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

>100	95	[111] ADRIANI	93D	L3	Z parameters
(>500)	90	[112] ALTARELLI	93B	RVUE	Z parameters
>230	95	[113] ABE	92B	CDF	$p\overline{p}$
(>450)	90	[114] DELAGUILA	92	RVUE	
(>315)		[115] LAYSSAC	92B	RVUE	Z parameters
>118	95	[116] LEIKE	92	RVUE	Z parameters
(>470)		[117] RENTON	92	RVUE	
(> 300)	90	[118] ALTARELLI	91B	RVUE	Z parameters
>120	90	[119] GONZALEZ-G..91		RVUE	
>125	90	[120,121] ABE	90F	VNS	e^+e^-
>115	90	[121,122] ABE	90F	RVUE	e^+e^-, $\nu_\mu e$
>340		[123] BARGER	90B	RVUE	$p\overline{p}$
[> 820]		[124] GONZALEZ-G..90D		COSM	Nucleosynthesis; light ν_R
[> 3300]		[125] GRIFOLS	90	ASTR	SN 1987A; light ν_R
>100	90	[126] HAGIWARA	90	RVUE	e^+e^-
[> 1040]		[124] LOPEZ	90	COSM	Nucleosynthesis; light ν_R
>173		[127] DELAGUILA	89	RVUE	$p\overline{p}$
>129	90	[128] COSTA	88	RVUE	
>156	90	[129] ELLIS	88	RVUE	
>167	90	[130] ELLIS	88	RVUE	$p\overline{p}$
>111	90	[128] AMALDI	87	RVUE	
>143	90	[131] BARGER	86B	RVUE	$p\overline{p}$
>130	90	[132] DURKIN	86	RVUE	
[> 760]		[124] ELLIS	86	COSM	Nucleosynthesis; light ν_R
[> 500]		[124] STEIGMAN	86	COSM	Nucleosynthesis; light ν_R

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

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

[110] LANGACKER 92B give 95%CL limits on the Z-Z' mixing $-0.038 < \theta < 0.002$.

[111] ADRIANI 93D give limits on the Z-Z' mixing $-0.029 < \theta < 0.010$ assuming the ABE 92B mass limit.

[112] 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 90%CL limit on the Z-Z' mixing angle is in Fig. 2.

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

[114] See Fig. 7d in DELAGUILA 92 for the allowed region in $m_{Z'}$-mixing plane from electroweak fit including '90 LEP data.

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

[116] LEIKE 92 is based on '90 LEP data published in LEP 92.

[117] RENTON 92 limits use LEP data taken up to '90 as well as m_W, νN, and atomic parity violation data. Specific Higgs structure is assumed.

[118] 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.

[119] GONZALEZ-GARCIA 91 limit is based on low-energy neutral current data, LEP 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. 8.

[120] ABE 90F use data for R, $R_{\ell\ell}$, and $A_{\ell\ell}$.

[121] ABE 90F fix $m_W = 80.49 \pm 0.43 \pm 0.24$ GeV and $m_Z = 91.13 \pm 0.03$ GeV.

[122] 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.

[123] 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.

[124] These authors claim that the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) constrains Z' masses if ν_R is light ($\lesssim$ 1 MeV).

[125] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. See also GRIFOLS 90D, RIZZO 91.

[126] 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.

[127] 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.

[128] A wide range of neutral current data as of 1986 are used in the fit.

[129] Z_η mass limits obtained by combining constraints from non-observation of an excess of $\ell^+\ell^-$ pairs at the CERN $p\overline{p}$ collider and the global analysis of neutral current data by COSTA 88. Least favorable spectrum of three (E_6 27) generations of particles and their superpartners are assumed.

[130] 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.

[131] BARGER 86B limit is based on UA1/UA2 limit on $p\overline{p} \rightarrow Z'$, $Z' \rightarrow e^+e^-$ (Lepton Photon Symp., Kyoto, '85). Extra decay channels for Z' are assumed not be open.

[132] A wide range of neutral current data as of 1985 are used in the fit.

Limits for other Z'

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[133] DELAGUILA	92	RVUE	
>360		[134] ALTARELLI	91	RVUE	Z_β with $\tan\beta = \sqrt{3/5}$; Cs
>190		[135] MAHANTHAP..91		RVUE	Z_β with $\tan\beta = \sqrt{3/5}$; Cs
		[136] GRIFOLS	90C	RVUE	
		[137] DELAGUILA	89	RVUE	$p\overline{p}$
>180	90	[138,139] COSTA	88	RVUE	Z_β with $\tan\beta = \sqrt{15}$
>158	90	[140] ELLIS	88	RVUE	Z_β ($\tan\beta = \sqrt{15}$), $p\overline{p}$

[133] Fig. 7c and 7e in DELAGUILA 92 give limits for $\tan\beta = -1/\sqrt{15}$ and $\sqrt{15}$ from electroweak fit including '90 LEP data.

[134] ALTARELLI 91 limit is from atomic parity violation in Cs together with LEP, CDF data. Z-Z' mixing is assumed to be zero to set the limit.

[135] MAHANTHAPPA 91 limit is from atomic parity violation in Cs with m_W, m_Z. See Table III of MAHANTHAPPA 91 (corrected in erratum) for limits on various Z' models.

[136] GRIFOLS 90C obtains a limit for Z' mass as a function of mixing angle β (his $\theta = \beta - \pi/2$), which is derived from a LAMPF experiment on $\sigma(\nu_e e)$ (ALLEN 90). The result is shown in Fig. 1.

[137] See Table I of DELAGUILA 89 for limits on various Z' models.

[138] $g_\beta = e/\cos\theta_W$ and $\rho = 1$ assumed.

[139] A wide range of neutral current data as of 1986 are used in the fit.

[140] 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.

MASS LIMITS for Leptoquarks from Pair Production

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

VALUE (GeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
>120	95		[141] ABACHI	94B	D0	First generation
> 80	95		[142] ABE	93I	CDF	First generation
> 45.5	95		[143,144] ABREU	93J	DLPH	First + second generation
> 44.4	95		[145] ADRIANI	93M	L3	First generation
> 44.5	95		[145] ADRIANI	93M	L3	Second generation
> 44.6	95		[146] ADRIANI	93M	L3	Third generation
> 44	95		[145] DECAMP	92	ALEP	First or second generation
> 45	95		[145] DECAMP	92	ALEP	Third generation
> 44.2	95		[145] ALEXANDER	91	OPAL	First or second generation
> 41.4	95		[145] ALEXANDER	91	OPAL	Third generation
• • • We do not use the following data for averages, fits, limits, etc. • • •						
> 42.1	95		[147] ABREU	92F	DLPH	Second generation
> 74	95		[148] ALITTI	92E	UA2	First generation
> 43.2	95		[145] ADEVA	91B	L3	First generation
> 43.4	95		[145] ADEVA	91B	L3	Second generation
none 8.9–22.6	95		[149] KIM	90	AMY	First generation
none 10.2–23.2	95		[149] KIM	90	AMY	Second generation
none 5–20.8	95		[150] BARTEL	87B	JADE	
none 7–20.5	95	2	[151] BEHREND	86B	CELL	

[141] ABACHI 94B search for $eejj$ and $e\nu jj$ events in $p\overline{p}$ collisions at E_{cm}=1.8 TeV. The limit is for scalar leptoquarks decaying with B(eq)=B(νq)=0.5 and improves to >133 GeV for B(eq)=1. This limit does not depend on the electroweak quantum numbers of the leptoquark.

[142] ABE 93I search for $\ell\ell jj$ events in $p\overline{p}$ collisions at E_{cm}=1.8 TeV. The limit is for B(eq) = B(νq) = 0.5 and improves to >113 GeV for B(eq) = 1. This limit does not depend on electroweak quantum numbers of the leptoquark.

[143] Limit is for charge $-1/3$ isospin-0 leptoquark with B(ℓq) = 2/3.

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

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

[146] ADRIANI 93M limit for charge $-1/3$, isospin-0 leptoquark decaying to τb.

[147] ABREU 92F limit is for charge $-1/3$ isosin-0 leptoquark with B(μq)=2/3. If first and second generation leptoquarks are degenerate, the limit is 43.0 GeV, and for a charge 2/3 second generation leptoquark 43.4 GeV. Cross-section limit for pair production of states decaying to ℓq is given in the paper.

[148] ALITTI 92E search for $\ell\ell jj$ and $\ell\nu jj$ events in $p\overline{p}$ collisions at E_{cm}=630 GeV. The limit is for B(eq) = 1 and is reduced to 67 GeV for B(eq) = B(νq) = 0.5. This limit does not depend on electroweak quantum numbers of the leptoquark.

[149] 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 de^+ and $u\overline{\nu}$ ($s\mu^+$ and $c\overline{\nu}$). See paper for limits for specific branching ratios.

[150] 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 B(X $\rightarrow c\overline{\nu}_\mu$) + B(X $\rightarrow s\mu^+$) = 1.

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

MASS LIMITS for Leptoquarks from Single Production

These limits depend on the q-ℓ-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.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 73	95	[152] ABREU	93J	DLPH	Second generation
>181	95	[153] ABT	93	H1	First generation
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 65	95	[152] ABREU	93J	DLPH	First generation
>168	95	[154] DERRICK	93	ZEUS	First generation

[152] Limit from single production in Z decay. The limit is for a leptoquark coupling of electromagnetic strength and assumes B(ℓq) = 2/3. The limit is 77 GeV if first and second leptoquarks are degenerate.

[153] ABT 93 search for single leptoquark production in ep collisions with the decays eq and νq. The limit is for a leptoquark coupling of electromagnetic strength and assumes B(eq) = B(νq) = 1/2. The limit for B(eq) = 1 is 178 GeV. For limits on states with different quantum numbers, see their Fig. 2.