[50] POLAK 92B limit is from a simultaneous fit to charged and neutral sector in $SU(2)_L \times SU(2)_R \times U(1)$ model using $Z$ parameters, $m_W$, and low-energy neutral current data as of 1991. Light $\nu_R$ assumed and $m_t$=$m_H$=100 GeV used. Supersedes POLAK 91.
[51] RENTON 92 limits use LEP data taken up to '90 as well as $m_W$, $\nu N$, and atomic parity violation data. Specific Higgs structure is assumed.
[52] ALTARELLI 91B is based on $Z$ mass, widths, and $A_{FB}$. The limits are for superstring motivated models with extra assumption on the Higgs sector. $m_t > 90$ GeV and $m_{H^0} < 1$ TeV assumed. For large $m_t$, the bound improves drastically. Bounds for $Z$-$Z'$ mixing angle and $Z$ mass shift without this model assumption are also given in the paper.
[53] DELAGUILA 91 bounds have extra assumption of superstring motivated Higgs sector. From $\nu N$ neutral current data with $m_Z = 91.10 \pm 0.04$ GeV, $m_t > 77$ GeV, $m_{H^0} < 1$ TeV assumed.
[54] POLAK 91 limit is from a simultaneous fit to charged and neutral sector in $SU(2)_L \times SU(2)_R \times U(1)$ model using $m_W$, $m_Z$, and low-energy neutral current data as of 1990. Light $\nu_R$ assumed and $m_t$=$m_H$=100 GeV used. Superseded by POLAK 92B.
[55] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. See also GRIFOLS 90D, RIZZO 91.
[56] HE 90B model assumes a specific Higgs sector. Neutral current data of COSTA 88 as well as $m_Z$ is used. $g_R$ is left free in the fit.
[57] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.
[58] DELAGUILA 89 limit is based on $\sigma(p\overline{p} \rightarrow Z')\cdot B(Z' \rightarrow e^+e^-) < 1.8$ pb at CERN $p\overline{p}$ collider.
[59] A wide range of neutral current data as of 1986 are used in the fit.
[60] A wide range of neutral current data as of 1985 are used in the fit.
[61] ADEVA 85B measure asymmetry of $\mu$-pair production, following formalism of RIZZO 81.

### Limits for $Z_\chi$

$Z_\chi$ 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.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **>340** | 95 | [62] ABE | 92B | CDF | $p\overline{p}$ |
| **>321** | 95 | [63,64] LANGACKER | 92B | RVUE | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| | | [65] BUSKULIC | 94 | ALEP | $Z$ parameters |
| >117 | 95 | [66] ADRIANI | 93D | L3 | $Z$ parameters |
| (>900) | 90 | [67] ALTARELLI | 93B | RVUE | $Z$ parameters |
| >280 | 95 | [68] ABE | 92B | CDF | $p\overline{p}$ |
| (>650) | 90 | [69] DELAGUILA | 92 | RVUE | |
| (>760) | | [70] LAYSSAC | 92B | RVUE | $Z$ parameters |
| >148 | 95 | [71] LEIKE | 92 | RVUE | $Z$ parameters |
| (>700) | | [72] RENTON | 92 | RVUE | |
| (> 500) | 90 | [73] ALTARELLI | 91B | RVUE | $Z$ parameters |
| (> 570) | | [74] BUCHMUEL... | 91 | RVUE | $Z$ parameters |
| (> 555) | 90 | [75] DELAGUILA | 91 | RVUE | |
| [>1470] | | [76] FARAGGI | 91 | COSM | Nucleosynthesis; light $\nu_R$ |
| >320 | 90 | [77] GONZALEZ-G... | 91 | RVUE | |
| >221 | | [78] MAHANTHAP... | 91 | RVUE | Cs |
| >231 | 90 | [79,80] ABE | 90F | VNS | $e^+e^-$ |
| >206 | 90 | [80,81] ABE | 90F | RVUE | $e^+e^-$, $\nu_\mu e$ |
| >335 | | [82] BARGER | 90B | RVUE | $p\overline{p}$ |
| (> 650) | 90 | [83] GLASHOW | 90 | RVUE | |
| [> 1140] | | [84] GONZALEZ-G... | 90D | COSM | Nucleosynthesis; light $\nu_R$ |
| [> 2100] | | [85] GRIFOLS | 90 | ASTR | SN 1987A; light $\nu_R$ |
| none <150 or > 363 | 90 | [86] HAGIWARA | 90 | RVUE | $e^+e^-$ |
| >177 | | [87] DELAGUILA | 89 | RVUE | $p\overline{p}$ |
| >280 | 95 | [88] DORENBOS... | 89 | CHRM | $g_\chi = g_Z$ |
| >352 | 90 | [89] COSTA | 88 | RVUE | |
| >170 | 90 | [90] ELLIS | 88 | RVUE | $p\overline{p}$ |
| >273 | 90 | [89] AMALDI | 87 | RVUE | |
| >266 | 90 | [91] MARCIANO | 87 | RVUE | |
| >283 | 90 | [92] DURKIN | 86 | RVUE | |

[62] These limits assume that $Z'$ decays to known fermions only.
[63] LANGACKER 92B fit to a wide range of electroweak data including LEP results available early '91. $m_t > 89$ GeV used.
[64] LANGACKER 92B give 95%CL limits on the $Z$-$Z'$ mixing $-0.0048 < \theta < 0.0097$.
[65] BUSKULIC 94 give 95%CL limits on the $Z$-$Z'$ mixing $-0.0091 < \theta < 0.0023$.
[66] ADRIANI 93D give limits on the $Z$-$Z'$ mixing $-0.004 < \theta < 0.015$ assuming the ABE 92B mass limit.
[67] ALTARELLI 93B limit is from LEP data available in summer '93 and is for $m_t = 110$ GeV. $m_H = 100$ GeV and $\alpha_s = 0.118$ assumed. The limit improves for larger $m_t$ (see their Fig. 5). The 90%CL limit on the $Z$-$Z'$ mixing angle is in their Fig. 2.
[68] These limits assume that $Z'$ decays to all $E_6$ fermions and their superpartners.
[69] See Fig. 7a and 8 in DELAGUILA 92 for the allowed region in $m_{Z'}$-mixing plane and $m_{Z'} - m_t$ plane from electroweak fit including '90 LEP data.
[70] LAYSSAC 92B limit is from LEP data available spring '92. Specific Higgs sector is assumed. See also LAYSSAC 92.
[71] LEIKE 92 is based on '90 LEP data published in LEP 92.
[72] RENTON 92 limits use LEP data taken up to '90 as well as $m_W$, $\nu N$, and atomic parity violation data. Specific Higgs structure is assumed.
[73] ALTARELLI 91B is based on $Z$ mass, widths, and $A_{FB}$. The limits are for superstring motivated models with extra assumption on the Higgs sector. $m_t > 90$ GeV and $m_{H^0} < 1$ TeV assumed. For large $m_t$, the bound improves drastically. Bounds for $Z$-$Z'$ mixing angle and $Z$ mass shift without this model assumption are also given in the paper.
[74] BUCHMUELLER 91 limit is from LEP data. Specific assumption is made for the Higgs sector.
[75] DELAGUILA 91 bounds have extra assumption of superstring motivated Higgs sector. From $\nu N$ neutral current data with $m_Z = 91.10 \pm 0.04$ GeV, $m_t > 77$ GeV, $m_{H^0} < 1$ TeV assumed.
[76] 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.
[77] GONZALEZ-GARCIA 91 limit is based on low-energy neutral current data, $Z$ mass and widths, $m_W$ from ABE 90G. $100 < m_t < 200$ GeV, $m_{H^0} = 100$ GeV assumed. Dependence on $m_t$ is shown in Fig. 7.
[78] MAHANTHAPPA 91 limit is from atomic parity violation in Cs with $m_W$, $m_Z$.
[79] ABE 90F use data for $R$, $R_{\ell\ell}$, and $A_{\ell\ell}$.
[80] ABE 90F fix $m_W = 80.49 \pm 0.43 \pm 0.24$ GeV and $m_Z = 91.13 \pm 0.03$ GeV.
[81] $e^+e^-$ data for $R$, $R_{\ell\ell}$, $A_{\ell\ell}$, and $A_{c\overline{c}}$ below $Z$ as well as $\nu_\mu e$ scattering data of GEIREGAT 89 is used in the fit.
[82] BARGER 90B limit is based on CDF limit $\sigma(p\overline{p} \rightarrow Z')\cdot B(Z' \rightarrow e^+e^-) < 1$ pb (Nodulman, EPS Conf. '89). Assumes no new threshold is open for $Z'$ decay.
[83] GLASHOW 90 model assumes a specific Higgs sector. See GLASHOW 90B.
[84] 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).
[85] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. See also GRIFOLS 90D, RIZZO 91.
[86] HAGIWARA 90 perform a fit to $e^+e^-$ data at PEP, PETRA, and TRISTAN including $\mu^+\mu^-$, $\tau^+\tau^-$, and hadron cross sections and asymmetries. The upper mass limit disappears at 2.7 s.d.
[87] DELAGUILA 89 limit is based on $\sigma(p\overline{p} \rightarrow Z')\cdot B(Z' \rightarrow e^+e^-) < 1.8$ pb at CERN $p\overline{p}$ collider.
[88] DORENBOSCH 89 obtain the limit $(g_\chi/g_Z)^2 \cdot (m_Z/m_{Z_\chi})^2 < 0.11$ at 95% CL from the processes $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$ and $\nu_\mu e \rightarrow \nu_\mu e$.
[89] A wide range of neutral current data as of 1986 are used in the fit.
[90] $Z'$ mass limits from non-observation of an excess of $\ell^+\ell^-$ pairs at the CERN $p\overline{p}$ collider [based on ANSARI 87D and GEER Uppsala Conf. 87]. The limits apply when $Z'$ decays only into light quarks and leptons.
[91] MARCIANO 87 limit from unitarity of Cabibbo-Kobayashi-Maskawa matrix.
[92] A wide range of neutral current data as of 1985 are used in the fit.

### Limits for $Z_\psi$

$Z_\psi$ is the extra neutral boson in $E_6 \rightarrow SO(10) \times U(1)_\psi$. $g_\psi = e/\cos\theta_W$ 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.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **>320** | 95 | [93] ABE | 92B | CDF | $p\overline{p}$ |
| **>160** | 95 | [94,95] LANGACKER | 92B | RVUE | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| >118 | 95 | [96] ADRIANI | 93D | L3 | $Z$ parameters |
| >180 | 95 | [97] ABE | 92B | CDF | $p\overline{p}$ |
| >122 | 95 | [98] LEIKE | 92 | RVUE | $Z$ parameters |
| >105 | 90 | [99,100] ABE | 90F | VNS | $e^+e^-$ |
| >146 | 90 | [100,101] ABE | 90F | RVUE | $e^+e^-$, $\nu_\mu e$ |
| >320 | | [102] BARGER | 90B | RVUE | $p\overline{p}$ |
| [> 160] | | [103] GONZALEZ-G... | 90D | COSM | Nucleosynthesis; light $\nu_R$ |
| [> 2000] | | [104] GRIFOLS | 90D | ASTR | SN 1987A; light $\nu_R$ |
| >136 | 90 | [105] HAGIWARA | 90 | RVUE | $e^+e^-$ |
| >154 | 90 | [106] AMALDI | 87 | RVUE | |
| >146 | 90 | [107] DURKIN | 86 | RVUE | |

[93] These limits assume that $Z'$ decays to known fermions only.
[94] LANGACKER 92B fit to a wide range of electroweak data including LEP results available early '91. $m_t > 89$ GeV used.
[95] LANGACKER 92B give 95%CL limits on the $Z$-$Z'$ mixing $-0.0025 < \theta < 0.013$.
[96] ADRIANI 93D give limits on the $Z$-$Z'$ mixing $-0.003 < \theta < 0.020$ assuming the ABE 92B mass limit.
[97] These limits assume that $Z'$ decays to all $E_6$ fermions and their superpartners.
[98] LEIKE 92 is based on '90 LEP data published in LEP 92.
[99] ABE 90F use data for $R$, $R_{\ell\ell}$, and $A_{\ell\ell}$.
[100] ABE 90F fix $m_W = 80.49 \pm 0.43 \pm 0.24$ GeV and $m_Z = 91.13 \pm 0.03$ GeV.
[101] $e^+e^-$ data for $R$, $R_{\ell\ell}$, $A_{\ell\ell}$, and $A_{c\overline{c}}$ below $Z$ as well as $\nu_\mu e$ scattering data of GEIREGAT 89 is used in the fit.
[102] BARGER 90B limit is based on CDF limit $\sigma(p\overline{p} \rightarrow Z')\cdot B(Z' \rightarrow e^+e^-) < 1$ pb (Nodulman, EPS Conf. '89). Assumes no new threshold is open for $Z'$ decay.
[103] 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).
[104] GRIFOLS 90D limit holds for $m_{\nu_R} \lesssim 1$ MeV. See also RIZZO 91.
[105] HAGIWARA 90 perform a fit to $e^+e^-$ data at PEP, PETRA, and TRISTAN including $\mu^+\mu^-$, $\tau^+\tau^-$, and hadron cross sections and asymmetries.
[106] A wide range of neutral current data as of 1986 are used in the fit.
[107] A wide range of neutral current data as of 1985 are used in the fit.

### Limits for $Z_\eta$

$Z_\eta$ 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.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **>340** | 95 | [108] ABE | 92B | CDF | $p\overline{p}$ |
| **>182** | 95 | [109,110] LANGACKER | 92B | RVUE | |