couples to $\alpha T_{3R} - (1/2\alpha)(B-L)$ with the coupling strength g' (the weak hypercharge gauge coupling). The parameter α is model dependent. For left-right symmetric coupling $g_L = g_R$, $\alpha = (1-2\sin^2\theta_W)^{1/2}/\sin\theta_W \approx 1.53$, which is used for the limits in the listing unless noted. Another typical case $\alpha = (2/3)^{1/2}$ is identical to Z_χ (discussed below) with the coupling $g_\chi = g'$.

E_6 bosons: Two new neutral gauge bosons appear in E_6 models. One is contained in the SO(10) subgroup and the other is not:

$$E_6 \longrightarrow SO(10) \times U(1)_\psi ,$$

$$SO(10) \longrightarrow SU(5) \times U(1)_\chi .$$

One Z' is assumed to be relatively light, which in general is a linear combination of the two:

$$Z_\beta = Z_\chi \cos\beta + Z_\psi \sin\beta .$$

The gauge quantum numbers of the ordinary quarks and leptons are shown in the table:

f	T_{3R}	Y	$B-L$	$\sqrt{24}Q_\chi$	$\sqrt{\frac{72}{5}}Q_\psi$	Q_η
ν_L, e^-_L	0	$-\frac{1}{2}$	-1	$+3$	$+1$	$+\frac{1}{6}$
ν_R	$+\frac{1}{2}$	0	-1	$+5$	-1	$+\frac{5}{6}$
e^-_R	$-\frac{1}{2}$	-1	-1	$+1$	-1	$+\frac{1}{3}$
u_L, d_L	0	$+\frac{1}{6}$	$+\frac{1}{3}$	-1	$+1$	$-\frac{1}{3}$
u_R	$+\frac{1}{2}$	$+\frac{2}{3}$	$+\frac{1}{3}$	$+1$	-1	$+\frac{1}{3}$
d_R	$-\frac{1}{2}$	$-\frac{1}{3}$	$+\frac{1}{3}$	-3	-1	$-\frac{1}{6}$

In particular, the χ charge is related to others by $\sqrt{24}Q_\chi = 4Y - 5(B-L)$. Also notice that the Z_ψ coupling is pure axial for all quarks and leptons.

Another typical case Z_η is defined as

$$Z_\eta = \sqrt{\tfrac{3}{8}}Z_\chi - \sqrt{\tfrac{5}{8}}Z_\psi ,$$

which appears in a superstring-motivated model.

A reference gauge coupling for these bosons is $g' = e/\cos\theta_W$, which is predicted if there is no intermediate symmetry breaking scale.

In general, these Z' models require the existence of a set of new fermions (belonging to the 27 representation of E_6) to cancel gauge anomalies, and possibly superpartners. An exception is Z_χ, for which only right-handed neutrinos are necessary. For the direct limits from hadron colliders, it is often assumed that these new fermions are heavy and are not produced in the decay of the Z'.

Limits for Z'_{SM}

Z'_{SM} is assumed to have couplings with quarks and leptons which are identical to those of Z.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>412	95	ABE 92B	CDF	$p\overline{p}$; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
>779	95	[28,29] LANGACKER 92B	RVUE	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>237	90	[30] ALITTI 93	UA2	$p\overline{p}$; $Z'_{SM} \to q\overline{q}$
>119	90	[31] ALLEN 93	CALO	$\nu e \to \nu e$
none 490–560	95	[32] RIZZO 93	RVUE	$p\overline{p}$; $Z'_{SM} \to q\overline{q}$
>387	95	[33] ABE 91D	CDF	$p\overline{p}$; $Z'_{SM} \to e^+e^-$
>307	90	[34] GEIREGAT 91	CHM2	$\nu_\mu e \to \nu_\mu e$ and $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$
>426	90	[35] ABE 90F	VNS	e^+e^-
>208	90	[36] HAGIWARA 90	RVUE	e^+e^-
>173	90	[37] ALBAJAR 89	UA1	$p\overline{p}$; $Z'_{SM} \to e^+e^-$
>180	90	[38] ANSARI 87D	UA2	$p\overline{p}$; $Z'_{SM} \to e^+e^-$
>160	90	[39] ARNISON 86B	UA1	$p\overline{p}$; $Z'_{SM} \to e^+e^-$

[28] LANGACKER 92B fit to a wide range of electroweak data including LEP results available early '91. m_t >89 GeV used.

[29] LANGACKER 92B give 95%CL limits on the Z-Z' mixing $-0.0086 < \theta < 0.0005$.

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

[31] ALLEN 93 limit is from total cross section for $\nu e \to \nu e$, where $\nu = \nu_e, \nu_\mu, \overline{\nu}_\mu$.

[32] RIZZO 93 analyses CDF limit on possible two-jet resonances. The limit is sensitive to the inclusion of the assumed K factor.

[33] ABE 91D give $\sigma(Z')\cdot B(e^+e^-) <$ 1.31 pb (95%CL) for $m_{Z'} >$ 200 GeV at E_{cm} = 1.8 TeV. Limits ranging from 2 to 30 pb are given for $m_{Z'}$ = 100–200 GeV.

[34] GEIREGAT 91 limit is from comparison of g^e_V from $\nu_\mu e$ scattering with $\Gamma(Z \to ee)$ from LEP. Zero mixing assumed.

[35] 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.

[36] 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.

[37] ALBAJAR 89 cross section limit at 630 GeV is $\sigma(Z')$ B(ee) < 4.2 pb (90% CL).

[38] See Fig. 5 of ANSARI 87D for the excluded region in the $m_{Z'}$–$[(g_{Z'q})^2$ B($Z' \to e^+e^-$)] plane. Note that the quantity $(g_{Z'q})^2$B($Z' \to e^+e^-$) is normalized to unity for the standard Z couplings.

[39] ARNISON 86B find no excess e^+e^- pairs among 13 pairs from Z. Set limit $\sigma\times$B(e^+e^-) <13 pb at CL = 90% at E_{cm} = 546 and 630 GeV.

Limits for Z_{LR}

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 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
>310	95	[40] ABE 92B	CDF	$p\overline{p}$
>389	95	[41,42] LANGACKER 92B	RVUE	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>130	95	[43] ADRIANI 93D	L3	Z parameters
(> 1500)	90	[44] ALTARELLI 93B	RVUE	Z parameters
none 490–560	95	[45] RIZZO 93	RVUE	$p\overline{p}$; $Z_{LR} \to q\overline{q}$
>230	95	[46] ABE 92B	CDF	$p\overline{p}$
(> 900)	90	[47] DELAGUILA 92	RVUE	
(> 1400)		[48] LAYSSAC 92B	RVUE	Z parameters
(> 564)	90	[49] POLAK 92	RVUE	μ decay
>474	90	[50] POLAK 92B	RVUE	Electroweak
(> 1340)		[51] RENTON 92	RVUE	
(> 800)	90	[52] ALTARELLI 91B	RVUE	Z parameters
(> 795)	90	[53] DELAGUILA 91	RVUE	
>382	90	[54] POLAK 91	RVUE	Electroweak
[> 2000]		WALKER 91	COSM	Nucleosynthesis; light ν_R
[> 500]		[55] GRIFOLS 90	ASTR	SN 1987A; light ν_R
(> 460)	90	[56] HE 90B	RVUE	
[> 2400–6800]		[57] BARBIERI 89B	ASTR	SN 1987A; light ν_R
>189		[58] DELAGUILA 89	RVUE	$p\overline{p}$
[> 10000]		RAFFELT 88	ASTR	SN 1987A; light ν_R
>325	90	[59] AMALDI 87	RVUE	
>278	90	[60] DURKIN 86	RVUE	
>150	95	[61] ADEVA 85B	MRKJ	$e^+e^- \to \mu^+\mu^-$

[40] These limits assume that Z' decays to known fermions only.

[41] LANGACKER 92B fit to a wide range of electroweak data including LEP results available early '91. m_t >89 GeV used.

[42] LANGACKER 92B give 95%CL limits on the Z-Z' mixing $-0.0025 < \theta < 0.0083$.

[43] ADRIANI 93D give limits on the Z-Z' mixing $-0.002 < \theta < 0.015$ assuming the ABE 92B mass limit.

[44] ALTARELLI 93B limit is from LEP data available in summer '93 and is for m_t = 110 GeV. m_H = 100 GeV and α_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 Table 4.

[45] RIZZO 93 analyses CDF limit on possible two-jet resonances. The limit is sensitive to the inclusion of the assumed K factor.

[46] These limits assume that Z' decays to all E_6 fermions and their superpartners.

[47] See Fig. 7b 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.

[48] LAYSSAC 92B limit is from LEP data available spring '92. Specific Higgs sector is assumed. See also LAYSSAC 92.

[49] POLAK 92 limit is from m_{W_R} >477 GeV, which is derived from muon decay parameters assuming light ν_R. Specific Higgs sector is assumed.