New Heavy Bosons (W', Z', leptoquarks, etc.), Searches for

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. The latest unpublished results are described in "W' Searches" and "Z' Searches" reviews. For recent searches on scalar bosons which could be identified as Higgs bosons, see the listings in the Higgs boson section.

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A REVIEW GOES HERE – Check our WWW List of Reviews

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

Couplings of W' to quarks and leptons are taken to be identical with those of W. The following limits are obtained from $p\overline{p}$ or $pp \to W' X$ with W' decaying to the mode indicated in the comments. New decay channels (*e.g.*, $W' \to WZ$) are assumed to be suppressed. The most recent preliminary results can be found in the "W'-boson searches" review above.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>2220	95	[1] AABOUD	17B	ATLS	$W' \to hW$
>2600	95	[2] AABOUD	16AE	ATLS	$W' \to WZ$
>4070	95	[3] AABOUD	16V	ATLS	$W' \to e\nu, \mu\nu$
>1810	95	[4] AAD	16R	ATLS	$W' \to WZ$
>2600	95	[5] AAD	16S	ATLS	$W' \to q\overline{q}$
>2150	95	[6] KHACHATRY...	16AO	CMS	$W' \to tb$
none 1000–1600	95	[7] KHACHATRY...	16AP	CMS	$W' \to hW$
none 800–1500	95	[8] KHACHATRY...	16BD	CMS	$W' \to hW \to b\overline{b}\ell\nu$
none 1500–2600	95	[9] KHACHATRY...	16K	CMS	$W' \to q\overline{q}$
none 500–1600	95	[10] KHACHATRY...	16L	CMS	$W' \to q\overline{q}$
none 300–2700	95	[11] KHACHATRY...	16O	CMS	$W' \to \tau\nu$
none 400–1590	95	[12] AAD	15AU	ATLS	$W' \to WZ$
none 1500–1760	95	[13] AAD	15AV	ATLS	$W' \to tb$
none 300–1490	95	[14] AAD	15AZ	ATLS	$W' \to WZ$
none 1300–1500	95	[15] AAD	15CP	ATLS	$W' \to WZ$
none 500–1920	95	[16] AAD	15R	ATLS	$W' \to tb$
none 800–2450	95	[17] AAD	15V	ATLS	$W' \to q\overline{q}$
>1470	95	[18] KHACHATRY...	15C	CMS	$W' \to WZ$
>3710	95	[19] KHACHATRY...	15T	CMS	$W' \to e\nu, \mu\nu$
none 1000–3010	95	[20] KHACHATRY...	14O	CMS	$W' \to N\ell \to \ell\ell jj$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[21] AAD	15BB	ATLS	$W' \to Wh$
none 300–880	95	[22] AALTONEN	15C	CDF	$W' \to tb$
none 1200–1900 and 2000–2200	95	[23] KHACHATRY...	15V	CMS	$W' \to q\overline{q}$
>3240	95	AAD	14AI	ATLS	$W' \to e\nu, \mu\nu$
		[24] AAD	14AT	ATLS	$W' \to W\gamma$
none 200–1520	95	[25] AAD	14S	ATLS	$W' \to WZ$
none 1000–1700	95	[26] KHACHATRY...	14	CMS	$W' \to WZ$
		[27] KHACHATRY...	14A	CMS	$W' \to WZ$
none 500–950	95	[28] AAD	13AO	ATLS	$W' \to WZ$
none 1100–1680	95	AAD	13D	ATLS	$W' \to q\overline{q}$
none 1000–1920	95	CHATRCHYAN	13A	CMS	$W' \to q\overline{q}$
		[29] CHATRCHYAN	13AJ	CMS	$W' \to WZ$
>2900	95	[30] CHATRCHYAN	13AQ	CMS	$W' \to e\nu, \mu\nu$
none 800–1510	95	[31] CHATRCHYAN	13E	CMS	$W' \to tb$
none 700–940	95	[32] CHATRCHYAN	13U	CMS	$W' \to WZ$
none 700–1130	95	[33] AAD	12AV	ATLS	$W' \to tb$
none 200–760	95	[34] AAD	12BB	ATLS	$W' \to WZ$
		[35] AAD	12CK	ATLS	$W' \to \overline{t}q$
>2550	95	[36] AAD	12CR	ATLS	$W' \to e\nu, \mu\nu$

		[37]	AAD	12M	ATLS	$W' \to N\ell \to \ell\ell jj$
		[38]	AALTONEN	12N	CDF	$W' \to \overline{t}q$
none 200–1143	95	[34]	CHATRCHYAN	12AF	CMS	$W' \to WZ$
		[39]	CHATRCHYAN	12AR	CMS	$W' \to \overline{t}q$
		[40]	CHATRCHYAN	12BG	CMS	$W' \to N\ell \to \ell\ell jj$
>1120	95		AALTONEN	11C	CDF	$W' \to e\nu$
none 180–690	95	[41]	ABAZOV	11H	D0	$W' \to WZ$
none 600–863	95	[42]	ABAZOV	11L	D0	$W' \to tb$
none 285–516	95	[43]	AALTONEN	10N	CDF	$W' \to WZ$
none 280–840	95	[44]	AALTONEN	09AC	CDF	$W' \to q\overline{q}$
>1000	95		ABAZOV	08C	D0	$W' \to e\nu$
none 300–800	95		ABAZOV	04C	D0	$W' \to q\overline{q}$
none 225–536	95	[45]	ACOSTA	03B	CDF	$W' \to tb$
none 200–480	95	[46]	AFFOLDER	02C	CDF	$W' \to WZ$
> 786	95	[47]	AFFOLDER	01I	CDF	$W' \to e\nu$, $\mu\nu$
none 300–420	95	[48]	ABE	97G	CDF	$W' \to q\overline{q}$
> 720	95	[49]	ABACHI	96C	D0	$W' \to e\nu$
> 610	95	[50]	ABACHI	95E	D0	$W' \to e\nu$, $\tau\nu$
none 260–600	95	[51]	RIZZO	93	RVUE	$W' \to q\overline{q}$

[1] AABOUD 17B search for resonances decaying to hW ($h \to b\overline{b}$, $c\overline{c}$; $W \to \ell\nu$) in pp collisions at $\sqrt{s} = 13$ TeV. The quoted limit is for heavy-vector-triplet W' with $g_V = 3$. The limit becomes $M_{W'} > 1750$ GeV for $g_V = 1$. If we assume $M_{W'} = M_{Z'}$, the limit increases $M_{W'} > 2310$ GeV and $M_{W'} > 1730$ GeV for $g_V = 3$ and $g_V = 1$, respectively. See their Fig.3 for limits on $\sigma \cdot B$.

[2] AABOUD 16AE search for resonances decaying to VV ($V = W$ or Z) in pp collisions at $\sqrt{s} = 13$ TeV. Results from $\nu\nu qq$, $\nu\ell qq$, $\ell\ell qq$ and $qqqq$ final states are combined. The quoted limit is for a heavy-vector-triplet W' with $g_V = 3$ and $M_{W'} = M_{Z'}$.

[3] AABOUD 16V limit is for W' with SM-like coupling using pp collisions at $\sqrt{s} = 13$ TeV. The bosonic decays of W' and the interference with SM W process are neglected.

[4] AAD 16R search for $W' \to WZ$ in pp collisions at $\sqrt{s} = 8$ TeV. $\ell\nu\ell'\ell'$, $\ell\ell q\overline{q}$, $\ell\nu q\overline{q}$, and all hadronic channels are combined. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[5] AAD 16S search for a new resonance decaying to dijets in pp collisions at $\sqrt{s} = 13$ TeV. The limit quoted above is for a W' having SM-like couplings to quarks.

[6] KHACHATRYAN 16AO limit is for a SM-like right-handed W' using pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit combines $t \to qqb$ and $t \to \ell\nu b$ events.

[7] KHACHATRYAN 16AP search for a resonance decaying to hW in pp collisions at $\sqrt{s} = 8$ TeV. Both h and W are assumed to decay to fat jets. The quoted limit is for heavy-vector-triplet W' with $g_V = 3$.

[8] KHACHATRYAN 16BD search for resonance decaying to hW in pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit is for heavy-vector-triplet (HVT) W' with $g_V = 3$. The HVT model $m_{W'} = m_{Z'} > 1.8$ TeV is also obtained by combining $W'/Z' \to Wh/Zh \to \ell\nu bb$, $qq\tau\tau$, $qq\overline{b}b$, and $qqqqqq$ channels.

[9] KHACHATRYAN 16K search for resonances decaying to dijets in pp collisions at $\sqrt{s} = 13$ TeV.

[10] KHACHATRYAN 16L search for resonances decaying to dijets in pp collisions at $\sqrt{s} = 8$ TeV with the data scouting technique, increasing the sensitivity to the low mass resonances.

[11] KHACHATRYAN 16O limit is for W' having universal couplings. Interferences with the SM amplitudes are assumed to be absent.

[12] AAD 15AU search for W' decaying into the WZ final state with $W \rightarrow q\overline{q}'$, $Z \rightarrow \ell^+\ell^-$ using pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[13] AAD 15AV limit is for a SM like right-handed W' using pp collisions at $\sqrt{s} = 8$ TeV. $W' \rightarrow \ell\nu$ decay is assumed to be forbidden.

[14] AAD 15AZ search for W' decaying into the WZ final state with $W \rightarrow \ell\nu$, $Z \rightarrow q\overline{q}$ using pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[15] AAD 15CP search for W' decaying into the WZ final state with $W \rightarrow q\overline{q}$, $Z \rightarrow q\overline{q}$ using pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[16] AAD 15R limit is for a SM like right-handed W' using pp collisions at $\sqrt{s} = 8$ TeV. $W' \rightarrow \ell\nu$ decay is assumed to be forbidden.

[17] AAD 15V search for new resonance decaying to dijets in pp collisions at $\sqrt{s} = 8$ TeV.

[18] KHACHATRYAN 15C search for W' decaying via WZ to fully leptonic final states using pp collisions at $\sqrt{s}$=8 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = M_W M_Z/M^2_{W'}$.

[19] KHACHATRYAN 15T limit is for W' with SM-like coupling which interferes the SM W boson constructively using pp collisions at $\sqrt{s} = 8$ TeV. For W' without interference, the limit becomes $>$ 3280 GeV.

[20] KHACHATRYAN 14O search for right-handed W_R in pp collisions at $\sqrt{s} = 8$ TeV. W_R is assumed to decay into ℓ and hypothetical heavy neutrino N, with N decaying into ℓjj. The quoted limit is for $M_{\nu_{eR}} = M_{\nu_{\mu R}} = M_{W_R}/2$. See their Fig. 3 and Fig. 5 for excluded regions in the $M_{W_R} - M_\nu$ plane.

[21] AAD 15BB search for W' decaying into Wh with $W \rightarrow \ell\nu$, $h \rightarrow b\overline{b}$. See their Fig. 4 for the exclusion limits in the heavy vector triplet benchmark model parameter space.

[22] AALTONEN 15C limit is for a SM-like right-handed W' assuming $W' \rightarrow \ell\nu$ decays are forbidden, using $p\overline{p}$ collisions at $\sqrt{s}$=1.96 TeV. See their Fig. 3 for limit on $g_{W'}/g_W$.

[23] KHACHATRYAN 15V search new resonance decaying to dijets in pp collisions at $\sqrt{s} =$ 8 TeV.

[24] AAD 14AT search for a narrow charged vector boson decaying to $W\gamma$. See their Fig. 3a for the exclusion limit in $m_{W'} - \sigma B$ plane.

[25] AAD 14S search for W' decaying into the WZ final state with $W \rightarrow \ell\nu$, $Z \rightarrow \ell\ell$ using pp collisions at $\sqrt{s}$=8 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[26] KHACHATRYAN 14 search for W' decaying into WZ final state with $W \rightarrow q\overline{q}$, $Z \rightarrow q\overline{q}$ using pp collisions at $\sqrt{s}$=8 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[27] KHACHATRYAN 14A search for W' decaying into the WZ final state with $W \rightarrow \ell\nu$, $Z \rightarrow q\overline{q}$, or $W \rightarrow q\overline{q}$, $Z \rightarrow \ell\ell$. pp collisions data at $\sqrt{s}$=8 TeV are used for the search. See their Fig. 13 for the exclusion limit on the number of events in the mass–width plane.

[28] AAD 13AO search for W' decaying into the WZ final state with $W \rightarrow \ell\nu$, $Z \rightarrow 2j$ using pp collisions at $\sqrt{s}$=7 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[29] CHATRCHYAN 13AJ search for resonances decaying to WZ pair, using the hadronic decay modes of W and Z, in pp collisions at $\sqrt{s}$=7 TeV. See their Fig. 7 for the limit on the cross section.

[30] CHATRCHYAN 13AQ limit is for W' with SM-like coupling which interferes with the SM W boson using pp collisions at $\sqrt{s}$=7 TeV.

[31] CHATRCHYAN 13E limit is for W' with SM-like coupling which intereferes with the SM W boson using pp collisions at $\sqrt{s}$=7 TeV. For W' with right-handed coupling, the bound becomes >1850 GeV (>1910 GeV) if W' decays to both leptons and quarks (only to quarks). If both left- and right-handed couplings are present, the limit becomes >1640 GeV.

[32] CHATRCHYAN 13U search for W' decaying to the WZ final state, with W decaying into jets, in pp collisions at $\sqrt{s}$=7 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[33] The AAD 12AV quoted limit is for a SM-like right-handed W' using pp collisions at $\sqrt{s}$=7 TeV. $W' \rightarrow \ell\nu$ decay is assumed to be forbidden.

[34] AAD 12BB use pp collisions data at $\sqrt{s}$=7 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$.

[35] AAD 12CK search for $pp \rightarrow tW'$, $W' \rightarrow \overline{t}q$ events in pp collisions. See their Fig. 5 for the limit on $\sigma \cdot$ B.

[36] AAD 12CR use pp collisions at $\sqrt{s}$=7 TeV.

[37] AAD 12M search for right-handed W_R in pp collisions at $\sqrt{s}$ = 7 TeV. W_R is assumed to decay into ℓ and hypothetical heavy neutrino N, with N decaying into ℓjj. See their Fig. 4 for the limit in the $m_N - m_{W'}$ plane.

[38] AALTONEN 12N search for $p\overline{p} \rightarrow tW'$, $W' \rightarrow \overline{t}d$ events in $p\overline{p}$ collisions. See their Fig. 3 for the limit on $\sigma \cdot$ B.

[39] CHATRCHYAN 12AR search for $pp \rightarrow tW'$, $W' \rightarrow \overline{t}d$ events in pp collisions. See their Fig. 2 for the limit on $\sigma \cdot$ B.

[40] CHATRCHYAN 12BG search for right-handed W_R in pp collisions $\sqrt{s}$ = 7 TeV. W_R is assumed to decay into ℓ and hypothetical heavy neutrino N, with N decaying into ℓjj. See their Fig. 3 for the limit in the $m_N - m_{W'}$ plane.

[41] ABAZOV 11H use data from $p\overline{p}$ collisions at $\sqrt{s}$=1.96 TeV. The quoted limit is obtained assuming $W'WZ$ coupling strength is the same as the ordinary WWZ coupling strength in the Standard Model.

[42] ABAZOV 11L limit is for W' with SM-like coupling which interferes with the SM W boson, using $p\overline{p}$ collisions at $\sqrt{s}$=1.96 TeV. For W' with right-handed coupling, the bound becomes >885 GeV (>890 GeV) if W' decays to both leptons and quarks (only to quarks). If both left- and right-handed couplings present, the limit becomes >916 GeV.

[43] AALTONEN 10N use $p\overline{p}$ collision data at $\sqrt{s}$=1.96 TeV. The quoted limit assumes $g_{W'WZ}/g_{WWZ} = (M_W/M_{W'})^2$. See their Fig. 4 for limits in mass-coupling plane.

[44] AALTONEN 09AC search for new particle decaying to dijets using $p\overline{p}$ collisions at $\sqrt{s}$=1.96 TeV.

[45] The ACOSTA 03B quoted limit is for $M_{W'} \gg M_{\nu_R}$, using $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV. For $M_{W'} < M_{\nu_R}$, $M_{W'}$ between 225 and 566 GeV is excluded.

[46] The quoted limit is obtained assuming $W'WZ$ coupling strength is the same as the ordinary WWZ coupling strength in the Standard Model, using $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV. See their Fig. 2 for the limits on the production cross sections as a function of the W' width.

[47] AFFOLDER 01I combine a new bound on $W' \rightarrow e\nu$ of 754 GeV, using $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV, with the bound of ABE 00 on $W' \rightarrow \mu\nu$ to obtain quoted bound.

[48] ABE 97G search for new particle decaying to dijets using $p\overline{p}$ collisions at $\sqrt{s}$=1.8 TeV.

[49] For bounds on W_R with nonzero right-handed mass, see Fig. 5 from ABACHI 96C.

[50] ABACHI 95E assume that the decay $W' \rightarrow WZ$ is suppressed and that the neutrino from W' decay is stable and has a mass significantly less $m_{W'}$.

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

W_R (Right-Handed W Boson) MASS LIMITS

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 ζ are found in the next section. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 592	90	[1] BUENO	11	TWST	μ decay
> 715	90	[2] CZAKON	99	RVUE	Electroweak
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 235	90	[3] PRIEELS	14	PIE3	μ decay
> 245	90	[4] WAUTERS	10	CNTR	^{60}Co β decay
>2500		[5] ZHANG	08	THEO	$m_{K^0_L} - m_{K^0_S}$
> 180	90	[6] MELCONIAN	07	CNTR	^{37}K β^+ decay
> 290.7	90	[7] SCHUMANN	07	CNTR	Polarized neutron decay
[> 3300]	95	[8] CYBURT	05	COSM	Nucleosynthesis; light ν_R
> 310	90	[9] THOMAS	01	CNTR	β^+ decay
> 137	95	[10] ACKERSTAFF	99D	OPAL	τ decay
>1400	68	[11] BARENBOIM	98	RVUE	Electroweak, Z-Z' mixing
> 549	68	[12] BARENBOIM	97	RVUE	μ decay
> 220	95	[13] STAHL	97	RVUE	τ decay
> 220	90	[14] ALLET	96	CNTR	β^+ decay
> 281	90	[15] KUZNETSOV	95	CNTR	Polarized neutron decay
> 282	90	[16] KUZNETSOV	94B	CNTR	Polarized neutron decay
> 439	90	[17] BHATTACH...	93	RVUE	Z-Z' mixing
> 250	90	[18] SEVERIJNS	93	CNTR	β^+ decay
		[19] IMAZATO	92	CNTR	K^+ decay
> 475	90	[20] POLAK	92B	RVUE	μ decay
> 240	90	[21] AQUINO	91	RVUE	Neutron decay
> 496	90	[21] AQUINO	91	RVUE	Neutron and muon decay
> 700		[22] COLANGELO	91	THEO	$m_{K^0_L} - m_{K^0_S}$
> 477	90	[23] POLAK	91	RVUE	μ decay
[none 540–23000]		[24] BARBIERI	89B	ASTR	SN 1987A; light ν_R
> 300	90	[25] LANGACKER	89B	RVUE	General
> 160	90	[26] BALKE	88	CNTR	$\mu \to e \nu \overline{\nu}$
> 406	90	[27] JODIDIO	86	ELEC	Any ζ
> 482	90	[27] JODIDIO	86	ELEC	$\zeta = 0$
> 800		MOHAPATRA	86	RVUE	$SU(2)_L \times SU(2)_R \times U(1)$
> 400	95	[28] STOKER	85	ELEC	Any ζ
> 475	95	[28] STOKER	85	ELEC	$\zeta < 0.041$
		[29] BERGSMA	83	CHRM	$\nu_\mu e \to \mu \nu_e$
> 380	90	[30] CARR	83	ELEC	μ^+ decay
>1600		[31] BEALL	82	THEO	$m_{K^0_L} - m_{K^0_S}$

[1] The quoted limit is for manifest left-right symmetric model.

[2] CZAKON 99 perform a simultaneous fit to charged and neutral sectors.

[3] PRIEELS 14 limit is from $\mu^+ \rightarrow e^+ \nu \overline{\nu}$ decay parameter ξ'', which is determined by the positron polarization measurement.

[4] WAUTERS 10 limit is from a measurement of the asymmetry parameter of polarized ^{60}Co β decays. The listed limit assumes no mixing.

[5] ZHANG 08 limit uses a lattice QCD calculation of the relevant hadronic matrix elements, while BEALL 82 limit used the vacuum saturation approximation.

[6] MELCONIAN 07 measure the neutrino angular asymmetry in β^+-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.

[7] SCHUMANN 07 limit is from measurements of the asymmetry $\langle \vec{p}_\nu \cdot \sigma_n \rangle$ in the β decay of polarized neutrons. Zero mixing is assumed.

[8] CYBURT 05 limit follows by requiring that three light ν_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)$^{3/4}$.

[9] THOMAS 01 limit is from measurement of β^+ polarization in decay of polarized ^{12}N. The listed limit assumes no mixing.

[10] ACKERSTAFF 99D limit is from τ decay parameters. Limit increase to 145 GeV for zero mixing.

[11] 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.

[12] The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L-K_S mass difference.

[13] STAHL 97 limit is from fit to τ-decay parameters.

[14] ALLET 96 measured polarization-asymmetry correlation in ^{12}N β^+ decay. The listed limit assumes zero L-R mixing.

[15] KUZNETSOV 95 limit is from measurements of the asymmetry $\langle \vec{p}_\nu \cdot \sigma_n \rangle$ in the β decay of polarized neutrons. Zero mixing assumed. See also KUZNETSOV 94B.

[16] KUZNETSOV 94B limit is from measurements of the asymmetry $\langle \vec{p}_\nu \cdot \sigma_n \rangle$ in the β decay of polarized neutrons. Zero mixing assumed.

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

[18] SEVERIJNS 93 measured polarization-asymmetry correlation in ^{107}In β^+ decay. The listed limit assumes zero L-R mixing. Value quoted here is from SEVERIJNS 94 erratum.

[19] IMAZATO 92 measure positron asymmetry in $K^+ \rightarrow \mu^+ \nu_\mu$ 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 $|V^R_{us}|^2 = 1 - |V^R_{ud}|^2$.

[20] POLAK 92B limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming ζ=0. Supersedes POLAK 91.

[21] 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.

[22] 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.

[23] POLAK 91 limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming ζ=0. Superseded by POLAK 92B.

[24] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.

[25] LANGACKER 89B limit is for any ν_R mass (either Dirac or Majorana) and for a general class of right-handed quark mixing matrices.

[26] 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.

[27] 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 μ^+.

[28] 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.

[29] BERGSMA 83 set limit m_{W_2}/m_{W_1} >1.9 at CL = 90%.

[30] CARR 83 is TRIUMF experiment with a highly polarized μ^+ 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.

[31] 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.

Limit on W_L-W_R Mixing Angle ζ

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.020 to 0.017	90	BUENO	11	TWST	$\mu \rightarrow e\nu\overline{\nu}$
< 0.022	90	MACDONALD	08	TWST	$\mu \rightarrow e\nu\overline{\nu}$
< 0.12	95	[1] ACKERSTAFF	99D	OPAL	τ decay
< 0.013	90	[2] CZAKON	99	RVUE	Electroweak
< 0.0333		[3] BARENBOIM	97	RVUE	μ decay
< 0.04	90	[4] MISHRA	92	CCFR	νN scattering
−0.0006 to 0.0028	90	[5] AQUINO	91	RVUE	
[none 0.00001–0.02]		[6] BARBIERI	89B	ASTR	SN 1987A
< 0.040	90	[7] JODIDIO	86	ELEC	μ decay
−0.056 to 0.040	90	[7] JODIDIO	86	ELEC	μ decay

[1] ACKERSTAFF 99D limit is from τ decay parameters.

[2] CZAKON 99 perform a simultaneous fit to charged and neutral sectors.

[3] The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L-K_S mass difference.

[4] MISHRA 92 limit is from the absence of extra large-x, large-y $\overline{\nu}_\mu N \rightarrow \overline{\nu}_\mu X$ events at Tevatron, assuming left-handed ν 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 ν_R mass.

[5] AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right asymmetry is assumed.

[6] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.

[7] First JODIDIO 86 result assumes $m_{W_R}=\infty$, second is for unconstrained m_{W_R}.

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

Limits for Z'_{SM}

Z'_{SM} is assumed to have couplings with quarks and leptons which are identical to those of Z, and decays only to known fermions. The most recent preliminary results can be found in the "Z'-boson searches" review above.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>3360	95	[1] AABOUD	16U	ATLS	pp; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
>2020	95	[2] AAD	15AM	ATLS	pp; $Z'_{SM} \to \tau^+\tau^-$
>2900	95	[3] KHACHATRY...	15AE	CMS	pp; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
none 1200–1700	95	[4] KHACHATRY...	15V	CMS	pp; $Z'_{SM} \to q\overline{q}$
>2900	95	[5] AAD	14V	ATLS	pp; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>1900	95	[6] AABOUD	16AA	ATLS	pp; $Z'_{SM} \to \tau^+\tau^-$
>1400	95	[7] AAD	13S	ATLS	pp; $Z'_{SM} \to \tau^+\tau^-$
>1470	95	[8] CHATRCHYAN	13A	CMS	pp; $Z'_{SM} \to q\overline{q}$
>2590	95	[9] CHATRCHYAN	13AF	CMS	pp; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
>2220	95	[10] AAD	12CC	ATLS	pp; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
>1400	95	[11] CHATRCHYAN	12O	CMS	pp; $Z'_{SM} \to \tau^+\tau^-$
>1071	95	[12] AALTONEN	11I	CDF	$p\overline{p}$; $Z'_{SM} \to \mu^+\mu^-$
>1023	95	[13] ABAZOV	11A	D0	$p\overline{p}$, $Z'_{SM} \to e^+e^-$
none 247–544	95	[14] AALTONEN	10N	CDF	$Z' \to WW$
none 320–740	95	[15] AALTONEN	09AC	CDF	$Z' \to q\overline{q}$
> 963	95	[13] AALTONEN	09T	CDF	$p\overline{p}$, $Z'_{SM} \to e^+e^-$
>1403	95	[16] ERLER	09	RVUE	Electroweak
>1305	95	[17] ABDALLAH	06C	DLPH	e^+e^-
> 399	95	[18] ACOSTA	05R	CDF	$\overline{p}p$: $Z'_{SM} \to \tau^+\tau^-$
none 400–640	95	ABAZOV	04C	D0	$p\overline{p}$: $Z'_{SM} \to q\overline{q}$
>1018	95	[19] ABBIENDI	04G	OPAL	e^+e^-
> 670	95	[20] ABAZOV	01B	D0	$p\overline{p}$, $Z'_{SM} \to e^+e^-$
>1500	95	[21] CHEUNG	01B	RVUE	Electroweak
> 710	95	[22] ABREU	00S	DLPH	e^+e^-
> 898	95	[23] BARATE	00I	ALEP	e^+e^-
> 809	95	[24] ERLER	99	RVUE	Electroweak
> 690	95	[25] ABE	97S	CDF	$p\overline{p}$; $Z'_{SM} \to e^+e^-$, $\mu^+\mu^-$
> 398	95	[26] VILAIN	94B	CHM2	$\nu_\mu e \to \nu_\mu e$ and $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$
> 237	90	[27] ALITTI	93	UA2	$p\overline{p}$; $Z'_{SM} \to q\overline{q}$
none 260–600	95	[28] RIZZO	93	RVUE	$p\overline{p}$; $Z'_{SM} \to q\overline{q}$
> 426	90	[29] ABE	90F	VNS	e^+e^-

[1] AABOUD 16U search for resonances decaying to $\ell^+\ell^-$ in pp collisions at $\sqrt{s} = 13$ TeV.

[2] AAD 15AM search for resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s} = 8$ TeV.

[3] KHACHATRYAN 15AE search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s} = 8$ TeV.

[4] KHACHATRYAN 15V search for resonances decaying to dijets in pp collisions at $\sqrt{s} = 8$ TeV.

[5] AAD 14V search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s}$ = 8 TeV.
[6] AABOUD 16AA search for resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s}$ = 13 TeV.
[7] AAD 13S search for resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s}$ = 7 TeV.
[8] CHATRCHYAN 13A use pp collisions at $\sqrt{s}$=7 TeV.
[9] CHATRCHYAN 13AF search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s}$ = 7 TeV and 8 TeV.
[10] AAD 12CC search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s}$ = 7 TeV.
[11] CHATRCHYAN 12O search for resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s}$ = 7 TeV.
[12] AALTONEN 11I search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.
[13] ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.
[14] The quoted limit assumes $g_{WWZ'}/g_{WWZ} = (M_W/M_{Z'})^2$. See their Fig. 4 for limits in mass-coupling plane.
[15] AALTONEN 09AC search for new particle decaying to dijets.
[16] ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0026 < \theta < 0.0006$.
[17] ABDALLAH 06C use data $\sqrt{s}$ = 130–207 GeV.
[18] ACOSTA 05R search for resonances decaying to tau lepton pairs in $\overline{p}p$ collisions at $\sqrt{s}$ = 1.96 TeV.
[19] ABBIENDI 04G give 95% CL limit on Z-Z' mixing $-0.00422 < \theta <0.00091$. $\sqrt{s}$ = 91 to 207 GeV.
[20] 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.
[21] CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
[22] ABREU 00S uses LEP data at $\sqrt{s}$=90 to 189 GeV.
[23] BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume θ=0. Bounds in the mass-mixing plane are shown in their Figure 18.
[24] ERLER 99 give 90%CL limit on the Z-Z' mixing $-0.0041 < \theta < 0.0003$. ρ_0=1 is assumed.
[25] ABE 97S find $\sigma(Z')\times$B(e^+e^-,$\mu^+\mu^-$)< 40 fb for $m_{Z'} > 600$ GeV at $\sqrt{s}$= 1.8 TeV.
[26] VILAIN 94B assume m_t = 150 GeV.
[27] 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.
[28] RIZZO 93 analyses CDF limit on possible two-jet resonances.
[29] 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.

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 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.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>1162	95	[1] DEL-AGUILA	10	RVUE	Electroweak
> 630	95	[2] 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. • • •

> 998	95	[3] ERLER	09	RVUE	Electroweak
> 600	95	SCHAEL	07A	ALEP	e^+e^-
> 455	95	[4] ABDALLAH	06C	DLPH	e^+e^-
> 518	95	[5] ABBIENDI	04G	OPAL	e^+e^-
> 860	95	[6] CHEUNG	01B	RVUE	Electroweak
> 380	95	[7] ABREU	00S	DLPH	e^+e^-
> 436	95	[8] BARATE	00I	ALEP	Repl. by SCHAEL 07A
> 550	95	[9] CHAY	00	RVUE	Electroweak
		[10] ERLER	00	RVUE	Cs
		[11] CASALBUONI	99	RVUE	Cs
(> 1205)	90	[12] CZAKON	99	RVUE	Electroweak
> 564	95	[13] ERLER	99	RVUE	Electroweak
(> 1673)	95	[14] ERLER	99	RVUE	Electroweak
(> 1700)	68	[15] BARENBOIM	98	RVUE	Electroweak
> 244	95	[16] CONRAD	98	RVUE	$\nu_\mu N$ scattering
> 253	95	[17] VILAIN	94B	CHM2	$\nu_\mu e \rightarrow \nu_\mu e$ and $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$
none 200–600	95	[18] RIZZO	93	RVUE	$p\overline{p}$; $Z_{LR} \rightarrow q\overline{q}$
[> 2000]		WALKER	91	COSM	Nucleosynthesis; light ν_R
none 200–500		[19] GRIFOLS	90	ASTR	SN 1987A; light ν_R
none 350–2400		[20] BARBIERI	89B	ASTR	SN 1987A; light ν_R

[1] DEL-AGUILA 10 give 95% CL limit on the Z-Z' mixing $-0.0012 < \theta < 0.0004$.

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

[3] ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0013 < \theta < 0.0006$.

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

[5] 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.

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

[7] 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.

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

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

[10] 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_χ.

[11] 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.

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

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

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

[15] 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.

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

[17] VILAIN 94B assume m_t = 150 GeV and θ=0. See Fig. 2 for limit contours in the mass-mixing plane.
[18] RIZZO 93 analyses CDF limit on possible two-jet resonances.
[19] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. A specific Higgs sector is assumed. See also GRIFOLS 90D, RIZZO 91.
[20] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV. Bounds depend on assumed supernova core temperature.

Limits for Z_χ

Z_χ is the extra neutral boson in SO(10) → SU(5) × 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
>3050	95	[1] AABOUD	16U	ATLS	pp; $Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
>2620	95	[2] AAD	14V	ATLS	pp, $Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>1970	95	[3] AAD	12CC	ATLS	pp, $Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
> 930	95	[4] AALTONEN	11I	CDF	$p\overline{p}$; $Z'_\chi \rightarrow \mu^+\mu^-$
> 903	95	[5] ABAZOV	11A	D0	$p\overline{p}$, $Z'_\chi \rightarrow e^+e^-$
>1022	95	[6] DEL-AGUILA	10	RVUE	Electroweak
> 862	95	[5] AALTONEN	09T	CDF	$p\overline{p}$, $Z'_\chi \rightarrow e^+e^-$
> 892	95	[7] AALTONEN	09V	CDF	Repl. by AALTONEN 11I
>1141	95	[8] ERLER	09	RVUE	Electroweak
> 822	95	[5] AALTONEN	07H	CDF	Repl. by AALTONEN 09T
> 680	95	SCHAEL	07A	ALEP	e^+e^-
> 545	95	[9] ABDALLAH	06C	DLPH	e^+e^-
> 740		[5] ABULENCIA	06L	CDF	Repl. by AALTONEN 07H
> 690	95	[10] ABULENCIA	05A	CDF	$p\overline{p}$; $Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
> 781	95	[11] ABBIENDI	04G	OPAL	e^+e^-
>2100		[12] BARGER	03B	COSM	Nucleosynthesis; light ν_R
> 680	95	[13] CHEUNG	01B	RVUE	Electroweak
> 440	95	[14] ABREU	00S	DLPH	e^+e^-
> 533	95	[15] BARATE	00I	ALEP	Repl. by SCHAEL 07A
> 554	95	[16] CHO	00	RVUE	Electroweak
		[17] ERLER	00	RVUE	Cs
		[18] ROSNER	00	RVUE	Cs
> 545	95	[19] ERLER	99	RVUE	Electroweak
(> 1368)	95	[20] ERLER	99	RVUE	Electroweak
> 215	95	[21] CONRAD	98	RVUE	$\nu_\mu N$ scattering
> 595	95	[22] ABE	97S	CDF	$p\overline{p}$; $Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
> 190	95	[23] ARIMA	97	VNS	Bhabha scattering
> 262	95	[24] VILAIN	94B	CHM2	$\nu_\mu e \rightarrow \nu_\mu e$; $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$
[>1470]		[25] FARAGGI	91	COSM	Nucleosynthesis; light ν_R
> 231	90	[26] ABE	90F	VNS	e^+e^-
[> 1140]		[27] GONZALEZ...	90D	COSM	Nucleosynthesis; light ν_R
[> 2100]		[28] GRIFOLS	90	ASTR	SN 1987A; light ν_R

[1] AABOUD 16U search for resonances decaying to $\ell^+ \ell^-$ in pp collisions at $\sqrt{s} = 13$ TeV.
[2] AAD 14V search for resonances decaying to $e^+ e^-$, $\mu^+ \mu^-$ in pp collisions at $\sqrt{s} = 8$ TeV.
[3] AAD 12CC search for resonances decaying to $e^+ e^-$, $\mu^+ \mu^-$ in pp collisions at $\sqrt{s} = 7$ TeV.
[4] AALTONEN 11I search for resonances decaying to $\mu^+ \mu^-$ in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
[5] ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to $e^+ e^-$ in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
[6] DEL-AGUILA 10 give 95% CL limit on the Z-Z' mixing $-0.0011 < \theta < 0.0007$.
[7] AALTONEN 09V search for resonances decaying to $\mu^+ \mu^-$ in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
[8] ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0016 < \theta < 0.0006$.
[9] ABDALLAH 06C give 95% CL limit $\left|\theta\right| < 0.0031$. See their Fig. 14 for limit contours in the mass-mixing plane.
[10] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
[11] 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.
[12] 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.
[13] CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
[14] ABREU 00S give 95% CL limit on Z-Z' mixing $\left|\theta\right| < 0.0017$. See their Fig. 6 for the limit contour in the mass-mixing plane. $\sqrt{s}$=90 to 189 GeV.
[15] BARATE 00I search for deviations in cross section and asymmetries in $e^+ e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume θ=0. Bounds in the mass-mixing plane are shown in their Figure 18.
[16] 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.
[17] 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_χ.
[18] 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_χ.
[19] ERLER 99 give 90% CL limit on the Z-Z' mixing $-0.0020 < \theta < 0.0015$.
[20] ERLER 99 assumes 2 Higgs doublets, transforming as 10 of SO(10), embedded in E_6.
[21] CONRAD 98 limit is from measurements at CCFR, assuming no Z-Z' mixing.
[22] ABE 97S find $\sigma(Z')\times$B($e^+ e^-$,$\mu^+ \mu^-$)< 40 fb for $m_{Z'} > 600$ GeV at $\sqrt{s}$= 1.8 TeV.
[23] Z-Z' mixing is assumed to be zero. $\sqrt{s}$= 57.77 GeV.
[24] VILAIN 94B assume m_t = 150 GeV and θ=0. See Fig. 2 for limit contours in the mass-mixing plane.
[25] 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.
[26] 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.
[27] Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that ν_R is light ($\lesssim$ 1 MeV).
[28] GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim$ 1 MeV. See also GRIFOLS 90D, RIZZO 91.

Limits for Z_ψ

Z_ψ 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.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>2740	95	[1] AABOUD	16U	ATLS	pp; $Z'_\psi \to e^+e^-, \mu^+\mu^-$
>2570	95	[2] KHACHATRY...	15AE	CMS	pp; $Z'_\psi \to e^+e^-, \mu^+\mu^-$
>2510	95	[3] AAD	14V	ATLS	pp, $Z'_\psi \to e^+e^-, \mu^+\mu^-$
>1100	95	[4] CHATRCHYAN	12O	CMS	pp, $Z'_\psi \to \tau^+\tau^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>2260	95	[5] CHATRCHYAN	13AF	CMS	pp, $Z'_\psi \to e^+e^-, \mu^+\mu^-$
>1790	95	[6] AAD	12CC	ATLS	pp, $Z'_\psi \to e^+e^-, \mu^+\mu^-$
>2000	95	[7] CHATRCHYAN	12M	CMS	Repl. by CHATRCHYAN 13AF
> 917	95	[8] AALTONEN	11I	CDF	$p\overline{p}$; $Z'_\psi \to \mu^+\mu^-$
> 891	95	[9] ABAZOV	11A	D0	$p\overline{p}$, $Z'_\psi \to e^+e^-$
> 476	95	[10] DEL-AGUILA	10	RVUE	Electroweak
> 851	95	[9] AALTONEN	09T	CDF	$p\overline{p}$, $Z'_\psi \to e^+e^-$
> 878	95	[11] AALTONEN	09V	CDF	Repl. by AALTONEN 11I
> 147	95	[12] ERLER	09	RVUE	Electroweak
> 822	95	[9] AALTONEN	07H	CDF	Repl. by AALTONEN 09T
> 410	95	SCHAEL	07A	ALEP	e^+e^-
> 475	95	[13] ABDALLAH	06C	DLPH	e^+e^-
> 725		[9] ABULENCIA	06L	CDF	Repl. by AALTONEN 07H
> 675	95	[14] ABULENCIA	05A	CDF	Repl. by AALTONEN 11I and AALTONEN 09T
> 366	95	[15] ABBIENDI	04G	OPAL	e^+e^-
> 600		[16] BARGER	03B	COSM	Nucleosynthesis; light ν_R
> 350	95	[17] ABREU	00S	DLPH	e^+e^-
> 294	95	[18] BARATE	00I	ALEP	Repl. by SCHAEL 07A
> 137	95	[19] CHO	00	RVUE	Electroweak
> 146	95	[20] ERLER	99	RVUE	Electroweak
> 54	95	[21] CONRAD	98	RVUE	$\nu_\mu N$ scattering
> 590	95	[22] ABE	97S	CDF	$p\overline{p}$; $Z'_\psi \to e^+e^-, \mu^+\mu^-$
> 135	95	[23] VILAIN	94B	CHM2	$\nu_\mu e \to \nu_\mu e$; $\overline{\nu}_\mu e \to \overline{\nu}_\mu e$
> 105	90	[24] ABE	90F	VNS	e^+e^-
[> 160]		[25] GONZALEZ...	90D	COSM	Nucleosynthesis; light ν_R
[> 2000]		[26] GRIFOLS	90D	ASTR	SN 1987A; light ν_R

[1] AABOUD 16U search for resonances decaying to $\ell^+\ell^-$ in pp collisions at $\sqrt{s} = 13$ TeV.

[2] KHACHATRYAN 15AE search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s} = 8$ TeV.

[3] AAD 14V search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s} = 8$ TeV.

[4] CHATRCHYAN 12O search for resonances decaying to $\tau^+\tau^-$ in pp collisions at $\sqrt{s} = 7$ TeV.

[5] CHATRCHYAN 13AF search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s} = 7$ TeV and 8 TeV.

[6] AAD 12CC search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s}=7$ TeV.
[7] CHATRCHYAN 12M search for resonances decaying to e^+e^- or $\mu^+\mu^-$ in pp collisions at $\sqrt{s}=7$ TeV.
[8] AALTONEN 11I search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV.
[9] ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV.
[10] DEL-AGUILA 10 give 95% CL limit on the Z-Z' mixing $-0.0019 < \theta < 0.0007$.
[11] AALTONEN 09V search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV.
[12] ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0018 < \theta < 0.0009$.
[13] ABDALLAH 06C give 95% CL limit $|\theta| < 0.0027$. See their Fig. 14 for limit contours in the mass-mixing plane.
[14] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV.
[15] 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.
[16] 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.
[17] 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.
[18] BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s}$=90 to 183 GeV. Assume θ=0. Bounds in the mass-mixing plane are shown in their Figure 18.
[19] 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.
[20] ERLER 99 give 90% CL limit on the Z-Z' mixing $-0.0013 < \theta < 0.0024$.
[21] CONRAD 98 limit is from measurements at CCFR, assuming no Z-Z' mixing.
[22] ABE 97S find $\sigma(Z')\times$B(e^+e^-,$\mu^+\mu^-$)< 40 fb for $m_{Z'} > 600$ GeV at $\sqrt{s}$= 1.8 TeV.
[23] VILAIN 94B assume m_t = 150 GeV and θ=0. See Fig. 2 for limit contours in the mass-mixing plane.
[24] 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.
[25] Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that ν_R is light ($\lesssim$ 1 MeV).
[26] GRIFOLS 90D limit holds for $m_{\nu_R} \lesssim$ 1 MeV. See also RIZZO 91.

Limits for Z_η

Z_η 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
>2810	95	[1] AABOUD	16U	ATLS	pp; $Z'_\eta \rightarrow e^+e^-$, $\mu^+\mu^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>1870	95	[2] AAD	12CC	ATLS	pp, $Z'_\eta \rightarrow e^+e^-$, $\mu^+\mu^-$

$>$ 938	95	[3] AALTONEN	11I	CDF	$p\overline{p}$; $Z'_{\eta} \rightarrow \mu^+\mu^-$
$>$ 923	95	[4] ABAZOV	11A	D0	$p\overline{p}$, $Z'_{\eta} \rightarrow e^+e^-$
$>$ 488	95	[5] DEL-AGUILA	10	RVUE	Electroweak
$>$ 877	95	[4] AALTONEN	09T	CDF	$p\overline{p}$, $Z'_{\eta} \rightarrow e^+e^-$
$>$ 904	95	[6] AALTONEN	09V	CDF	Repl. by AALTONEN 11I
$>$ 427	95	[7] ERLER	09	RVUE	Electroweak
$>$ 891	95	[4] AALTONEN	07H	CDF	Repl. by AALTONEN 09T
$>$ 350	95	SCHAEL	07A	ALEP	e^+e^-
$>$ 360	95	[8] ABDALLAH	06C	DLPH	e^+e^-
$>$ 745		[4] ABULENCIA	06L	CDF	Repl. by AALTONEN 07H
$>$ 720	95	[9] ABULENCIA	05A	CDF	Repl. by AALTONEN 11I and AALTONEN 09T
$>$ 515	95	[10] ABBIENDI	04G	OPAL	e^+e^-
$>$1600		[11] BARGER	03B	COSM	Nucleosynthesis; light ν_R
$>$ 310	95	[12] ABREU	00S	DLPH	e^+e^-
$>$ 329	95	[13] BARATE	00I	ALEP	Repl. by SCHAEL 07A
$>$ 619	95	[14] CHO	00	RVUE	Electroweak
$>$ 365	95	[15] ERLER	99	RVUE	Electroweak
$>$ 87	95	[16] CONRAD	98	RVUE	$\nu_{\mu} N$ scattering
$>$ 620	95	[17] ABE	97S	CDF	$p\overline{p}$; $Z'_{\eta} \rightarrow e^+e^-$, $\mu^+\mu^-$
$>$ 100	95	[18] VILAIN	94B	CHM2	$\nu_{\mu} e \rightarrow \nu_{\mu} e$; $\overline{\nu}_{\mu} e \rightarrow \overline{\nu}_{\mu} e$
$>$ 125	90	[19] ABE	90F	VNS	e^+e^-
[$>$ 820]		[20] GONZALEZ...	90D	COSM	Nucleosynthesis; light ν_R
[$>$ 3300]		[21] GRIFOLS	90	ASTR	SN 1987A; light ν_R
[$>$ 1040]		[20] LOPEZ	90	COSM	Nucleosynthesis; light ν_R

[1] AABOUD 16U search for resonances decaying to $\ell^+\ell^-$ in pp collisions at $\sqrt{s} = 13$ TeV.

[2] AAD 12CC search for resonances decaying to e^+e^-, $\mu^+\mu^-$ in pp collisions at $\sqrt{s} = 7$ TeV.

[3] AALTONEN 11I search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

[4] ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

[5] DEL-AGUILA 10 give 95% CL limit on the Z-Z' mixing $-0.0023 < \theta < 0.0027$.

[6] AALTONEN 09V search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

[7] ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0047 < \theta < 0.0021$.

[8] ABDALLAH 06C give 95% CL limit $|\theta| < 0.0092$. See their Fig. 14 for limit contours in the mass-mixing plane.

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

[10] 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.

[11] 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.

[12] 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.

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

[14] 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.

[15] ERLER 99 give 90% CL limit on the Z-Z' mixing $-0.0062 < \theta < 0.0011$.

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

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

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

[19] 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.

[20] 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).

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

Limits for other Z'

VALUE (GeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>1580	95	[1] AABOUD	17B	ATLS	$Z' \rightarrow hZ$
none 1100–1500	95	[2] AABOUD	16	ATLS	$Z' \rightarrow b\bar{b}$
		[3] AAD	16L	ATLS	$Z' \rightarrow a\gamma$, $a \rightarrow \gamma\gamma$
none 1500–2600	95	[4] AAD	16S	ATLS	$Z' \rightarrow q\bar{q}$
none 1000–1100, none 1300–1500	95	[5] KHACHATRY...	16AP	CMS	$Z' \rightarrow hZ$
>2400	95	[6] KHACHATRY...	16E	CMS	$Z' \rightarrow t\bar{t}$
		[7] AAD	15AO	ATLS	$Z' \rightarrow t\bar{t}$
		[8] AAD	15AT	ATLS	monotop
		[9] AAD	15CD	ATLS	$h \rightarrow ZZ'$, $Z'Z'$; $Z' \rightarrow \ell^+\ell^-$
		[10] KHACHATRY...	15F	CMS	monotop
		[11] KHACHATRY...	15O	CMS	$Z' \rightarrow hZ$
		[12] AAD	14AT	ATLS	$Z' \rightarrow Z\gamma$
		[13] KHACHATRY...	14A	CMS	$Z' \rightarrow VV$
		[14] MARTINEZ	14	RVUE	Electroweak
none 500–1740	95	[15] AAD	13AQ	ATLS	$Z' \rightarrow t\bar{t}$
>1320 or 1000–1280	95	[16] AAD	13G	ATLS	$Z' \rightarrow t\bar{t}$
> 915	95	[16] AALTONEN	13A	CDF	$Z' \rightarrow t\bar{t}$
>1300	95	[17] CHATRCHYAN	13AP	CMS	$Z' \rightarrow t\bar{t}$
>2100	95	[16] CHATRCHYAN	13BM	CMS	$Z' \rightarrow t\bar{t}$
		[18] AAD	12BV	ATLS	$Z' \rightarrow t\bar{t}$
		[19] AAD	12K	ATLS	$Z' \rightarrow t\bar{t}$
		[20] AALTONEN	12AR	CDF	Chromophilic
		[21] AALTONEN	12N	CDF	$Z' \rightarrow \bar{t}u$
> 835	95	[22] ABAZOV	12R	D0	$Z' \rightarrow t\bar{t}$
		[23] CHATRCHYAN	12AI	CMS	$Z' \rightarrow t\bar{u}$
		[24] CHATRCHYAN	12AQ	CMS	$Z' \rightarrow t\bar{t}$
>1490	95	[16] CHATRCHYAN	12BL	CMS	$Z' \rightarrow t\bar{t}$
		[25] AALTONEN	11AD	CDF	$Z' \rightarrow t\bar{t}$
		[26] AALTONEN	11AE	CDF	$Z' \rightarrow t\bar{t}$
		[27] CHATRCHYAN	11O	CMS	$pp \rightarrow tt$

[28] AALTONEN	08D	CDF	$Z' \rightarrow t\overline{t}$
[28] AALTONEN	08Y	CDF	$Z' \rightarrow t\overline{t}$
[28] ABAZOV	08AA	D0	$Z' \rightarrow t\overline{t}$
[29] ABAZOV	04A	D0	Repl. by ABAZOV 08AA
[30] BARGER	03B	COSM	Nucleosynthesis; light ν_R
[31] CHO	00	RVUE	E_6-motivated
[32] CHO	98	RVUE	E_6-motivated
[33] ABE	97G	CDF	$Z' \rightarrow \overline{q}q$

[1] AABOUD 17B search for resonances decaying to hZ ($h \rightarrow b\overline{b}$, $c\overline{c}$; $Z \rightarrow \ell^+\ell^-$, $\nu\overline{\nu}$) in pp collisions at $\sqrt{s} = 13$ TeV. The quoted limit is for heavy-vector-triplet Z' with $g_V = 3$. The limit becomes $M_{Z'} > 1490$ GeV for $g_V = 1$. If we assume $M_{Z'} = M_{W'}$, the limit increases $M_{Z'} > 2310$ GeV and $M_{Z'} > 1730$ GeV for $g_V = 3$ and $g_V = 1$, respectively. See their Fig.3 for limits on $\sigma \cdot B$.

[2] AABOUD 16 search for a narrow resonance decaying into $b\overline{b}$ in pp collisions at $\sqrt{s} = 13$ TeV. The limit quoted above is for a leptophobic Z' with SM-like couplings to quarks. See their Fig.6 for limits on $\sigma \cdot B$.

[3] AAD 16L search for $Z' \rightarrow a\gamma$, $a \rightarrow \gamma\gamma$ in pp collisions at $\sqrt{s} = 8$ TeV. See their Table 6 for limits on $\sigma \cdot B$.

[4] AAD 16S search for a new resonance decaying to dijets in pp collisions at $\sqrt{s} = 13$ TeV. The limit quoted above is for a leptophobic Z' having coupling strength with quark $g_q = 0.3$ and is taken from their Figure 3.

[5] KHACHATRYAN 16AP search for a resonance decaying to hZ in pp collisions at $\sqrt{s} = 8$ TeV. Both h and Z are assumed to decay to fat jets. The quoted limit is for heavy-vector-triplet Z' with $g_V = 3$.

[6] KHACHATRYAN 16E search for a leptophobic top-color Z' decaying to $t\overline{t}$ using pp collisions at $\sqrt{s} = 8$ TeV. The quoted limit assumes that $\Gamma_{Z'}/m_{Z'} = 0.012$. Also $m_{Z'} < 2.9$ TeV is excluded for wider topcolor Z' with $\Gamma_{Z'}/m_{Z'} = 0.1$.

[7] AAD 15AO search for narrow resonance decaying to $t\overline{t}$ using pp collisions at $\sqrt{s} = 8$ TeV. See Fig. 11 for limit on σB.

[8] AAD 15AT search for monotop production plus large missing E_T events in pp collisions at $\sqrt{s} = 8$ TeV and give constraints on a Z' model having $Z' u \overline{t}$ coupling. Z' is assumed to decay invisibly. See their Fig. 6 for limits on $\sigma \cdot B$.

[9] AAD 15CD search for decays of Higgs bosons to 4 ℓ states via Z' bosons, $h \rightarrow Z Z' \rightarrow 4\ell$ or $h \rightarrow Z' Z' \rightarrow 4\ell$. See Fig. 5 for the limit on the signal strength of the $h \rightarrow Z Z' \rightarrow 4\ell$ process and Fig. 16 for the limit on $h \rightarrow Z' Z' \rightarrow 4\ell$.

[10] KHACHATRYAN 15F search for monotop production plus large missing E_T events in pp collisions at $\sqrt{s} = 8$ TeV and give constraints on a Z' model having $Z' u \overline{t}$ coupling. Z' is assumed to decay invisibly. See Fig. 3 for limits on σB.

[11] KHACHATRYAN 15O search for narrow Z' resonance decaying to Zh in pp collisions at $\sqrt{s} = 8$ TeV. See their Fig. 6 for limit on σB.

[12] AAD 14AT search for a narrow neutral vector boson decaying to $Z\gamma$. See their Fig. 3b for the exclusion limit in $m_{Z'} - \sigma B$ plane.

[13] KHACHATRYAN 14A search for new resonance in the WW ($\ell\nu q\overline{q}$) and the ZZ ($\ell\ell q\overline{q}$) channels using pp collisions at $\sqrt{s}$=8 TeV. See their Fig.13 for the exclusion limit on the number of events in the mass-width plane.

[14] MARTINEZ 14 use various electroweak data to constrain the Z' boson in the 3-3-1 models.

[15] AAD 13AQ search for a leptophobic top-color Z' decaying to $t\overline{t}$. The quoted limit assumes that $\Gamma_{Z'}/m_{Z'} = 0.012$.

[16] CHATRCHYAN 13BM search for top-color Z' decaying to $t\overline{t}$ using pp collisions at $\sqrt{s}$=8 TeV. The quoted limit is for $\Gamma_{Z'}/m_{Z'} = 0.012$.

[17] CHATRCHYAN 13AP search for top-color leptophobic Z' decaying to $t\overline{t}$ using pp collisions at $\sqrt{s}$=7 TeV. The quoted limit is for $\Gamma_{Z'}/m_{Z'} = 0.012$.
[18] AAD 12BV search for narrow resonance decaying to $t\overline{t}$ using pp collisions at $\sqrt{s}$=7 TeV. See their Fig. 7 for limit on $\sigma \cdot$ B.
[19] AAD 12K search for narrow resonance decaying to $t\overline{t}$ using pp collisions at $\sqrt{s}$=7 TeV. See their Fig. 5 for limit on $\sigma \cdot$ B.
[20] AALTONEN 12AR search for chromophilic Z' in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. See their Fig. 5 for limit on $\sigma \cdot$ B.
[21] AALTONEN 12N search for $p\overline{p} \rightarrow tZ'$, $Z' \rightarrow \overline{t}u$ events in $p\overline{p}$ collisions. See their Fig. 3 for the limit on $\sigma \cdot$ B.
[22] ABAZOV 12R search for top-color Z' boson decaying exclusively to $t\overline{t}$. The quoted limit is for $\Gamma_{Z'}/m_{Z'}$= 0.012.
[23] CHATRCHYAN 12AI search for $pp \rightarrow tt$ events and give constraints on a Z' model having $Z'\overline{u}t$ coupling. See their Fig. 4 for the limit in mass-coupling plane.
[24] Search for resonance decaying to $t\overline{t}$. See their Fig. 6 for limit on $\sigma \cdot$ B.
[25] Search for narrow resonance decaying to $t\overline{t}$. See their Fig. 4 for limit on $\sigma \cdot$ B.
[26] Search for narrow resonance decaying to $t\overline{t}$. See their Fig. 3 for limit on $\sigma \cdot$ B.
[27] CHATRCHYAN 11O search for same-sign top production in pp collisions induced by a hypothetical FCNC Z' at $\sqrt{s}$ = 7 TeV. See their Fig. 3 for limit in mass-coupling plane.
[28] Search for narrow resonance decaying to $t\overline{t}$. See their Fig. 3 for limit on $\sigma \cdot$ B.
[29] Search for narrow resonance decaying to $t\overline{t}$. See their Fig. 2 for limit on $\sigma \cdot$ B.
[30] BARGER 03B use the nucleosynthesis bound on the effective number of light neutrino δN_ν. See their Figs. 4–5 for limits in general E_6 motivated models.
[31] 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.
[32] CHO 98 study constraints on four-Fermi contact interactions obtained from low-energy electroweak experiments, assuming no Z-Z' mixing.
[33] Search for Z' decaying to dijets at $\sqrt{s}$=1.8 TeV. For Z' with electromagnetic strength coupling, no bound is obtained.

Searches for Z' with Lepton-Flavor-Violating decays

The following limits are obtained from $p\overline{p}$ or $pp \rightarrow Z'X$ with Z' decaying to the mode indicated in the comments.

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] AABOUD	16P	ATLS	$Z' \rightarrow e\mu$, $e\tau$, $\mu\tau$
	[2] KHACHATRY...	16BE	CMS	$Z' \rightarrow e\mu$
	[3] AAD	15O	ATLS	$Z' \rightarrow e\mu$, $e\tau$, $\mu\tau$
	[4] AAD	11H	ATLS	$Z' \rightarrow e\mu$
	[5] AAD	11Z	ATLS	$Z' \rightarrow e\mu$
	[6] ABULENCIA	06M	CDF	$Z' \rightarrow e\mu$

[1] AABOUD 16P search for new particle with lepton flavor violating decay in pp collisions at $\sqrt{s}$ = 13 TeV. See their Figs.2, 3, and 4 for limits on $\sigma \cdot B$.
[2] KHACHATRYAN 16BE search for new particle Z' with lepton flavor violating decay in pp collisions at $\sqrt{s}$ = 8 TeV in the range of 200 GeV < $M_{Z'}$ < 2000 GeV. See their Fig.4 for limits on $\sigma \cdot B$ and their Table 5 for bounds on various masses.
[3] AAD 15O search for new particle Z' with lepton flavor violating decay in pp collisions at $\sqrt{s}$ = 8 TeV in the range of 500 GeV < $M_{Z'}$ < 3000 GeV. See their Fig. 2 for limits on σB.
[4] AAD 11H search for new particle Z' with lepton flavor violating decay in pp collisions at $\sqrt{s}$ = 7 TeV in the range of 700 GeV < $M_{Z'}$ < 1000 GeV. See their Fig. 3 for limits on $\sigma \cdot B$.

[5] AAD 11Z search for new particle Z' with lepton flavor violating decay in pp collisions at $\sqrt{s}$ = 7 TeV in the range 700 GeV < $M_{Z'}$ < 2000 GeV. See their Fig. 3 for limits on $\sigma \cdot B$.

[6] ABULENCIA 06M search for new particle Z' with lepton flavor violating decay in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV in the range of 100 GeV < $M_{Z'}$ < 800 GeV. See their Fig. 4 for limits in the mass-coupling plane.

Indirect Constraints on Kaluza-Klein Gauge Bosons

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*.

VALUE (TeV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 4.7		[1] MUECK	02	RVUE	Electroweak
> 3.3	95	[2] CORNET	00	RVUE	$e\nu qq'$
>5000		[3] DELGADO	00	RVUE	ϵ_K
> 2.6	95	[4] DELGADO	00	RVUE	Electroweak
> 3.3	95	[5] RIZZO	00	RVUE	Electroweak
> 2.9	95	[6] MARCIANO	99	RVUE	Electroweak
> 2.5	95	[7] MASIP	99	RVUE	Electroweak
> 1.6	90	[8] NATH	99	RVUE	Electroweak
> 3.4	95	[9] STRUMIA	99	RVUE	Electroweak

[1] MUECK 02 limit is 2σ 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.

[2] Bound is derived from limits on $e\nu qq'$ contact interaction, using data from HERA and the Tevatron.

[3] 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 Δm_K.

[4] 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.

[5] 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.

[6] Bound is derived from global electroweak analysis but considering only presence of the KK W bosons.

[7] Global electroweak analysis used to obtain bound independent of position of Higgs on brane or in bulk.

[8] Bounds from effect of KK states on G_F, α, 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.

[9] 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.

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MASS LIMITS for Leptoquarks from Pair Production

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>1050	95	[1] AAD	16G	ATLS	First generation
>1000	95	[2] AAD	16G	ATLS	Second generation
> 625	95	[3] AAD	16G	ATLS	Third generation
none 200–640	95	[4] AAD	16G	ATLS	Third generation
>1010	95	[5] KHACHATRY...	16AF	CMS	First generation
>1080	95	[6] KHACHATRY...	16AF	CMS	Second generation
> 685	95	[7] KHACHATRY...	15AJ	CMS	Third generation
> 740	95	[8] KHACHATRY...	14T	CMS	Third generation
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 534	95	[9] AAD	13AE	ATLS	Third generation
> 525	95	[10] CHATRCHYAN	13M	CMS	Third generation
> 660	95	[11] AAD	12H	ATLS	First generation
> 685	95	[12] AAD	12O	ATLS	Second generation
> 830	95	[13] CHATRCHYAN	12AG	CMS	First generation
> 840	95	[14] CHATRCHYAN	12AG	CMS	Second generation
> 450	95	[15] CHATRCHYAN	12BO	CMS	Third generation
> 376	95	[16] AAD	11D	ATLS	Superseded by AAD 12H
> 422	95	[17] AAD	11D	ATLS	Superseded by AAD 12O
> 326	95	[18] ABAZOV	11V	D0	First generation
> 339	95	[19] CHATRCHYAN	11N	CMS	Superseded by CHATRCHYAN 12AG
> 384	95	[20] KHACHATRY...	11D	CMS	Superseded by CHATRCHYAN 12AG
> 394	95	[21] KHACHATRY...	11E	CMS	Superseded by CHATRCHYAN 12AG
> 247	95	[22] ABAZOV	10L	D0	Third generation
> 316	95	[23] ABAZOV	09	D0	Second generation
> 299	95	[24] ABAZOV	09AF	D0	Superseded by ABAZOV 11V
		[25] AALTONEN	08P	CDF	Third generation
> 153	95	[26] AALTONEN	08Z	CDF	Third generation
> 205	95	[27] ABAZOV	08AD	D0	All generations
> 210	95	[26] ABAZOV	08AN	D0	Third generation
> 229	95	[28] ABAZOV	07J	D0	Superseded by ABAZOV 10L
> 251	95	[29] ABAZOV	06A	D0	Superseded by ABAZOV 09
> 136	95	[30] ABAZOV	06L	D0	Superseded by ABAZOV 08AD
> 226	95	[31] ABULENCIA	06T	CDF	Second generation
> 256	95	[32] ABAZOV	05H	D0	First generation
> 117	95	[27] ACOSTA	05I	CDF	First generation
> 236	95	[33] ACOSTA	05P	CDF	First generation
> 99	95	[34] ABBIENDI	03R	OPAL	First generation
> 100	95	[34] ABBIENDI	03R	OPAL	Second generation
> 98	95	[34] ABBIENDI	03R	OPAL	Third generation
> 98	95	[35] ABAZOV	02	D0	All generations
> 225	95	[36] ABAZOV	01D	D0	First generation
> 85.8	95	[37] ABBIENDI	00M	OPAL	Superseded by ABBIENDI 03R
> 85.5	95	[37] ABBIENDI	00M	OPAL	Superseded by ABBIENDI 03R
> 82.7	95	[37] ABBIENDI	00M	OPAL	Superseded by ABBIENDI 03R
> 200	95	[38] ABBOTT	00C	D0	Second generation

$>$ 123	95	[39] AFFOLDER	00K	CDF	Second generation
$>$ 148	95	[40] AFFOLDER	00K	CDF	Third generation
$>$ 160	95	[41] ABBOTT	99J	D0	Second generation
$>$ 225	95	[42] ABBOTT	98E	D0	First generation
$>$ 94	95	[43] ABBOTT	98J	D0	Third generation
$>$ 202	95	[44] ABE	98S	CDF	Second generation
$>$ 242	95	[45] GROSS-PILCH...	98		First generation
$>$ 99	95	[46] ABE	97F	CDF	Third generation
$>$ 213	95	[47] ABE	97X	CDF	First generation
$>$ 45.5	95	[48,49] ABREU	93J	DLPH	First + second generation
$>$ 44.4	95	[50] ADRIANI	93M	L3	First generation
$>$ 44.5	95	[50] ADRIANI	93M	L3	Second generation
$>$ 45	95	[50] DECAMP	92	ALEP	Third generation
none 8.9–22.6	95	[51] KIM	90	AMY	First generation
none 10.2–23.2	95	[51] KIM	90	AMY	Second generation
none 5–20.8	95	[52] BARTEL	87B	JADE	
none 7–20.5	95	[53] BEHREND	86B	CELL	

[1] AAD 16G search for scalar leptoquarks using $eejj$ events in collisions at $\sqrt{s}$ = 8 TeV. The limit above assumes $B(eq) = 1$.

[2] AAD 16G search for scalar leptoquarks using $\mu\mu jj$ events in collisions at $\sqrt{s}$ = 8 TeV. The limit above assumes $B(\mu q) = 1$.

[3] AAD 16G search for scalar leptoquarks decaying to $b\nu$. The limit above assumes $B(b\nu) = 1$.

[4] AAD 16G search for scalar leptoquarks decaying to $t\nu$. The limit above assumes $B(t\nu) = 1$.

[5] KHACHATRYAN 16AF search for scalar leptoquarks using $eejj$ and $e\nu jj$ events in pp collisions at $\sqrt{s}$ = 8 TeV. The limit above assumes B(eq)= 1. For B(eq) = 0.5, the limit becomes 850 GeV.

[6] KHACHATRYAN 16AF search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in pp collisions at $\sqrt{s}$ = 8 TeV. The limit above assumes B(μq) = 1. For B(μq) = 0.5, the limit becomes 760 GeV.

[7] KHACHATRYAN 15AJ search for scalar leptoquarks using $\tau\tau tt$ events in pp collisions at $\sqrt{s}$ = 8 TeV. The limit above assumes $B(\tau t) = 1$.

[8] KHACHATRYAN 14T search for scalar leptoquarks decaying to τb using pp collisions at $\sqrt{s}$=8 TeV. The limit above assumes B(τb) = 1. See their Fig. 5 for exclusion limit as function of B(τb).

[9] AAD 13AE search for scalar leptoquarks using $\tau\tau bb$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(τb) = 1.

[10] CHATRCHYAN 13M search for scalar and vector leptoquarks decaying to τb in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above is for scalar leptoquarks with B(τb) = 1.

[11] AAD 12H search for scalar leptoquarks using $eejj$ and $e\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(eq) = 1. For B(eq) = 0.5, the limit becomes 607 GeV.

[12] AAD 12O search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(μq) = 1. For B(μq) = 0.5, the limit becomes 594 GeV.

[13] CHATRCHYAN 12AG search for scalar leptoquarks using $eejj$ and $e\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(eq) = 1. For B(eq) = 0.5, the limit becomes 640 GeV.

[14] CHATRCHYAN 12AG search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(μq) = 1. For B(μq) = 0.5, the limit becomes 650 GeV.

[15] CHATRCHYAN 12BO search for scalar leptoquarks decaying to νb in pp collisions at $\sqrt{s}$ = 7 TeV. The limit above assumes B(νb) = 1.

[16] AAD 11D search for scalar leptoquarks using $eejj$ and $e\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV.The limit above assumes B(eq) = 1. For B(eq) = 0.5, the limit becomes 319 GeV.

[17] AAD 11D search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(μq) = 1. For B(μq) = 0.5, the limit becomes 362 GeV.

[18] ABAZOV 11V search for scalar leptoquarks using $e\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. The limit above assumes B(eq) = 0.5.

[19] CHATRCHYAN 11N search for scalar leptoquarks using $e\nu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(eq) = 0.5.

[20] KHACHATRYAN 11D search for scalar leptoquarks using $eejj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(eq) = 1.

[21] KHACHATRYAN 11E search for scalar leptoquarks using $\mu\mu jj$ events in pp collisions at $E_{\rm cm}$ = 7 TeV. The limit above assumes B(μq) = 1.

[22] ABAZOV 10L search for pair productions of scalar leptoquark state decaying to νb in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. The limit above assumes B(νb) = 1.

[23] ABAZOV 09 search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. The limit above assumes B(μq) = 1. For B(μq) = 0.5, the limit becomes 270 GeV.

[24] ABAZOV 09AF search for scalar leptoquarks using $eejj$ and $e\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. The limit above assumes B(eq) = 1. For B(eq) = 0.5 the bound becomes 284 GeV.

[25] AALTONEN 08P search for vector leptoquarks using $\tau^+\tau^- b\overline{b}$ events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. Assuming Yang-Mills (minimal) couplings, the mass limit is >317 GeV (251 GeV) at 95% CL for B(τb) = 1.

[26] Search for pair production of scalar leptoquark state decaying to τb in $p\overline{p}$ collisions at $E_{\rm cm}$= 1.96 TeV. The limit above assumes B(τb) = 1.

[27] Search for scalar leptoquarks using $\nu\nu jj$ events in $\overline{p}p$ collisions at $E_{\rm cm}$ = 1.96 TeV. The limit above assumes B(νq) = 1.

[28] ABAZOV 07J search for pair productions of scalar leptoquark state decaying to νb in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. The limit above assumes B(νb) = 1.

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

[30] ABAZOV 06L search for scalar leptoquarks using $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.8 TeV and at 1.96 TeV. The limit above assumes B(νq) = 1.

[31] ABULENCIA 06T search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV. The quoted limit assumes B(μq) = 1. For B(μq) = 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(μq).

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

[33] ACOSTA 05P search for scalar leptoquarks using $eejj$, $e\nu jj$ events in $\overline{p}p$ collisions at $E_{\rm cm}$ = 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.

[34] 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(ℓq) = 1. See their table 12 for other cases.

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

[36] ABAZOV 01D search for scalar leptoquarks using $e\nu jj$, $eejj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}$=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.

[37] 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(ℓq)=1. See their Table 8 and Figs. 6–9 for other cases.

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

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

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

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

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

[43] 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(νb)=1.

[44] ABE 98S search for scalar leptoquarks using $\mu\mu j j$ events in $p\overline{p}$ collisions at E_{cm}= 1.8 TeV. The limit is for B(μq)= 1. For B(μq)=B(νq)=0.5, the limit is $>$ 160 GeV.

[45] 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.

[46] 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(τb) = 1.

[47] ABE 97X search for scalar leptoquarks using $e e j j$ events in $p\overline{p}$ collisions at E_{cm}=1.8 TeV. The limit is for B($e q$)=1.

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

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

[50] 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.

[51] 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.

[52] 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.

[53] 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
>1755	95	[1] KHACHATRY...16AG	CMS	First generation
> 660	95	[2] KHACHATRY...16AG	CMS	Second generation
> 304	95	[3] ABRAMOWICZ12A	ZEUS	First generation
> 73	95	[4] ABREU 93J	DLPH	Second generation

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

		[5] DEY	16	ICCB	$\nu q \rightarrow$ LQ $\rightarrow$ νq
		[6] AARON	11A	H1	Lepton-flavor violation
$>$ 300	95	[7] AARON	11B	H1	First generation
		[8] ABAZOV	07E	D0	Second generation
$>$ 295	95	[9] AKTAS	05B	H1	First generation
		[10] CHEKANOV	05A	ZEUS	Lepton-flavor violation
$>$ 298	95	[11] CHEKANOV	03B	ZEUS	First generation
$>$ 197	95	[12] ABBIENDI	02B	OPAL	First generation
		[13] CHEKANOV	02	ZEUS	Repl. by CHEKANOV 05A
$>$ 290	95	[14] ADLOFF	01C	H1	First generation
$>$ 204	95	[15] BREITWEG	01	ZEUS	First generation
		[16] BREITWEG	00E	ZEUS	First generation
$>$ 161	95	[17] ABREU	99G	DLPH	First generation
$>$ 200	95	[18] ADLOFF	99	H1	First generation
		[19] DERRICK	97	ZEUS	Lepton-flavor violation
$>$ 168	95	[20] DERRICK	93	ZEUS	First generation

[1] KHACHATRYAN 16AG search for single production of charge $\pm 1/3$ scalar leptoquarks using eej events in pp collisions at $\sqrt{s} = 8$ TeV. The limit above assumes B(eq) = 1 and the leptoquark coupling strength $\lambda = 1$.

[2] KHACHATRYAN 16AG search for single production of charge $\pm 1/3$ scalar leptoquarks using $\mu\mu j$ events in pp collisions at $\sqrt{s} = 8$ TeV. The limit above assumes B(μq) = 1 and the leptoquark coupling strength $\lambda = 1$.

[3] ABRAMOWICZ 12A limit is for a scalar, weak isoscalar, charge $-1/3$ leptoquark coupled with e_R. See their Figs. 12–17 and Table 4 for states with different quantum numbers.

[4] 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.

[5] DEY 16 use the 2010-2012 IceCube PeV energy data set to constrain the leptoquark production cross section through the $\nu q \rightarrow$ LQ $\rightarrow$ νq process. See their Figure 4 for the exclusion limit in the mass-coupling plane.

[6] AARON 11A search for various leptoquarks with lepton-flavor violating couplings. See their Figs. 2–3 and Tables 1–4 for detailed limits.

[7] The quoted limit is for a scalar, weak isoscalar, charge $-1/3$ leptoquark coupled with e_R. See their Figs. 3–5 for limits on states with different quantum numbers.

[8] 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.

[9] 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.

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

[11] 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.

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

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

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

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

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

[17] ABREU 99G limit obtained from process $e\gamma \rightarrow LQ+q$. 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.

[18] 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.

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

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

Indirect Limits for Leptoquarks

VALUE (TeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] BARRANCO	16	RVUE	D decays
		[2] KUMAR	16	RVUE	neutral K mixing, rare K decays
		[3] BESSAA	15	RVUE	$q\overline{q} \rightarrow e^+e^-$
>14	95	[4] SAHOO	15A	RVUE	$B_{s,d} \rightarrow \mu^+\mu^-$
		[5] SAKAKI	13	RVUE	$B \rightarrow D^{(*)}\tau\overline{\nu}$, $B \rightarrow X_s\nu\overline{\nu}$
		[6] KOSNIK	12	RVUE	$b \rightarrow s\ell^+\ell^-$
>2.5	95	[7] AARON	11C	H1	First generation
		[8] DORSNER	11	RVUE	scalar, weak singlet, charge 4/3
		[9] AKTAS	07A	H1	Lepton-flavor violation
>0.49	95	[10] SCHAEL	07A	ALEP	$e^+e^- \rightarrow q\overline{q}$
		[11] SMIRNOV	07	RVUE	$K \rightarrow e\mu$, $B \rightarrow e\tau$
		[12] CHEKANOV	05A	ZEUS	Lepton-flavor violation
>1.7	96	[13] ADLOFF	03	H1	First generation
>46	90	[14] CHANG	03	BELL	Pati-Salam type
		[15] CHEKANOV	02	ZEUS	Repl. by CHEKANOV 05A
>1.7	95	[16] CHEUNG	01B	RVUE	First generation
>0.39	95	[17] ACCIARRI	00P	L3	$e^+e^- \rightarrow qq$
>1.5	95	[18] ADLOFF	00	H1	First generation
>0.2	95	[19] BARATE	00I	ALEP	Repl. by SCHAEL 07A
		[20] BARGER	00	RVUE	Cs
		[21] GABRIELLI	00	RVUE	Lepton flavor violation
>0.74	95	[22] ZARNECKI	00	RVUE	S_1 leptoquark
		[23] ABBIENDI	99	OPAL	
>19.3	95	[24] ABE	98V	CDF	$B_s \rightarrow e^\pm\mu^\mp$, Pati-Salam type
		[25] ACCIARRI	98J	L3	$e^+e^- \rightarrow q\overline{q}$
		[26] ACKERSTAFF	98V	OPAL	$e^+e^- \rightarrow q\overline{q}$, $e^+e^- \rightarrow b\overline{b}$
>0.76	95	[27] DEANDREA	97	RVUE	$\widetilde{R}_2$ leptoquark
		[28] DERRICK	97	ZEUS	Lepton-flavor violation
		[29] GROSSMAN	97	RVUE	$B \rightarrow \tau^+\tau^-(X)$
		[30] JADACH	97	RVUE	$e^+e^- \rightarrow q\overline{q}$
>1200		[31] KUZNETSOV	95B	RVUE	Pati-Salam type
		[32] MIZUKOSHI	95	RVUE	Third generation scalar leptoquark
>0.3	95	[33] BHATTACH...	94	RVUE	Spin-0 leptoquark coupled to $\overline{e}_R t_L$

		[34] DAVIDSON	94	RVUE	
$>$ 18		[35] KUZNETSOV	94	RVUE	Pati-Salam type
$>$ 0.43	95	[36] LEURER	94	RVUE	First generation spin-1 leptoquark
$>$ 0.44	95	[36] LEURER	94B	RVUE	First generation spin-0 leptoquark
		[37] MAHANTA	94	RVUE	P and T violation
$>$ 1		[38] SHANKER	82	RVUE	Nonchiral spin-0 leptoquark
$>$ 125		[38] SHANKER	82	RVUE	Nonchiral spin-1 leptoquark

[1] BARRANCO 16 give bounds on leptoquark induced four-fermion interactions from $D \rightarrow K \ell \nu$ and $D_s \rightarrow \ell \nu$.

[2] KUMAR 16 gives bound on SU(2) singlet scalar leptoquark with chrge $-1/3$ from $K^0-\overline{K}^0$ mixing, $K \rightarrow \pi \nu \overline{\nu}$, $K^0_L \rightarrow \mu^+ \mu^-$, and $K^0_L \rightarrow \mu^\pm e^\mp$ decays.

[3] BESSAA 15 obtain limit on leptoquark induced four-fermion interactions from the ATLAS and CMS limit on the $\overline{q} q \overline{e} e$ contact interactions.

[4] SAHOO 15A obtain limit on leptoquark induced four-fermion interactions from $B_{s,d} \rightarrow \mu^+ \mu^-$ for $\lambda \simeq O(1)$.

[5] SAKAKI 13 explain the $B \rightarrow D^{(*)} \tau \overline{\nu}$ anomaly using Wilson coefficients of leptoquark-induced four-fermion operators.

[6] KOSNIK 12 obtains limits on leptoquark induced four-fermion interactions from $b \rightarrow s \ell^+ \ell^-$ decays.

[7] AARON 11C limit is for 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 of $e q$ contact intereractions.

[8] DORSNER 11 give bounds on scalar, weak singlet, charge 4/3 leptoquark from K, B, τ decays, meson mixings, LFV, $g-2$ and $Z \rightarrow b \overline{b}$.

[9] AKTAS 07A search for lepton-flavor violation in $e p$ collision. See their Tables 4–7 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks.

[10] 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.

[11] SMIRNOV 07 obtains mass limits for the vector and scalar chiral leptoquark states from $K \rightarrow e \mu$, $B \rightarrow e \tau$ decays.

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

[13] 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.

[14] The bound is derived from $B(B^0 \rightarrow e^\pm \mu^\mp) < 1.7 \times 10^{-7}$.

[15] CHEKANOV 02 search for lepton-flavor violation in $e p$ collisions. See their Tables 1–4 for limits on lepton-flavor violating and four-fermion interactions induced by various leptoquarks.

[16] 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.

[17] 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.

[18] 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 $e^+ p \rightarrow e^+ X$.

[19] 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.

[20] BARGER 00 explain the deviation of atomic parity violation in cesium atoms from prediction is explained by scalar leptoquark exchange.
[21] GABRIELLI 00 calculate various process with lepton flavor violation in leptoquark models.
[22] 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.
[23] 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.
[24] 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 bounds assume the non-canonical association of the b quark with electrons or muons under SU(4).
[25] 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.
[26] 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.
[27] 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.
[28] DERRICK 97 search for lepton-flavor violation in ep collision. See their Tables 2–5 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks.
[29] 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.
[30] 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.
[31] KUZNETSOV 95B use π, K, B, τ decays and μe 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.
[32] 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.
[33] 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.
[34] DAVIDSON 94 gives an extensive list of the bounds on leptoquark-induced four-fermion interactions from π, K, D, B, μ, τ decays and meson mixings, *etc.* See Table 15 of DAVIDSON 94 for detail.
[35] KUZNETSOV 94 gives mixing independent bound of the Pati-Salam leptoquark from the cosmological limit on $\pi^0 \rightarrow \overline{\nu}\nu$.
[36] 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.
[37] MAHANTA 94 gives bounds of P- and T-violating scalar-leptoquark couplings from atomic and molecular experiments.
[38] 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.

MASS LIMITS for Diquarks

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>6000 (CL = 95%) OUR LIMIT					
none 1500–6000	95	[1] KHACHATRY...	16K	CMS	E_6 diquark
none 500–1600	95	[2] KHACHATRY...	16L	CMS	E_6 diquark
none 1200–4700	95	[3] KHACHATRY...	15V	CMS	E_6 diquark
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>3750	95	[4] CHATRCHYAN	13A	CMS	E_6 diquark
none 1000–4280	95	[5] CHATRCHYAN	13AS	CMS	Superseded by KHACHATRYAN 15V
>3520	95	[6] CHATRCHYAN	11Y	CMS	Superseded by CHATRCHYAN 13A
none 970–1080, 1450–1600	95	[7] KHACHATRY...	10	CMS	Superseded by CHATRCHYAN 13A
none 290–630	95	[8] AALTONEN	09AC	CDF	E_6 diquark
none 290–420	95	[9] ABE	97G	CDF	E_6 diquark
none 15–31.7	95	[10] ABREU	94O	DLPH	SUSY E_6 diquark

[1] KHACHATRYAN 16K search for resonances decaying to dijets in pp collisions at $\sqrt{s}$ = 13 TeV.
[2] KHACHATRYAN 16L search for resonances decaying to dijets in pp collisions at $\sqrt{s}$ = 8 TeV with the data scouting technique, increasing the sensitivity to the low mass resonances.
[3] KHACHATRYAN 15V search for resonances decaying to dijets in pp collisions at $\sqrt{s}$ = 8 TeV.
[4] CHATRCHYAN 13A search for new resonance decaying to dijets in pp collisions at $\sqrt{s}$ = 7 TeV.
[5] CHATRCHYAN 13AS search for new resonance decaying to dijets in pp collisions at $\sqrt{s}$ = 8 TeV.
[6] CHATRCHYAN 11Y search for new resonance decaying to dijets in pp collisions at $\sqrt{s}$ = 7 TeV.
[7] KHACHATRYAN 10 search for new resonance decaying to dijets in pp collisions at $\sqrt{s}$ = 7 TeV.
[8] AALTONEN 09AC search for new narrow resonance decaying to dijets.
[9] ABE 97G search for new particle decaying to dijets.
[10] ABREU 94O limit is from $e^+ e^- \rightarrow \overline{c}\,\overline{s}\,c\,s$. Range extends up to 43 GeV if diquarks are degenerate in mass.

MASS LIMITS for g_A (axigluon) and Other Color-Octet Gauge Bosons

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.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>5100 (CL = 95%) OUR LIMIT					
none 1500–5100	95	[1] KHACHATRY...	16K	CMS	$pp \rightarrow g_A X$, $g_A \rightarrow 2j$
none 500–1600	95	[2] KHACHATRY...	16L	CMS	$pp \rightarrow g_A X$, $g_A \rightarrow 2j$
none 1300–3600	95	[3] KHACHATRY...	15V	CMS	$pp \rightarrow g_A X$, $g_A \rightarrow 2j$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[4] AAD	16W	ATLS	$pp \rightarrow g_A X$, $g_A \rightarrow b\overline{b}b\overline{b}$
>2800	95	[5] KHACHATRY...	16E	CMS	$pp \rightarrow g_{KK} X$, $g_{KK} \rightarrow t\overline{t}$

		[6] KHACHATRY...	15AV	CMS	$pp \to \Theta^0 \Theta^0 \to b\overline{b}Zg$
		[7] AALTONEN	13R	CDF	$p\overline{p} \to g_A X$, $g_A \to \sigma\sigma$, $\sigma \to 2j$
>3360	95	[8] CHATRCHYAN	13A	CMS	$pp \to g_A X$, $g_A \to 2j$
none 1000–3270	95	[9] CHATRCHYAN	13AS	CMS	Superseded by KHACHATRYAN 15V
none 250–740	95	[10] CHATRCHYAN	13AU	CMS	$pp \to 2g_A X$,$g_A \to 2j$
> 775	95	[11] ABAZOV	12R	D0	$p\overline{p} \to g_A X$, $g_A \to t\overline{t}$
>2470	95	[12] CHATRCHYAN	11Y	CMS	Superseded by CHATRCHYAN 13A
		[13] AALTONEN	10L	CDF	$p\overline{p} \to g_A X$, $g_A \to t\overline{t}$
none 1470–1520	95	[14] KHACHATRY...	10	CMS	Superseded by CHATRCHYAN 13A
none 260–1250	95	[15] AALTONEN	09AC	CDF	$p\overline{p} \to g_A X$, $g_A \to 2j$
> 910	95	[16] CHOUDHURY	07	RVUE	$p\overline{p} \to t\overline{t}X$
> 365	95	[17] DONCHESKI	98	RVUE	$\Gamma(Z \to$ hadron)
none 200–980	95	[18] ABE	97G	CDF	$p\overline{p} \to g_A X$, $g_A \to 2j$
none 200–870	95	[19] ABE	95N	CDF	$p\overline{p} \to g_A X$, $g_A \to q\overline{q}$
none 240–640	95	[20] ABE	93G	CDF	$p\overline{p} \to g_A X$, $g_A \to 2j$
> 50	95	[21] CUYPERS	91	RVUE	$\sigma(e^+e^- \to$ hadrons)
none 120–210	95	[22] ABE	90H	CDF	$p\overline{p} \to g_A X$, $g_A \to 2j$
> 29		[23] ROBINETT	89	THEO	Partial-wave unitarity
none 150–310	95	[24] ALBAJAR	88B	UA1	$p\overline{p} \to g_A X$, $g_A \to 2j$
> 20		BERGSTROM	88	RVUE	$p\overline{p} \to \Upsilon X$ via $g_A g$
> 9		[25] CUYPERS	88	RVUE	Υ decay
> 25		[26] DONCHESKI	88B	RVUE	Υ decay

[1] KHACHATRYAN 16K search for resonances decaying to dijets in pp collisions at $\sqrt{s}$ = 13 TeV.

[2] KHACHATRYAN 16L search for resonances decaying to dijets in pp collisions at $\sqrt{s}$ = 8 TeV with the data scouting technique, increasing the sensitivity to the low mass resonances.

[3] KHACHATRYAN 15V search for resonances decaying to dijets in pp collisions at $\sqrt{s}$ = 8 TeV.

[4] AAD 16W search for a new resonance decaying to a pair of b and B_H in pp collisions at $\sqrt{s}$ = 8 TeV. The vector-like quark B_H is assumed to decay to bH. See their Fig. 3 and Fig. 4 for limits on $\sigma \cdot B$.

[5] KHACHATRYAN 16E search for KK gluon decaying to $t\overline{t}$ in pp collisions at $\sqrt{s}$ = 8 TeV.

[6] KHACHATRYAN 15AV search for pair productions of neutral color-octet weak-triplet scalar particles (Θ^0), decaying to $b\overline{b}$, Zg or γg, in pp collisions at $\sqrt{s}$ = 8 TeV. The Θ^0 particle is often predicted in coloron (G', color-octet gauge boson) models and appear in the pp collisions through $G' \to \Theta^0 \Theta^0$ decays. Assuming B($\Theta^0 \to b\overline{b}$) = 0.5, they give limits $m_{\Theta^0} > 623$ GeV (426 GeV) for $m_{G'} = 2.3\ m_{\Theta^0}$ ($m_{G'} = 5\ m_{\Theta^0}$).

[7] AALTONEN 13R search for new resonance decaying to $\sigma\sigma$, with hypothetical strongly interacting σ particle subsequently decaying to 2 jets, in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV, using data corresponding to an integrated luminosity of 6.6 fb^{-1}. For 50 GeV $< m_\sigma < m_{g_A}/2$, axigluons in mass range 150–400 GeV are excluded.

[8] CHATRCHYAN 13A search for new resonance decaying to dijets in pp collisions at $\sqrt{s}$ = 7 TeV.

[9] CHATRCHYAN 13AS search for new resonance decaying to dijets in pp collisions at $\sqrt{s}$ = 8 TeV.

[10] CHATRCHYAN 13AU search for the pair produced color-octet vector bosons decaying to $q\overline{q}$ pairs in pp collisions. The quoted limit is for B($g_A \to q\overline{q}$) = 1.

[11] ABAZOV 12R search for massive color octet vector particle decaying to $t\overline{t}$. The quoted limit assumes g_A couplings with light quarks are suppressed by 0.2.

[12] CHATRCHYAN 11Y search for new resonance decaying to dijets in pp collisions at $\sqrt{s} = 7$ TeV.

[13] AALTONEN 10L search for massive color octet non-chiral vector particle decaying into $t\overline{t}$ pair with mass in the range 400 GeV $<$ M $<$ 800 GeV. See their Fig. 6 for limit in the mass-coupling plane.

[14] KHACHATRYAN 10 search for new resonance decaying to dijets in pp collisions at $\sqrt{s} = 7$ TeV.

[15] AALTONEN 09AC search for new narrow resonance decaying to dijets.

[16] CHOUDHURY 07 limit is from the $t\overline{t}$ production cross section measured at CDF.

[17] DONCHESKI 98 compare α_s derived from low-energy data and that from $\Gamma(Z \rightarrow \text{hadrons})/\Gamma(Z \rightarrow \text{leptons})$.

[18] ABE 97G search for new particle decaying to dijets.

[19] ABE 95N assume axigluons decaying to quarks in the Standard Model only.

[20] ABE 93G assume $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 10$.

[21] CUYPERS 91 compare α_s measured in Υ decay and that from R at PEP/PETRA energies.

[22] 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.

[23] 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.

[24] 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.

[25] CUYPERS 88 requires $\Gamma(\Upsilon \rightarrow g g_A) < \Gamma(\Upsilon \rightarrow g g g)$. A similar result is obtained by DONCHESKI 88.

[26] 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.

MASS LIMITS for Color-Octet Scalar Bosons

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] KHACHATRY...	15AV	CMS	$pp \rightarrow \Theta^0 \Theta^0 \rightarrow b\overline{b} Z g$
none 150–287	95	[2] AAD	13K	ATLS	$pp \rightarrow S_8 S_8 X, S_8 \rightarrow 2$ jets

[1] KHACHATRYAN 15AV search for pair productions of neutral color-octet weak-triplet scalar particles (Θ^0), decaying to $b\overline{b}$, Zg or γg, in pp collisions at $\sqrt{s} = 8$ TeV. The Θ^0 particle is often predicted in coloron (G', color-octet gauge boson) models and appear in the pp collisions through $G' \rightarrow \Theta^0 \Theta^0$ decays. Assuming B($\Theta^0 \rightarrow b\overline{b}$) = 0.5, they give limits $m_{\Theta^0} > 623$ GeV (426 GeV) for $m_{G'} = 2.3\ m_{\Theta^0}$ ($m_{G'} = 5\ m_{\Theta^0}$).

[2] AAD 13K search for pair production of color-octet scalar particles in pp collisions at $\sqrt{s}$ = 7 TeV. Cross section limits are interpreted as mass limits on scalar partners of a Dirac gluino.

X^0 (Heavy Boson) Searches in Z Decays

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.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[1] BARATE	98U	ALEP	$X^0 \to \ell\overline{\ell}$, $q\overline{q}$, gg, $\gamma\gamma$, $\nu\overline{\nu}$
		[2] ACCIARRI	97Q	L3	$X^0 \to$ invisible particle(s)
		[3] ACTON	93E	OPAL	$X^0 \to \gamma\gamma$
		[4] ABREU	92D	DLPH	$X^0 \to$ hadrons
		[5] ADRIANI	92F	L3	$X^0 \to$ hadrons
		[6] ACTON	91	OPAL	$X^0 \to$ anything
$<1.1 \times 10^{-4}$	95	[7] ACTON	91B	OPAL	$X^0 \to e^+e^-$
$<9 \times 10^{-5}$	95	[7] ACTON	91B	OPAL	$X^0 \to \mu^+\mu^-$
$<1.1 \times 10^{-4}$	95	[7] ACTON	91B	OPAL	$X^0 \to \tau^+\tau^-$
$<2.8 \times 10^{-4}$	95	[8] ADEVA	91D	L3	$X^0 \to e^+e^-$
$<2.3 \times 10^{-4}$	95	[8] ADEVA	91D	L3	$X^0 \to \mu^+\mu^-$
$<4.7 \times 10^{-4}$	95	[9] ADEVA	91D	L3	$X^0 \to$ hadrons
$<8 \times 10^{-4}$	95	[10] AKRAWY	90J	OPAL	$X^0 \to$ hadrons

[1] BARATE 98U obtain limits on B($Z \to \gamma X^0$)B($X^0 \to \ell\overline{\ell}$, $q\overline{q}$, gg, $\gamma\gamma$, $\nu\overline{\nu}$). See their Fig. 17.

[2] See Fig. 4 of ACCIARRI 97Q for the upper limit on B($Z \to \gamma X^0$; $E_\gamma > E_{\text{min}}$) as a function of E_{min}.

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

[4] ABREU 92D give σ_Z $\cdot$ B($Z \to \gamma X^0$) $\cdot$ B($X^0 \to$ hadrons) $<$(3–10) pb for m_{X^0} = 10–78 GeV. A very similar limit is obtained for spin-1 X^0.

[5] ADRIANI 92F search for isolated γ in hadronic Z decays. The limit σ_Z $\cdot$ B($Z \to \gamma X^0$) $\cdot$ B($X^0 \to$ hadrons) $<$(2–10) pb (95%CL) is given for m_{X^0} = 25–85 GeV.

[6] ACTON 91 searches for $Z \to Z^* X^0$, $Z^* \to e^+e^-$, $\mu^+\mu^-$, 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.

[7] ACTON 91B limits are for m_{X^0} = 60–85 GeV.

[8] ADEVA 91D limits are for m_{X^0} = 30–89 GeV.

[9] ADEVA 91D limits are for m_{X^0} = 30–86 GeV.

[10] AKRAWY 90J give $\Gamma(Z \to \gamma X^0)\cdot$B($X^0 \to$ 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($Z \to \gamma q\overline{q}$) $<$ 8.2 MeV assuming three-body phase space distribution.

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 55–61		[1] ODAKA	89	VNS	$\Gamma(X^0 \rightarrow e^+ e^-) \cdot$ $B(X^0 \rightarrow \text{had.}) \gtrsim 0.2$ MeV
>45	95	[2] DERRICK	86	HRS	$\Gamma(X^0 \rightarrow e^+ e^-)$=6 MeV
>46.6	95	[3] ADEVA	85	MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-)$=10 keV
>48	95	[3] ADEVA	85	MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-)$=4 MeV
		[4] BERGER	85B	PLUT	
none 39.8–45.5		[5] ADEVA	84	MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-)$=10 keV
>47.8	95	[5] ADEVA	84	MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-)$=4 MeV
none 39.8–45.2		[5] BEHREND	84C	CELL	
>47	95	[5] BEHREND	84C	CELL	$\Gamma(X^0 \rightarrow e^+ e^-)$=4 MeV

[1] ODAKA 89 looked for a narrow or wide scalar resonance in $e^+ e^- \rightarrow$ hadrons at E_{cm} = 55.0–60.8 GeV.

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

[3] ADEVA 85 first limit is from 2γ, $\mu^+ \mu^-$, hadrons assuming X^0 is a scalar. Second limit is from $e^+ e^-$ channel. E_{cm} = 40–47 GeV. Supersedes ADEVA 84.

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

[5] ADEVA 84 and BEHREND 84C have E_{cm} = 39.8–45.5 GeV. MARK-J searched X^0 in $e^+ e^- \rightarrow$ hadrons, 2γ, $\mu^+ \mu^-$, $e^+ e^-$ and CELLO in the same channels plus τ pair. No narrow or broad X^0 is found in the energy range. They also searched for the effect of X^0 with $m_X > E_{cm}$. The second limits are from Bhabha data and for spin-0 singlet. The same limits apply for $\Gamma(X^0 \rightarrow e^+ e^-)$ = 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.

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

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

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<10^3$	95	[1] ABE	93C	VNS	$\Gamma(ee)$
$<(0.4–10)$	95	[2] ABE	93C	VNS	$f = \gamma\gamma$
$<(0.3–5)$	95	[3,4] ABE	93D	TOPZ	$f = \gamma\gamma$
$<(2–12)$	95	[3,4] ABE	93D	TOPZ	f = hadrons
$<(4–200)$	95	[4,5] ABE	93D	TOPZ	$f = ee$
$<(0.1–6)$	95	[4,5] ABE	93D	TOPZ	$f = \mu\mu$
$<(0.5–8)$	90	[6] STERNER	93	AMY	$f = \gamma\gamma$

[1] Limit is for $\Gamma(X^0 \to e^+e^-)$ m_{X^0} = 56–63.5 GeV for $\Gamma(X^0)$ = 0.5 GeV.
[2] 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 Γ = 1,2 GeV.
[3] Limit is for m_{X^0} = 57.2–60 GeV.
[4] Limit is valid for $\Gamma(X^0) \ll 100$ MeV. See paper for limits for Γ = 1 GeV and those for $J = 2$ resonances.
[5] Limit is for m_{X^0} = 56.6–60 GeV.
[6] 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 Γ = 1,3 GeV.

Search for X^0 Resonance in ep Collisions

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] CHEKANOV	02B	ZEUS	$X \to jj$

[1] 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.

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

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

[1] ABBIENDI 03D measure the $e^+e^- \to \gamma\gamma\gamma$ cross section at $\sqrt{s}$=181–209 GeV. The upper bound on the production cross section, $\sigma(e^+e^- \to X^0\gamma)$ times the branching ratio for $X^0 \to \gamma\gamma$, 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.
[2] 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.
[3] 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 $\sigma(e^+e^- \to \gamma X^0)$.

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

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

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

[1] ABREU 96T obtain limit as a function of m_{X^0}. See their Fig. 6.
[2] Limit is for m_{X^0} around 60 GeV.
[3] ABREU 96T obtain limit as a function of m_{X^0}. See their Fig. 15.
[4] ADRIANI 92F give $\sigma_Z \cdot$ B($Z \to q\overline{q}X^0$) $\cdot$ B($X^0 \to \gamma\gamma$)<(0.75–1.5) pb (95%CL) for m_{X^0} = 10–70 GeV. The limit is 1 pb at 60 GeV.

Search for X^0 Resonance in WX^0 final state

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] AALTONEN	13AA	CDF	$X^0 \to jj$
	[2] CHATRCHYAN	12BR	CMS	$X^0 \to jj$
	[3] ABAZOV	11I	D0	$X^0 \to jj$
	[4] ABE	97W	CDF	$X^0 \to b\overline{b}$

[1] AALTONEN 13AA search for X^0 production associated with W (or Z) in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. The upper limit on the cross section $\sigma(p\overline{p} \to WX^0)$ is 2.2 pb for M_{X^0} = 145 GeV.
[2] CHATRCHYAN 12BR search for X^0 production associated with W in pp collisions at E_{cm} = 7 TeV. The upper limit on the cross section is 5.0 pb at 95% CL for m_{X^0} = 150 GeV.
[3] ABAZOV 11I search for X^0 production associated with W in $p\overline{p}$ collisions at E_{cm} = 1.96 TeV. The 95% CL upper limit on the cross section ranges from 2.57 to 1.28 pb for X^0 mass between 110 and 170 GeV.
[4] 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 $X^0 \to b\overline{b}$ 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}.

Search for X^0 Resonance in Quarkonium Decays

Limits are for branching ratios to modes shown. Spin 1 is assumed for X^0.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<3\times10^{-5}$–6×10^{-3}	90	[1] BALEST	95	CLE2	$\Upsilon(1S) \to X^0\overline{X}^0\gamma$, $m_{X^0} < 3.9$ GeV

[1] BALEST 95 three-body limit is for phase-space photon energy distribution and angular distribution same as for $\Upsilon \to gg\gamma$.

REFERENCES FOR Searches for New Heavy Bosons (W', Z', leptoquarks, etc.)

AABOUD	17B	PL B765 32	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16	PL B759 229	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16AA	EPJ C76 585	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16AE	JHEP 1609 173	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16P	EPJ C76 541	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16U	PL B761 372	M. Aaboud et al.	(ATLAS Collab.)
AABOUD	16V	PL B762 334	M. Aaboud et al.	(ATLAS Collab.)
AAD	16G	EPJ C76 5	G. Aad et al.	(ATLAS Collab.)
AAD	16L	EPJ C76 210	G. Aad et al.	(ATLAS Collab.)
AAD	16R	PL B755 285	G. Aad et al.	(ATLAS Collab.)
AAD	16S	PL B754 302	G. Aad et al.	(ATLAS Collab.)
AAD	16W	PL B758 249	G. Aad et al.	(ATLAS Collab.)

BARRANCO	16	JP G43 115004	J. Barranco *et al.*	
DEY	16	JHEP 1604 187	U.K. Dey, S. Mohanty	
KHACHATRY...	16AF	PR D93 032004	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16AG	PR D93 032005	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16AO	JHEP 1602 122	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16AP	JHEP 1602 145	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16BD	EPJ C76 237	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16BE	EPJ C76 317	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16E	PR D93 012001	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16K	PRL 116 071801	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16L	PRL 117 031802	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16O	PL B755 196	V. Khachatryan *et al.*	(CMS Collab.)
KUMAR	16	PR D94 014022	G. Kumar	
AAD	15AM	JHEP 1507 157	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AO	JHEP 1508 148	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AT	EPJ C75 79	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AU	EPJ C75 69	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AV	EPJ C75 165	G. Aad *et al.*	(ATLAS Collab.)
AAD	15AZ	EPJ C75 209	G. Aad *et al.*	(ATLAS Collab.)
Also		EPJ C75 370 (errat.)	G. Aad *et al.*	(ATLAS Collab.)
AAD	15BB	EPJ C75 263	G. Aad *et al.*	(ATLAS Collab.)
AAD	15CD	PR D92 092001	G. Aad *et al.*	(ATLAS Collab.)
AAD	15CP	JHEP 1512 055	G. Aad *et al.*	(ATLAS Collab.)
AAD	15O	PRL 115 031801	G. Aad *et al.*	(ATLAS Collab.)
AAD	15R	PL B743 235	G. Aad *et al.*	(ATLAS Collab.)
AAD	15V	PR D91 052007	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	15C	PRL 115 061801	T. Aaltonen *et al.*	(CDF Collab.)
BESSAA	15	EPJ C75 97	A. Bessaa, S. Davidson	
KHACHATRY...	15AE	JHEP 1504 025	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15AJ	JHEP 1507 042	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15AV	JHEP 1509 201	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15C	PL B740 83	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15F	PRL 114 101801	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15O	PL B748 255	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15T	PR D91 092005	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15V	PR D91 052009	V. Khachatryan *et al.*	(CMS Collab.)
SAHOO	15A	PR D91 094019	S. Sahoo, R. Mohanta	
AAD	14AI	JHEP 1409 037	G. Aad *et al.*	(ATLAS Collab.)
AAD	14AT	PL B738 428	G. Aad *et al.*	(ATLAS Collab.)
AAD	14S	PL B737 223	G. Aad *et al.*	(ATLAS Collab.)
AAD	14V	PR D90 052005	G. Aad *et al.*	(ATLAS Collab.)
KHACHATRY...	14	JHEP 1408 173	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	14A	JHEP 1408 174	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	14O	EPJ C74 3149	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	14T	PL B739 229	V. Khachatryan *et al.*	(CMS Collab.)
MARTINEZ	14	PR D90 015028	R. Martinez, F. Ochoa	
PRIEELS	14	PR D90 112003	R. Prieels *et al.*	(LOUV, ETH, PSI+)
AAD	13AE	JHEP 1306 033	G. Aad *et al.*	(ATLAS Collab.)
AAD	13AO	PR D87 112006	G. Aad *et al.*	(ATLAS Collab.)
AAD	13AQ	PR D88 012004	G. Aad *et al.*	(ATLAS Collab.)
AAD	13D	JHEP 1301 029	G. Aad *et al.*	(ATLAS Collab.)
AAD	13G	JHEP 1301 116	G. Aad *et al.*	(ATLAS Collab.)
AAD	13K	EPJ C73 2263	G. Aad *et al.*	(ATLAS Collab.)
AAD	13S	PL B719 242	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	13A	PRL 110 121802	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	13AA	PR D88 092004	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	13R	PRL 111 031802	T. Aaltonen *et al.*	(CDF Collab.)
CHATRCHYAN	13A	JHEP 1301 013	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AF	PL B720 63	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AJ	PL B723 280	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AP	PR D87 072002	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AQ	PR D87 072005	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AS	PR D87 114015	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13AU	PRL 110 141802	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13BM	PRL 111 211804	S. Chatrchyan *et al.*	(CMS Collab.)
Also		PRL 112 119903 (errat.)	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13E	PL B718 1229	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13M	PRL 110 081801	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13U	JHEP 1302 036	S. Chatrchyan *et al.*	(CMS Collab.)
SAKAKI	13	PR D88 094012	Y. Sakaki *et al.*	
AAD	12AV	PRL 109 081801	G. Aad *et al.*	(ATLAS Collab.)

AAD	12BB	PR D85 112012	G. Aad *et al.*	(ATLAS Collab.)
AAD	12BV	JHEP 1209 041	G. Aad *et al.*	(ATLAS Collab.)
AAD	12CC	JHEP 1211 138	G. Aad *et al.*	(ATLAS Collab.)
AAD	12CK	PR D86 091103	G. Aad *et al.*	(ATLAS Collab.)
AAD	12CR	EPJ C72 2241	G. Aad *et al.*	(ATLAS Collab.)
AAD	12H	PL B709 158	G. Aad *et al.*	(ATLAS Collab.)
Also		PL B711 442 (errat.)	G. Aad *et al.*	(ATLAS Collab.)
AAD	12K	EPJ C72 2083	G. Aad *et al.*	(ATLAS Collab.)
AAD	12M	EPJ C72 2056	G. Aad *et al.*	(ATLAS Collab.)
AAD	12O	EPJ C72 2151	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	12AR	PR D86 112002	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	12N	PRL 108 211805	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	12R	PR D85 051101	V.M. Abazov *et al.*	(D0 Collab.)
ABRAMOWICZ	12A	PR D86 012005	H. Abramowicz *et al.*	(ZEUS Collab.)
CHATRCHYAN	12AF	PRL 109 141801	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12AG	PR D86 052013	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12AI	JHEP 1208 110	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12AQ	JHEP 1209 029	S. Chatrchyan *et al.*	(CMS Collab.)
Also		JHEP 1403 132 (errat.)	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12AR	PL B717 351	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12BG	PRL 109 261802	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12BL	JHEP 1212 015	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12BO	JHEP 1212 055	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12BR	PRL 109 251801	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12M	PL B714 158	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	12O	PL B716 82	S. Chatrchyan *et al.*	(CMS Collab.)
KOSNIK	12	PR D86 055004	N. Kosnik	(LALO, STFN)
AAD	11D	PR D83 112006	G. Aad *et al.*	(ATLAS Collab.)
AAD	11H	PRL 106 251801	G. Aad *et al.*	(ATLAS Collab.)
AAD	11Z	EPJ C71 1809	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	11AD	PR D84 072003	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	11AE	PR D84 072004	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	11C	PR D83 031102	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	11I	PRL 106 121801	T. Aaltonen *et al.*	(CDF Collab.)
AARON	11A	PL B701 20	F. D. Aaron *et al.*	(H1 Collab.)
AARON	11B	PL B704 388	F. D. Aaron *et al.*	(H1 Collab.)
AARON	11C	PL B705 52	F. D. Aaron *et al.*	(H1 Collab.)
ABAZOV	11A	PL B695 88	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	11H	PRL 107 011801	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	11I	PRL 107 011804	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	11L	PL B699 145	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	11V	PR D84 071104	V.M. Abazov *et al.*	(D0 Collab.)
BUENO	11	PR D84 032005	J.F. Bueno *et al.*	(TWIST Collab.)
Also		PR D85 039908 (errat.)	J.F. Bueno *et al.*	(TWIST Collab.)
CHATRCHYAN	11N	PL B703 246	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	11O	JHEP 1108 005	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	11Y	PL B704 123	S. Chatrchyan *et al.*	(CMS Collab.)
DORSNER	11	JHEP 1111 002	I. Dorsner *et al.*	
KHACHATRY...	11D	PRL 106 201802	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	11E	PRL 106 201803	V. Khachatryan *et al.*	(CMS Collab.)
AALTONEN	10L	PL B691 183	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	10N	PRL 104 241801	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	10L	PL B693 95	V.M. Abazov *et al.*	(D0 Collab.)
DEL-AGUILA	10	JHEP 1009 033	F. del Aguila, J. de Blas, M. Perez-Victoria	(GRAN)
KHACHATRY...	10	PRL 105 211801	V. Khachatryan *et al.*	(CMS Collab.)
Also		PRL 106 029902	V. Khachatryan *et al.*	(CMS Collab.)
WAUTERS	10	PR C82 055502	F. Wauters *et al.*	(REZ, TAMU)
AALTONEN	09AC	PR D79 112002	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	09T	PRL 102 031801	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	09V	PRL 102 091805	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	09	PL B671 224	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	09AF	PL B681 224	V.M. Abazov *et al.*	(D0 Collab.)
ERLER	09	JHEP 0908 017	J. Erler *et al.*	
AALTONEN	08D	PR D77 051102	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	08P	PR D77 091105	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	08Y	PRL 100 231801	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	08Z	PRL 101 071802	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	08AA	PL B668 98	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	08AD	PL B668 357	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	08AN	PRL 101 241802	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	08C	PRL 100 031804	V.M. Abazov *et al.*	(D0 Collab.)

MACDONALD	08	PR D78 032010	R.P. MacDonald *et al.*	(TWIST Collab.)
ZHANG	08	NP B802 247	Y. Zhang *et al.*	(PKGU, UMD)
AALTONEN	07H	PRL 99 171802	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	07E	PL B647 74	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	07J	PRL 99 061801	V.M. Abazov *et al.*	(D0 Collab.)
AKTAS	07A	EPJ C52 833	A. Aktas *et al.*	(H1 Collab.)
CHOUDHURY	07	PL B657 69	D. Choudhury *et al.*	
MELCONIAN	07	PL B649 370	D. Melconian *et al.*	(TRIUMF)
SCHAEL	07A	EPJ C49 411	S. Schael *et al.*	(ALEPH Collab.)
SCHUMANN	07	PRL 99 191803	M. Schumann *et al.*	(HEID, ILLG, KARL+)
SMIRNOV	07	MPL A22 2353	A.D. Smirnov	
ABAZOV	06A	PL B636 183	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	06L	PL B640 230	V.M. Abazov *et al.*	(D0 Collab.)
ABDALLAH	06C	EPJ C45 589	J. Abdallah *et al.*	(DELPHI Collab.)
ABULENCIA	06L	PRL 96 211801	A. Abulencia *et al.*	(CDF Collab.)
ABULENCIA	06M	PRL 96 211802	A. Abulencia *et al.*	(CDF Collab.)
ABULENCIA	06T	PR D73 051102	A. Abulencia *et al.*	(CDF Collab.)
ABAZOV	05H	PR D71 071104	V.M. Abazov *et al.*	(D0 Collab.)
ABULENCIA	05A	PRL 95 252001	A. Abulencia *et al.*	(CDF Collab.)
ACOSTA	05I	PR D71 112001	D. Acosta *et al.*	(CDF Collab.)
ACOSTA	05P	PR D72 051107	D. Acosta *et al.*	(CDF Collab.)
ACOSTA	05R	PRL 95 131801	D. Acosta *et al.*	(CDF Collab.)
AKTAS	05B	PL B629 9	A. Aktas *et al.*	(H1 Collab.)
CHEKANOV	05	PL B610 212	S. Chekanov *et al.*	(HERA ZEUS Collab.)
CHEKANOV	05A	EPJ C44 463	S. Chekanov *et al.*	(ZEUS Collab.)
CYBURT	05	ASP 23 313	R.H. Cyburt *et al.*	
ABAZOV	04A	PRL 92 221801	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	04C	PR D69 111101	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	04G	EPJ C33 173	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	03D	EPJ C26 331	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	03R	EPJ C31 281	G. Abbiendi *et al.*	(OPAL)
ACOSTA	03B	PRL 90 081802	D. Acosta *et al.*	(CDF Collab.)
ADLOFF	03	PL B568 35	C. Adloff *et al.*	(H1 Collab.)
BARGER	03B	PR D67 075009	V. Barger, P. Langacker, H. Lee	
CHANG	03	PR D68 111101	M.-C. Chang *et al.*	(BELLE Collab.)
CHEKANOV	03B	PR D68 052004	S. Chekanov *et al.*	(ZEUS Collab.)
ABAZOV	02	PRL 88 191801	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	02B	PL B526 233	G. Abbiendi *et al.*	(OPAL Collab.)
AFFOLDER	02C	PRL 88 071806	T. Affolder *et al.*	(CDF Collab.)
CHEKANOV	02	PR D65 092004	S. Chekanov *et al.*	(ZEUS Collab.)
CHEKANOV	02B	PL B531 9	S. Chekanov *et al.*	(ZEUS Collab.)
MUECK	02	PR D65 085037	A. Mueck, A. Pilaftsis, R. Rueckl	
ABAZOV	01B	PRL 87 061802	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	01D	PR D64 092004	V.M. Abazov *et al.*	(D0 Collab.)
ADLOFF	01C	PL B523 234	C. Adloff *et al.*	(H1 Collab.)
AFFOLDER	01I	PRL 87 231803	T. Affolder *et al.*	(CDF Collab.)
BREITWEG	01	PR D63 052002	J. Breitweg *et al.*	(ZEUS Collab.)
CHEUNG	01B	PL B517 167	K. Cheung	
THOMAS	01	NP A694 559	E. Thomas *et al.*	
ABBIENDI	00M	EPJ C13 15	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	00C	PRL 84 2088	B. Abbott *et al.*	(D0 Collab.)
ABE	00	PRL 84 5716	F. Abe *et al.*	(CDF Collab.)
ABREU	00S	PL B485 45	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00Z	EPJ C17 53	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	00P	PL B489 81	M. Acciarri *et al.*	(L3 Collab.)
ADLOFF	00	PL B479 358	C. Adloff *et al.*	(H1 Collab.)
AFFOLDER	00K	PRL 85 2056	T. Affolder *et al.*	(CDF Collab.)
BARATE	00I	EPJ C12 183	R. Barate *et al.*	(ALEPH Collab.)
BARGER	00	PL B480 149	V. Barger, K. Cheung	
BREITWEG	00E	EPJ C16 253	J. Breitweg *et al.*	(ZEUS Collab.)
CHAY	00	PR D61 035002	J. Chay, K.Y. Lee, S. Nam	
CHO	00	MPL A15 311	G. Cho	
CORNET	00	PR D61 037701	F. Cornet, M. Relano, J. Rico	
DELGADO	00	JHEP 0001 030	A. Delgado, A. Pomarol, M. Quiros	
ERLER	00	PRL 84 212	J. Erler, P. Langacker	
GABRIELLI	00	PR D62 055009	E. Gabrielli	
RIZZO	00	PR D61 016007	T.G. Rizzo, J.D. Wells	
ROSNER	00	PR D61 016006	J.L. Rosner	
ZARNECKI	00	EPJ C17 695	A. Zarnecki	
ABBIENDI	99	EPJ C6 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	99J	PRL 83 2896	B. Abbott *et al.*	(D0 Collab.)

ABREU	99G	PL B446 62	P. Abreu *et al.*	(DELPHI Collab.)
ACKERSTAFF	99D	EPJ C8 3	K. Ackerstaff *et al.*	(OPAL Collab.)
ADLOFF	99	EPJ C11 447	C. Adloff *et al.*	(H1 Collab.)
Also		EPJ C14 553 (errat.)	C. Adloff *et al.*	(H1 Collab.)
CASALBUONI	99	PL B460 135	R. Casalbuoni *et al.*	
CZAKON	99	PL B458 355	M. Czakon, J. Gluza, M. Zralek	
ERLER	99	PL B456 68	J. Erler, P. Langacker	
MARCIANO	99	PR D60 093006	W. Marciano	
MASIP	99	PR D60 096005	M. Masip, A. Pomarol	
NATH	99	PR D60 116004	P. Nath, M. Yamaguchi	
STRUMIA	99	PL B466 107	A. Strumia	
ABBOTT	98E	PRL 80 2051	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	98J	PRL 81 38	B. Abbott *et al.*	(D0 Collab.)
ABE	98S	PRL 81 4806	F. Abe *et al.*	(CDF Collab.)
ABE	98V	PRL 81 5742	F. Abe *et al.*	(CDF Collab.)
ACCIARRI	98J	PL B433 163	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	98V	EPJ C2 441	K. Ackerstaff *et al.*	(OPAL Collab.)
BARATE	98U	EPJ C4 571	R. Barate *et al.*	(ALEPH Collab.)
BARENBOIM	98	EPJ C1 369	G. Barenboim	
CHO	98	EPJ C5 155	G. Cho, K. Hagiwara, S. Matsumoto	
CONRAD	98	RMP 70 1341	J.M. Conrad, M.H. Shaevitz, T. Bolton	
DONCHESKI	98	PR D58 097702	M.A. Doncheski, R.W. Robinett	
GROSS-PILCH...	98	hep-ex/9810015	C. Grosso-Pilcher, G. Landsberg, M. Paterno	
ABE	97F	PRL 78 2906	F. Abe *et al.*	(CDF Collab.)
ABE	97G	PR D55 R5263	F. Abe *et al.*	(CDF Collab.)
ABE	97S	PRL 79 2192	F. Abe *et al.*	(CDF Collab.)
ABE	97W	PRL 79 3819	F. Abe *et al.*	(CDF Collab.)
ABE	97X	PRL 79 4327	F. Abe *et al.*	(CDF Collab.)
ACCIARRI	97Q	PL B412 201	M. Acciarri *et al.*	(L3 Collab.)
ARIMA	97	PR D55 19	T. Arima *et al.*	(VENUS Collab.)
BARENBOIM	97	PR D55 4213	G. Barenboim *et al.*	(VALE, IFIC)
DEANDREA	97	PL B409 277	A. Deandrea	(MARS)
DERRICK	97	ZPHY C73 613	M. Derrick *et al.*	(ZEUS Collab.)
GROSSMAN	97	PR D55 2768	Y. Grossman, Z. Ligeti, E. Nardi	(REHO, CIT)
JADACH	97	PL B408 281	S. Jadach, B.F.L. Ward, Z. Was	(CERN, INPK+)
STAHL	97	ZPHY C74 73	A. Stahl, H. Voss	(BONN)
ABACHI	96C	PRL 76 3271	S. Abachi *et al.*	(D0 Collab.)
ABREU	96T	ZPHY C72 179	P. Abreu *et al.*	(DELPHI Collab.)
ADAM	96C	PL B380 471	W. Adam *et al.*	(DELPHI Collab.)
AID	96B	PL B369 173	S. Aid *et al.*	(H1 Collab.)
ALLET	96	PL B383 139	M. Allet *et al.*	(VILL, LEUV, LOUV, WISC)
ABACHI	95E	PL B358 405	S. Abachi *et al.*	(D0 Collab.)
ABE	95N	PRL 74 3538	F. Abe *et al.*	(CDF Collab.)
BALEST	95	PR D51 2053	R. Balest *et al.*	(CLEO Collab.)
KUZNETSOV	95	PRL 75 794	I.A. Kuznetsov *et al.*	(PNPI, KIAE, HARV+)
KUZNETSOV	95B	PAN 58 2113	A.V. Kuznetsov, N.V. Mikheev	(YARO)
		Translated from YAF 58 2228.		
MIZUKOSHI	95	NP B443 20	J.K. Mizukoshi, O.J.P. Eboli, M.C. Gonzalez-Garcia	
ABREU	94O	ZPHY C64 183	P. Abreu *et al.*	(DELPHI Collab.)
BHATTACH...	94	PL B336 100	G. Bhattacharyya, J. Ellis, K. Sridhar	(CERN)
Also		PL B338 522 (erratum)	G. Bhattacharyya, J. Ellis, K. Sridhar	(CERN)
BHATTACH...	94B	PL B338 522 (erratum)	G. Bhattacharyya, J. Ellis, K. Sridhar	(CERN)
DAVIDSON	94	ZPHY C61 613	S. Davidson, D. Bailey, B.A. Campbell	(CFPA+)
KUZNETSOV	94	PL B329 295	A.V. Kuznetsov, N.V. Mikheev	(YARO)
KUZNETSOV	94B	JETPL 60 315	I.A. Kuznetsov *et al.*	(PNPI, KIAE, HARV+)
		Translated from ZETFP 60 311.		
LEURER	94	PR D50 536	M. Leurer	(REHO)
LEURER	94B	PR D49 333	M. Leurer	(REHO)
Also		PRL 71 1324	M. Leurer	(REHO)
MAHANTA	94	PL B337 128	U. Mahanta	(MEHTA)
SEVERIJNS	94	PRL 73 611 (erratum)	N. Severijns *et al.*	(LOUV, WISC, LEUV+)
VILAIN	94B	PL B332 465	P. Vilain *et al.*	(CHARM II Collab.)
ABE	93C	PL B302 119	K. Abe *et al.*	(VENUS Collab.)
ABE	93D	PL B304 373	T. Abe *et al.*	(TOPAZ Collab.)
ABE	93G	PRL 71 2542	F. Abe *et al.*	(CDF Collab.)
ABREU	93J	PL B316 620	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	93E	PL B311 391	P.D. Acton *et al.*	(OPAL Collab.)
ADRIANI	93M	PRPL 236 1	O. Adriani *et al.*	(L3 Collab.)
ALITTI	93	NP B400 3	J. Alitti *et al.*	(UA2 Collab.)
BHATTACH...	93	PR D47 R3693	G. Bhattacharyya *et al.*	(CALC, JADA, ICTP+)
BUSKULIC	93F	PL B308 425	D. Buskulic *et al.*	(ALEPH Collab.)

DERRICK	93	PL B306 173	M. Derrick *et al.*	(ZEUS Collab.)
RIZZO	93	PR D48 4470	T.G. Rizzo	(ANL)
SEVERIJNS	93	PRL 70 4047	N. Severijns *et al.*	(LOUV, WISC, LEUV+)
Also		PRL 73 611 (erratum)	N. Severijns *et al.*	(LOUV, WISC, LEUV+)
STERNER	93	PL B303 385	K.L. Sterner *et al.*	(AMY Collab.)
ABREU	92D	ZPHY C53 555	P. Abreu *et al.*	(DELPHI Collab.)
ADRIANI	92F	PL B292 472	O. Adriani *et al.*	(L3 Collab.)
DECAMP	92	PRPL 216 253	D. Decamp *et al.*	(ALEPH Collab.)
IMAZATO	92	PRL 69 877	J. Imazato *et al.*	(KEK, INUS, TOKY+)
MISHRA	92	PRL 68 3499	S.R. Mishra *et al.*	(COLU, CHIC, FNAL+)
POLAK	92B	PR D46 3871	J. Polak, M. Zralek	(SILES)
ACTON	91	PL B268 122	D.P. Acton *et al.*	(OPAL Collab.)
ACTON	91B	PL B273 338	D.P. Acton *et al.*	(OPAL Collab.)
ADEVA	91D	PL B262 155	B. Adeva *et al.*	(L3 Collab.)
AQUINO	91	PL B261 280	M. Aquino, A. Fernandez, A. Garcia	(CINV, PUEB)
COLANGELO	91	PL B253 154	P. Colangelo, G. Nardulli	(BARI)
CUYPERS	91	PL B259 173	F. Cuypers, A.F. Falk, P.H. Frampton	(DURH, HARV+)
FARAGGI	91	MPL A6 61	A.E. Faraggi, D.V. Nanopoulos	(TAMU)
POLAK	91	NP B363 385	J. Polak, M. Zralek	(SILES)
RIZZO	91	PR D44 202	T.G. Rizzo	(WISC, ISU)
WALKER	91	APJ 376 51	T.P. Walker *et al.*	(HSCA, OSU, CHIC+)
ABE	90F	PL B246 297	K. Abe *et al.*	(VENUS Collab.)
ABE	90H	PR D41 1722	F. Abe *et al.*	(CDF Collab.)
AKRAWY	90J	PL B246 285	M.Z. Akrawy *et al.*	(OPAL Collab.)
GONZALEZ...	90D	PL B240 163	M.C. Gonzalez-Garcia, J.W.F. Valle	(VALE)
GRIFOLS	90	NP B331 244	J.A. Grifols, E. Masso	(BARC)
GRIFOLS	90D	PR D42 3293	J.A. Grifols, E. Masso, T.G. Rizzo	(BARC, CERN+)
KIM	90	PL B240 243	G.N. Kim *et al.*	(AMY Collab.)
LOPEZ	90	PL B241 392	J.L. Lopez, D.V. Nanopoulos	(TAMU)
BARBIERI	89B	PR D39 1229	R. Barbieri, R.N. Mohapatra	(PISA, UMD)
LANGACKER	89B	PR D40 1569	P. Langacker, S. Uma Sankar	(PENN)
ODAKA	89	JPSJ 58 3037	S. Odaka *et al.*	(VENUS Collab.)
ROBINETT	89	PR D39 834	R.W. Robinett	(PSU)
ALBAJAR	88B	PL B209 127	C. Albajar *et al.*	(UA1 Collab.)
BAGGER	88	PR D37 1188	J. Bagger, C. Schmidt, S. King	(HARV, BOST)
BALKE	88	PR D37 587	B. Balke *et al.*	(LBL, UCB, COLO, NWES+)
BERGSTROM	88	PL B212 386	L. Bergstrom	(STOH)
CUYPERS	88	PRL 60 1237	F. Cuypers, P.H. Frampton	(UNCCH)
DONCHESKI	88	PL B206 137	M.A. Doncheski, H. Grotch, R. Robinett	(PSU)
DONCHESKI	88B	PR D38 412	M.A. Doncheski, H. Grotch, R.W. Robinett	(PSU)
BARTEL	87B	ZPHY C36 15	W. Bartel *et al.*	(JADE Collab.)
BEHREND	86B	PL B178 452	H.J. Behrend *et al.*	(CELLO Collab.)
DERRICK	86	PL 166B 463	M. Derrick *et al.*	(HRS Collab.)
Also		PR D34 3286	M. Derrick *et al.*	(HRS Collab.)
JODIDIO	86	PR D34 1967	A. Jodidio *et al.*	(LBL, NWES, TRIU)
Also		PR D37 237 (erratum)	A. Jodidio *et al.*	(LBL, NWES, TRIU)
MOHAPATRA	86	PR D34 909	R.N. Mohapatra	(UMD)
ADEVA	85	PL 152B 439	B. Adeva *et al.*	(Mark-J Collab.)
BERGER	85B	ZPHY C27 341	C. Berger *et al.*	(PLUTO Collab.)
STOKER	85	PRL 54 1887	D.P. Stoker *et al.*	(LBL, NWES, TRIU)
ADEVA	84	PRL 53 134	B. Adeva *et al.*	(Mark-J Collab.)
BEHREND	84C	PL 140B 130	H.J. Behrend *et al.*	(CELLO Collab.)
BERGSMA	83	PL 122B 465	F. Bergsma *et al.*	(CHARM Collab.)
CARR	83	PRL 51 627	J. Carr *et al.*	(LBL, NWES, TRIU)
BEALL	82	PRL 48 848	G. Beall, M. Bander, A. Soni	(UCI, UCLA)
SHANKER	82	NP B204 375	O. Shanker	(TRIU)