E_{cm}$=1.8 TeV. The 95%CL upper limit on the production cross section times the branching ratio for $X^0 \rightarrow b\overline{b}$ ranges from 14 to 19 pb for $X^0$ mass between 70 and 120 GeV. See their Fig. 3 for upper limits of the production cross section as a function of $m_{X^0}$. NODE=S056PPW;LINKAGE=A

## Heavy Particle Production in Quarkonium Decays

NODE=S056ONI

Limits are for branching ratios to modes shown. NODE=S056ONI

NODE=S056ONI

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT | |
|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $<1.5 \times 10^{-5}$ | 90 | [266] BALEST | 95 | CLE2 | $\Upsilon(1S) \rightarrow X^0\gamma$, $m_{X^0} < 5$ GeV | |
| $< 3 \times 10^{-5}$–$6 \times 10^{-3}$ | 90 | [267] BALEST | 95 | CLE2 | $\Upsilon(1S) \rightarrow X^0\overline{X}^0\gamma$, $m_{X^0} < 3.9$ GeV | OCCUR=2 |
| $<5.6 \times 10^{-5}$ | 90 | [268] ANTREASYAN | 90C | CBAL | $\Upsilon(1S) \rightarrow X^0\gamma$, $m_{X^0} < 7.2$ GeV | |
| | | [269] ALBRECHT | 89 | ARG | | |

266 BALEST 95 two-body limit is for pseudoscalar $X^0$. The limit becomes $< 10^{-4}$ for $m_{X^0} < 7.7$ GeV. NODE=S056ONI;LINKAGE=C

267 BALEST 95 three-body limit is for phase-space photon energy distribution and angular distribution same as for $\Upsilon \rightarrow g g \gamma$. NODE=S056ONI;LINKAGE=D

268 ANTREASYAN 90C assume that $X^0$ does not decay in the detector. NODE=S056ONI;LINKAGE=A

269 ALBRECHT 89 give limits for B($\Upsilon(1S)$, $\Upsilon(2S) \rightarrow X^0 \gamma$)·B($X^0 \rightarrow \pi^+ \pi^-$, $K^+ K^-$, $p \overline{p}$) for $m_{X^0} < 3.5$ GeV. NODE=S056ONI;LINKAGE=B

## REFERENCES FOR Searches for Heavy Bosons Other Than Higgs Bosons

NODE=S056


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| ABAZOV | 08C | PRL 100 031804 | V. M. Abazov *et al.* | (D0 Collab.) | REFID=52198 |
| AALTONEN | 07H | PRL 99 171802 | T. Aaltonen *et al.* | (CDF Collab.) | REFID=52013 |
| ABAZOV | 07E | PL B647 74 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=51741 |
| ABAZOV | 07J | PRL 99 061801 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=51871 |
| ABULENCIA | 07K | PR D75 091101R | A. Abulencia *et al.* | (CDF Collab.) | REFID=51789 |
| AKTAS | 07A | EPJ C52 833 | A. Aktas *et al.* | (H1 Collab.) | REFID=52035 |
| CHOUDHURY | 07 | PL B657 69 | D. Choudhury *et al.* | | REFID=52028 |
| MELCONIAN | 07 | PL B649 370 | D. Melconian *et al.* | (TRIUMF) | REFID=51822 |
| SCHAEL | 07A | EPJ C49 411 | S. Schael *et al.* | (ALEPH Collab.) | REFID=51743 |
| SCHUMANN | 07 | PRL 99 191803 | M. Schumann *et al.* | (HEID, ILLG, KARL+) | REFID=52019 |
| SMIRNOV | 07 | MPL A22 2353 | A.D. Smirnov | | REFID=51970 |
| ABAZOV | 06A | PL B636 183 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=51213 |
| ABAZOV | 06L | PL B640 230 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=51379 |
| ABAZOV | 06N | PL B641 423 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=51426 |
| ABDALLAH | 06C | EPJ C45 589 | J. Abdallah *et al.* | (DELPHI Collab.) | REFID=51224 |
| ABULENCIA | 06L | PRL 96 211801 | A. Abulencia *et al.* | (CDF Collab.) | REFID=51233 |
| ABULENCIA | 06M | PRL 96 211802 | A. Abulencia *et al.* | (CDF Collab.) | REFID=51232 |
| ABULENCIA | 06T | PR D73 051102R | A. Abulencia *et al.* | (CDF Collab.) | REFID=51269 |
| ABAZOV | 05H | PR D71 071104R | V.M. Abazov *et al.* | (D0 Collab.) | REFID=50628 |
| ABULENCIA | 05A | PRL 95 252001 | A. Abulencia *et al.* | (CDF Collab.) | REFID=51009 |
| ACOSTA | 05I | PR D71 112001 | D. Acosta *et al.* | (CDF Collab.) | REFID=50664 |
| ACOSTA | 05P | PR D72 051107R | D. Acosta *et al.* | (CDF Collab.) | REFID=50889 |
| ACOSTA | 05R | PRL 95 131801 | D. Acosta *et al.* | (CDF Collab.) | REFID=50916 |
| AKTAS | 05B | PL B629 9 | A. Aktas *et al.* | (H1 Collab.) | REFID=50884 |
| CHEKANOV | 05 | PL B610 212 | S. Chekanov *et al.* | (HERA ZEUS Collab.) | REFID=50531 |
| CHEKANOV | 05A | EPJ C44 463 | S. Chekanov *et al.* | (ZEUS Collab.) | REFID=50957 |
| CYBURT | 05 | ASP 23 313 | R.H. Cyburt *et al.* | | REFID=50710 |
| ABAZOV | 04A | PRL 92 221801 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=49944 |
| ABAZOV | 04C | PR D69 111101R | V.M. Abazov *et al.* | (D0 Collab.) | REFID=50005 |
| ABBIENDI | 04G | EPJ C33 173 | G. Abbiendi *et al.* | (OPAL Collab.) | REFID=49915 |
| ABBIENDI | 03D | EPJ C26 331 | G. Abbiendi *et al.* | (OPAL Collab.) | REFID=49290 |
| ABBIENDI | 03R | EPJ C31 281 | G. Abbiendi *et al.* | (OPAL) | REFID=50015 |
| ACOSTA | 03B | PRL 90 081802 | D. Acosta *et al.* | (CDF Collab.) | REFID=49354 |
| ADLOFF | 03 | PL B568 35 | C. Adloff *et al.* | (H1 Collab.) | REFID=49522 |
| BARGER | 03B | PR D67 075009 | V. Barger, P. Langacker, H. Lee | | REFID=49347 |
| CHANG | 03 | PR D68 111101R | M.-C. Chang *et al.* | (BELLE Collab.) | REFID=49640 |
| CHEKANOV | 03B | PR D68 052004 | S. Chekanov *et al.* | (ZEUS Collab.) | REFID=49547 |
| ABAZOV | 02 | PRL 88 191801 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=48646 |
| ABBIENDI | 02B | PL B526 233 | G. Abbiendi *et al.* | (OPAL Collab.) | REFID=48537 |
| AFFOLDER | 02C | PRL 88 071806 | T. Affolder *et al.* | (CDF Collab.) | REFID=48697 |
| CHEKANOV | 02 | PR D65 092004 | S. Chekanov *et al.* | (ZEUS Collab.) | REFID=48791 |
| CHEKANOV | 02B | PL B531 9 | S. Chekanov *et al.* | (ZEUS Collab.) | REFID=48937 |
| MUECK | 02 | PR D65 085037 | A. Mueck, A. Pilaftsis, R. Rueckl | | REFID=48887 |
| ABAZOV | 01B | PRL 87 061802 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=48208 |
| ABAZOV | 01D | PR D64 092004 | V.M. Abazov *et al.* | (D0 Collab.) | REFID=48394 |
| ADLOFF | 01C | PL B523 234 | C. Adloff *et al.* | (H1 Collab.) | REFID=48477 |
| AFFOLDER | 01I | PRL 87 231803 | T. Affolder *et al.* | (CDF Collab.) | REFID=48438 |
| BREITWEG | 01 | PR D63 052002 | J. Breitweg *et al.* | (ZEUS Collab.) | REFID=48089 |
| CHEUNG | 01B | PL B517 167 | K. Cheung | | REFID=48289 |
| THOMAS | 01 | NP A694 559 | E. Thomas *et al.* | | REFID=48407 |
| ABBIENDI | 00M | EPJ C13 15 | G. Abbiendi *et al.* | (OPAL Collab.) | REFID=47590 |
| ABBOTT | 00C | PRL 84 2088 | B. Abbott *et al.* | (D0 Collab.) | REFID=47518 |
| ABE | 00 | PRL 84 5716 | F. Abe *et al.* | (CDF Collab.) | REFID=47637 |
| ABREU | 00S | PL B485 45 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=47716 |
| ABREU | 00Z | EPJ C17 53 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=47790 |
| ACCIARRI | 00P | PL B489 81 | M. Acciarri *et al.* | (L3 Collab.) | REFID=47757 |
| ADLOFF | 00 | PL B479 358 | C. Adloff *et al.* | (H1 Collab.) | REFID=47621 |
| AFFOLDER | 00K | PRL 85 2056 | T. Affolder *et al.* | (CDF Collab.) | REFID=47752 |
| BARATE | 00I | EPJ C12 183 | R. Barate *et al.* | (ALEPH Collab.) | REFID=47537 |
| BARGER | 00 | PL B480 149 | V. Barger, K. Cheung | | REFID=47624 |
| BREITWEG | 00E | EPJ C16 253 | J. Breitweg *et al.* | (ZEUS Collab.) | REFID=47750 |
| CHAY | 00 | PR D61 035002 | J. Chay, K.Y. Lee, S. Nam | | REFID=47348 |
| CHO | 00 | MPL A15 311 | G. Cho | | REFID=47613 |
| CORNET | 00 | PR D61 037701 | F. Cornet, M. Relano, J. Rico | | REFID=47888 |
| DELGADO | 00 | JHEP 0001 030 | A. Delgado, A. Pomarol, M. Quiros | | REFID=48620 |
| ERLER | 00 | PRL 84 212 | J. Erler, P. Langacker | | REFID=47351 |
| GABRIELLI | 00 | PR D62 055009 | E. Gabrielli | | REFID=47701 |
| RIZZO | 00 | PR D61 016007 | T.G. Rizzo, J.D. Wells | | REFID=47887 |
| ROSNER | 00 | PR D61 016006 | J.L. Rosner | | REFID=47342 |
| ZARNECKI | 00 | EPJ C17 695 | A. Zarnecki | | REFID=47883 |
| ABBIENDI | 99 | EPJ C6 1 | G. Abbiendi *et al.* | (OPAL Collab.) | REFID=46533 |
| ABBOTT | 99J | PRL 83 2896 | B. Abbott *et al.* | (D0 Collab.) | REFID=47210 |
| ABREU | 99G | PL B446 62 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=46712 |
| ACKERSTAFF | 99D | EPJ C8 3 | K. Ackerstaff *et al.* | (OPAL Collab.) | REFID=47012 |
| ADLOFF | 99 | EPJ C11 447 | C. Adloff *et al.* | (H1 Collab.) | REFID=47307 |
| Also | | EPJ C14 553 (erratum) | C. Adloff *et al.* | (H1 Collab.) | REFID=47649 |
| CASALBUONI | 99 | PL B460 135 | R. Casalbuoni *et al.* | | REFID=47057 |
| CZAKON | 99 | PL B458 355 | M. Czakon, J. Gluza, M. Zralek | | REFID=47171 |
| ERLER | 99 | PL B456 68 | J. Erler, P. Langacker | | REFID=47166 |
| MARCIANO | 99 | PR D60 093006 | W. Marciano | | REFID=48622 |
| MASIP | 99 | PR D60 096005 | M. Masip, A. Pomarol | | REFID=48621 |
| NATH | 99 | PR D60 116004 | P. Nath, M. Yamaguchi | | REFID=48619 |
| STRUMIA | 99 | PL B466 107 | A. Strumia | | REFID=47357 |
| ABBOTT | 98E | PRL 80 2051 | B. Abbott *et al.* | (D0 Collab.) | REFID=45954 |
| ABBOTT | 98J | PRL 81 38 | B. Abbott *et al.* | (D0 Collab.) | REFID=46089 |
| ABE | 98S | PRL 81 4806 | F. Abe *et al.* | (CDF Collab.) | REFID=46495 |

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| ABE | 98V | PRL 81 5742 | F. Abe *et al.* | (CDF Collab.) | REFID=46697 |
| ACCIARRI | 98J | PL B433 163 | M. Acciarri *et al.* | (L3 Collab.) | REFID=46075 |
| ACKERSTAFF | 98V | EPJ C2 441 | K. Ackerstaff *et al.* | (OPAL Collab.) | REFID=46164 |
| BARATE | 98U | EPJ C4 571 | R. Barate *et al.* | (ALEPH Collab.) | REFID=46150 |
| BARENBOIM | 98 | EPJ C1 369 | G. Barenboim | | REFID=46143 |
| CHO | 98 | EPJ C5 155 | G. Cho, K. Hagiwara, S. Matsumoto | | REFID=46261 |
| CONRAD | 98 | RMP 70 1341 | J.M. Conrad, M.H. Shaevitz, T. Bolton | | REFID=46498 |
| DONCHESKI | 98 | PR D58 097702 | M.A. Doncheski, R.W. Robinett | | REFID=46486 |
| GROSS-PILCH... | 98 | hep-ex/9810015 | C. Grosso-Pilcher, G. Landsberg, M. Paterno | | REFID=48647 |
| ABE | 97F | PRL 78 2906 | F. Abe *et al.* | (CDF Collab.) | REFID=45301 |
| ABE | 97G | PR D55 R5263 | F. Abe *et al.* | (CDF Collab.) | REFID=45343 |
| ABE | 97S | PRL 79 2192 | F. Abe *et al.* | (CDF Collab.) | REFID=45595 |
| ABE | 97W | PRL 79 3819 | F. Abe *et al.* | (CDF Collab.) | REFID=45719 |
| ABE | 97X | PRL 79 4327 | F. Abe *et al.* | (CDF Collab.) | REFID=45724 |
| ACCIARRI | 97Q | PL B412 201 | M. Acciarri *et al.* | (L3 Collab.) | REFID=45738 |
| ARIMA | 97 | PR D55 19 | T. Arima *et al.* | (VENUS Collab.) | REFID=45264 |
| BARENBOIM | 97 | PR D55 4213 | G. Barenboim *et al.* | (VALE, IFIC) | REFID=45339 |
| DEANDREA | 97 | PL B409 277 | A. Deandrea | (MARS) | REFID=45662 |
| DERRICK | 97 | ZPHY C73 613 | M. Derrick *et al.* | (ZEUS Collab.) | REFID=45295 |
| GROSSMAN | 97 | PR D55 2768 | Y. Grossman, Z. Ligeti, E. Nardi | (REHO, CIT) | REFID=45274 |
| JADACH | 97 | PL B408 281 | S. Jadach, B.F.L. Ward, Z. Was | (CERN, INPK+) | REFID=45658 |
| STAHL | 97 | ZPHY C74 73 | A. Stahl, H. Voss | (BONN) | REFID=45483 |
| ABACHI | 96C | PRL 76 3271 | S. Abachi *et al.* | (D0 Collab.) | REFID=44802 |
| ABACHI | 96D | PL B385 471 | S. Abachi *et al.* | (D0 Collab.) | REFID=44918 |
| ABREU | 96T | ZPHY C72 179 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=45275 |
| ADAM | 96C | PL B380 471 | W. Adam *et al.* | (DELPHI Collab.) | REFID=44847 |
| AID | 96B | PL B369 173 | S. Aid *et al.* | (H1 Collab.) | REFID=44831 |
| ALLET | 96 | PL B383 139 | M. Allet *et al.* | (VILL, LEUV, LOUV, WISC) | REFID=44854 |
| ABACHI | 95E | PL B358 405 | S. Abachi *et al.* | (D0 Collab.) | REFID=44474 |
| ABE | 95M | PRL 74 2900 | F. Abe *et al.* | (CDF Collab.) | REFID=44195 |
| ABE | 95N | PRL 74 3538 | F. Abe *et al.* | (CDF Collab.) | REFID=44201 |
| BALEST | 95 | PR D51 2053 | R. Balest *et al.* | (CLEO Collab.) | REFID=44146 |
| KUZNETSOV | 95 | PRL 75 794 | I.A. Kuznetsov *et al.* | (PNPI, KIAE, HARV+) | REFID=44348 |
| KUZNETSOV | 95B | PAN 58 2113 | A.V. Kuznetsov, N.V. Mikheev | (YARO) | REFID=44743 |
| | | Translated from YAF 58 2228. | | | |
| MIZUKOSHI | 95 | NP B443 20 | J.K. Mizukoshi, O.J.P. Eboli, M.C. Gonzalez-Garcia | | REFID=44276 |
| ABREU | 94O | ZPHY C64 183 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=44046 |
| BHATTACH... | 94 | PL B336 100 | G. Bhattacharyya, J. Ellis, K. Sridhar | (CERN) | REFID=43964 |
| Also | | PL B338 522 (erratum) | G. Bhattacharyya, J. Ellis, K. Sridhar | (CERN) | REFID=44024 |
| BHATTACH... | 94B | PL B338 522 (erratum) | G. Bhattacharyya, J. Ellis, K. Sridhar | (CERN) | REFID=44024 |
| DAVIDSON | 94 | ZPHY C61 613 | S. Davidson, D. Bailey, B.A. Campbell | (CFPA+) | REFID=43910 |
| KUZNETSOV | 94 | PL B329 295 | A.V. Kuznetsov, N.V. Mikheev | (YARO) | REFID=43947 |
| KUZNETSOV | 94B | JETPL 60 315 | I.A. Kuznetsov *et al.* | (PNPI, KIAE, HARV+) | REFID=44031 |
| | | Translated from ZETFP 60 311. | | | |
| LEURER | 94 | PR D50 536 | M. Leurer | (REHO) | REFID=43865 |
| LEURER | 94B | PR D49 333 | M. Leurer | (REHO) | REFID=43981 |
| Also | | PRL 71 1324 | M. Leurer | (REHO) | REFID=43464 |
| MAHANTA | 94 | PL B337 128 | U. Mahanta | (MEHTA) | REFID=44012 |
| SEVERIJNS | 94 | PRL 73 611 (erratum) | N. Severijns *et al.* | (LOUV, WISC, LEUV+) | REFID=43880 |
| VILAIN | 94B | PL B332 465 | P. Vilain *et al.* | (CHARM II Collab.) | REFID=43900 |
| ABE | 93C | PL B302 119 | K. Abe *et al.* | (VENUS Collab.) | REFID=43291 |
| ABE | 93D | PL B304 373 | T. Abe *et al.* | (TOPAZ Collab.) | REFID=43337 |
| ABE | 93G | PRL 71 2542 | F. Abe *et al.* | (CDF Collab.) | REFID=43512 |
| ABREU | 93J | PL B316 620 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=43628 |
| ACTON | 93E | PL B311 391 | P.D. Acton *et al.* | (OPAL Collab.) | REFID=43438 |
| ADRIANI | 93M | PRPL 236 1 | O. Adriani *et al.* | (L3 Collab.) | REFID=43644 |
| ALITTI | 93 | NP B400 3 | J. Alitti *et al.* | (UA2 Collab.) | REFID=43544 |
| BHATTACH... | 93 | PR D47 R3693 | G. Bhattacharyya *et al.* | (CALC, JADA, ICTP+) | REFID=43374 |
| BUSKULIC | 93F | PL B308 425 | D. Buskulic *et al.* | (ALEPH Collab.) | REFID=43431 |
| DERRICK | 93 | PL B306 173 | M. Derrick *et al.* | (ZEUS Collab.) | REFID=43345 |
| RIZZO | 93 | PR D48 4470 | T.G. Rizzo | (ANL) | REFID=43549 |
| SEVERIJNS | 93 | PRL 70 4047 | N. Severijns *et al.* | (LOUV, WISC, LEUV+) | REFID=43365 |
| Also | | PRL 73 611 (erratum) | N. Severijns *et al.* | (LOUV, WISC, LEUV+) | REFID=43880 |
| STERNER | 93 | PL B303 385 | K.L. Sterner *et al.* | (AMY Collab.) | REFID=43299 |
| ABREU | 92D | ZPHY C53 555 | P. Abreu *et al.* | (DELPHI Collab.) | REFID=41957 |
| ADRIANI | 92F | PL B292 472 | O. Adriani *et al.* | (L3 Collab.) | REFID=42222 |
| DECAMP | 92 | PRPL 216 253 | D. Decamp *et al.* | (ALEPH Collab.) | REFID=41877 |
| IMAZATO | 92 | PRL 69 877 | J. Imazato *et al.* | (KEK, INUS, TOKY+) | REFID=42141 |
| MISHRA | 92 | PRL 68 3499 | S.R. Mishra *et al.* | (COLU, CHIC, FNAL+) | REFID=42035 |
| POLAK | 92B | PR D46 3871 | J. Polak, M. Zralek | (SILES) | REFID=43750 |
| ACTON | 91 | PL B268 122 | D.P. Acton *et al.* | (OPAL Collab.) | REFID=41617 |
| ACTON | 91B | PL B273 338 | D.P. Acton *et al.* | (OPAL Collab.) | REFID=41878 |
| ADEVA | 91D | PL B262 155 | B. Adeva *et al.* | (L3 Collab.) | REFID=41550 |
| AQUINO | 91 | PL B261 280 | M. Aquino, A. Fernandez, A. Garcia | (CINV, PUEB) | REFID=41687 |
| COLANGELO | 91 | PL B253 154 | P. Colangelo, G. Nardulli | (BARI) | REFID=41692 |
| CUYPERS | 91 | PL B259 173 | F. Cuypers, A.F. Falk, P.H. Frampton | (DURH, HARV+) | REFID=41666 |
| FARAGGI | 91 | MPL A6 61 | A.E. Faraggi, D.V. Nanopoulos | (TAMU) | REFID=41880 |
| POLAK | 91 | NP B363 385 | J. Polak, M. Zralek | (SILES) | REFID=43749 |
| RIZZO | 91 | PR D44 202 | T.G. Rizzo | (WISC, ISU) | REFID=41520 |
| WALKER | 91 | APJ 376 51 | T.P. Walker *et al.* | (HSCA, OSU, CHIC+) | REFID=41879 |
| ABE | 90F | PL B246 297 | K. Abe *et al.* | (VENUS Collab.) | REFID=41337 |
| ABE | 90H | PR D41 1722 | F. Abe *et al.* | (CDF Collab.) | REFID=41506 |
| AKRAWY | 90J | PL B246 285 | M.Z. Akrawy *et al.* | (OPAL Collab.) | REFID=41336 |
| ANTREASYAN | 90C | PL B251 204 | D. Antreasyan *et al.* | (Crystal Ball Collab.) | REFID=41455 |
| GONZALEZ-G... | 90D | PL B240 163 | M.C. Gonzalez-Garcia, J.W.F. Valle | (VALE) | REFID=41814 |
| GRIFOLS | 90 | NP B331 244 | J.A. Grifols, E. Masso | (BARC) | REFID=41230 |
| GRIFOLS | 90D | PR D42 3293 | J.A. Grifols, E. Masso, T.G. Rizzo | (BARC, CERN+) | REFID=41462 |
| KIM | 90 | PL B240 243 | G.N. Kim *et al.* | (AMY Collab.) | REFID=41211 |
| LOPEZ | 90 | PL B241 392 | J.L. Lopez, D.V. Nanopoulos | (TAMU) | REFID=41219 |
| ALBAJAR | 89 | ZPHY C44 15 | C. Albajar *et al.* | (UA1 Collab.) | REFID=40860 |
| ALBRECHT | 89 | ZPHY C42 349 | H. Albrecht *et al.* | (ARGUS Collab.) | REFID=40731 |
| BARBIERI | 89B | PR D39 1229 | R. Barbieri, R.N. Mohapatra | (PISA, UMD) | REFID=41881 |
| LANGACKER | 89B | PR D40 1569 | P. Langacker, S. Uma Sankar | (PENN) | REFID=41815 |

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| ODAKA | 89 | JPSJ 58 3037 | S. Odaka *et al.* | (VENUS Collab.) | REFID=40971 |
| ROBINETT | 89 | PR D39 834 | R.W. Robinett | (PSU) | REFID=40896 |
| ALBAJAR | 88B | PL B209 127 | C. Albajar *et al.* | (UA1 Collab.) | REFID=40894 |
| BAGGER | 88 | PR D37 1188 | J. Bagger, C. Schmidt, S. King | (HARV, BOST) | REFID=40895 |
| BALKE | 88 | PR D37 587 | B. Balke *et al.* | (LBL, UCB, COLO, NWES+) | REFID=40665 |
| BERGSTROM | 88 | PL B212 386 | L. Bergstrom | (STOH) | REFID=40980 |
| CUYPERS | 88 | PRL 60 1237 | F. Cuypers, P.H. Frampton | (UNCCH) | REFID=40599 |
| DONCHESKI | 88 | PL B206 137 | M.A. Doncheski, H. Grotch, R. Robinett | (PSU) | REFID=40898 |
| DONCHESKI | 88B | PR D38 412 | M.A. Doncheski, H. Grotch, R.W. Robinett | (PSU) | REFID=40897 |
| ANSARI | 87D | PL B195 613 | R. Ansari *et al.* | (UA2 Collab.) | REFID=40457 |
| BARTEL | 87B | ZPHY C36 15 | W. Bartel *et al.* | (JADE Collab.) | REFID=40455 |
| BEHREND | 86B | PL B178 452 | H.J. Behrend *et al.* | (CELLO Collab.) | REFID=40150 |
| DERRICK | 86 | PL 166B 463 | M. Derrick *et al.* | (HRS Collab.) | REFID=40135 |
| Also | | PR D34 3286 | M. Derrick *et al.* | (HRS Collab.) | REFID=43492 |
| JODIDIO | 86 | PR D34 1967 | A. Jodidio *et al.* | (LBL, NWES, TRIU) | REFID=40309 |
| Also | | PR D37 237 (erratum) | A. Jodidio *et al.* | (LBL, NWES, TRIU) | REFID=40467 |
| MOHAPATRA | 86 | PR D34 909 | R.N. Mohapatra | (UMD) | REFID=40148 |
| ADEVA | 85 | PL 152B 439 | B. Adeva *et al.* | (Mark-J Collab.) | REFID=10618 |
| BERGER | 85B | ZPHY C27 341 | C. Berger *et al.* | (PLUTO Collab.) | REFID=40465 |
| STOKER | 85 | PRL 54 1887 | D.P. Stoker *et al.* | (LBL, NWES, TRIU) | REFID=10256 |
| ADEVA | 84 | PRL 53 134 | B. Adeva *et al.* | (Mark-J Collab.) | REFID=10613 |
| BEHREND | 84C | PL 140B 130 | H.J. Behrend *et al.* | (CELLO Collab.) | REFID=12651 |
| BERGSMA | 83 | PL 122B 465 | F. Bergsma *et al.* | (CHARM Collab.) | REFID=10239 |
| CARR | 83 | PRL 51 627 | J. Carr *et al.* | (LBL, NWES, TRIU) | REFID=10240 |
| BEALL | 82 | PRL 48 848 | G. Beall, M. Bander, A. Soni | (UCI, UCLA) | REFID=40597 |
| SHANKER | 82 | NP B204 375 | O. Shanker | (TRIU) | REFID=12502 |