

Heavy Bosons Other Than Higgs Bosons, 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 axiguons.

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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 $p\bar{p} \rightarrow W'X$ with W' decaying to the mode indicated in the comments. New decay channels (e.g., $W' \rightarrow WZ$) are assumed to be suppressed. UA1 and UA2 experiments assume that the $t\bar{b}$ channel is not open.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>1000	95	ABAZOV	08C D0	$W' \rightarrow e\nu$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 800	95	¹ AALTONEN	09AA CDF	$W' \rightarrow tb$
none 280–840	95	² AALTONEN	09AC CDF	$W' \rightarrow q\bar{q}$
> 731	95	³ ABAZOV	08P D0	$W' \rightarrow tb$
> 788	95	ABULENCIA	07K CDF	$W' \rightarrow e\nu$
none 200–610	95	⁴ ABAZOV	06N D0	$W' \rightarrow tb$
> 800	95	ABAZOV	04C D0	$W' \rightarrow q\bar{q}$
225–536	95	⁵ ACOSTA	03B CDF	$W' \rightarrow tb$
none 200–480	95	⁶ AFFOLDER	02C CDF	$W' \rightarrow WZ$
> 786	95	⁷ AFFOLDER	01I CDF	$W' \rightarrow e\nu, \mu\nu$
> 660	95	⁸ ABE	00 CDF	$W' \rightarrow \mu\nu$
none 300–420	95	⁹ ABE	97G CDF	$W' \rightarrow q\bar{q}$
> 720	95	¹⁰ ABACHI	96C D0	$W' \rightarrow e\nu$
> 610	95	¹¹ ABACHI	95E D0	$W' \rightarrow e\nu, \tau\nu$
> 652	95	¹² ABE	95M CDF	$W' \rightarrow e\nu$
> 251	90	¹³ ALITTI	93 UA2	$W' \rightarrow q\bar{q}$
none 260–600	95	¹⁴ RIZZO	93 RVUE	$W' \rightarrow q\bar{q}$
> 220	90	¹⁵ ALBAJAR	89 UA1	$W' \rightarrow e\nu$
> 209	90	¹⁶ ANSARI	87D UA2	$W' \rightarrow e\nu$

¹ The AALTONEN 09AA quoted limit is for a right-handed W' with SM-like coupling allowing $W' \rightarrow \ell\nu$ decays.

² AALTONEN 09AC search for new particle decaying to dijets.

³ The ABAZOV 08P quoted limit is for W' with SM-like coupling which interferes with the SM W boson. For W' with right-handed coupling, the bound becomes >739 GeV (>768 GeV) if W' decays to both leptons and quarks (only to quarks).

⁴ The ABAZOV 06N quoted limit is for W' with SM-like coupling which interferes with the SM W boson. For W' with right-handed coupling, $M_{W'}$ between 200 and 630 (670) GeV is excluded for $M_{\nu_R} \ll M_{W'}$ ($M_{\nu_R} > M_{W'}$).

⁵ The ACOSTA 03B quoted limit is for $M_{W'} \gg M_{\nu_R}$. For $M_{W'} < M_{\nu_R}$, $M_{W'}$ between 225 and 566 GeV is excluded.

- ⁶ The quoted limit is obtained assuming $W' W Z$ coupling strength is the same as the ordinary $W W Z$ coupling strength in the Standard Model. See their Fig. 2 for the limits on the production cross sections as a function of the W' width.
- ⁷ AFFOLDER 01i combine a new bound on $W' \rightarrow e\nu$ of 754 GeV with the bound of ABE 00 on $W' \rightarrow \mu\nu$ to obtain quoted bound.
- ⁸ ABE 00 assume that the neutrino from W' decay is stable and has a mass significantly less than $m_{W'}$.
- ⁹ ABE 97G search for new particle decaying to dijets.
- ¹⁰ For bounds on W_R with nonzero right-handed mass, see Fig. 5 from ABACHI 96C.
- ¹¹ ABACHI 95E assume that the decay $W' \rightarrow W Z$ is suppressed and that the neutrino from W' decay is stable and has a mass significantly less $m_{W'}$.
- ¹² ABE 95M assume that the decay $W' \rightarrow W Z$ is suppressed and the (right-handed) neutrino is light, noninteracting, and stable. If $m_{\nu} = 60$ GeV, for example, the effect on the mass limit is negligible.
- ¹³ ALITTI 93 search for resonances in the two-jet invariant mass. The limit assumes $\Gamma(W')/m_{W'} = \Gamma(W)/m_W$ and $B(W' \rightarrow jj) = 2/3$. This corresponds to W_R with $m_{\nu_R} > m_{W_R}$ (no leptonic decay) and $W_R \rightarrow t\bar{b}$ allowed. See their Fig. 4 for limits in the $m_{W'} - B(q\bar{q})$ plane.
- ¹⁴ RIZZO 93 analyses CDF limit on possible two-jet resonances. The limit is sensitive to the inclusion of the assumed K factor.
- ¹⁵ ALBAJAR 89 cross section limit at 630 GeV is $\sigma(W') B(e\nu) < 4.1$ pb (90% CL).
- ¹⁶ See Fig. 5 of ANSARI 87D for the excluded region in the $m_{W'} - [(g_{W'q})^2 B(W' \rightarrow e\bar{\nu})]$ plane. Note that the quantity $(g_{W'q})^2 B(W' \rightarrow e\bar{\nu})$ is normalized to unity for the standard W couplings.

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
> 715	90	¹⁷ CZAKON	99	RVUE Electroweak
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 180	90	¹⁸ MELCONIAN	07	CNTR ³⁷ K β^+ decay
> 290.7	90	¹⁹ SCHUMANN	07	CNTR Polarized neutron decay
[> 3300]	95	²⁰ CYBURT	05	COSM Nucleosynthesis; light ν_R
> 310	90	²¹ THOMAS	01	CNTR β^+ decay
> 137	95	²² ACKERSTAFF	99D	OPAL τ decay
> 1400	68	²³ BARENBOIM	98	RVUE Electroweak, $Z - Z'$ mixing
> 549	68	²⁴ BARENBOIM	97	RVUE μ decay
> 220	95	²⁵ STAHL	97	RVUE τ decay
> 220	90	²⁶ ALLET	96	CNTR β^+ decay
> 281	90	²⁷ KUZNETSOV	95	CNTR Polarized neutron decay
> 282	90	²⁸ KUZNETSOV	94B	CNTR Polarized neutron decay
> 439	90	²⁹ BHATTACH...	93	RVUE $Z - Z'$ mixing
> 250	90	³⁰ SEVERIJNS	93	CNTR β^+ decay
		³¹ IMAZATO	92	CNTR K^+ decay

> 475	90	32 POLAK	92B	RVUE	μ decay
> 240	90	33 AQUINO	91	RVUE	Neutron decay
> 496	90	33 AQUINO	91	RVUE	Neutron and muon decay
> 700		34 COLANGELO	91	THEO	$m_{K_L^0} - m_{K_S^0}$
> 477	90	35 POLAK	91	RVUE	μ decay
[none 540–23000]		36 BARBIERI	89B	ASTR	SN 1987A; light ν_R
> 300	90	37 LANGACKER	89B	RVUE	General
> 160	90	38 BALKE	88	CNTR	$\mu \rightarrow e \nu \bar{\nu}$
> 406	90	39 JODIDIO	86	ELEC	Any ζ
> 482	90	39 JODIDIO	86	ELEC	$\zeta = 0$
> 800		MOHAPATRA	86	RVUE	$SU(2)_L \times SU(2)_R \times U(1)$
> 400	95	40 STOKER	85	ELEC	Any ζ
> 475	95	40 STOKER	85	ELEC	$\zeta < 0.041$
		41 BERGSMA	83	CHRM	$\nu_\mu e \rightarrow \mu \nu_e$
> 380	90	42 CARR	83	ELEC	μ^+ decay
>1600		43 BEALL	82	THEO	$m_{K_L^0} - m_{K_S^0}$

- ¹⁷ CZAKON 99 perform a simultaneous fit to charged and neutral sectors.
- ¹⁸ 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.
- ¹⁹ 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.
- ²⁰ 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 $M_{W_R} > 3.3 \text{ TeV} (T_{dec} / 140 \text{ MeV})^{3/4}$.
- ²¹ THOMAS 01 limit is from measurement of β^+ polarization in decay of polarized ^{12}N . The listed limit assumes no mixing.
- ²² ACKERSTAFF 99D limit is from τ decay parameters. Limit increase to 145 GeV for zero mixing.
- ²³ 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.
- ²⁴ The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from $K_L - K_S$ mass difference.
- ²⁵ STAHL 97 limit is from fit to τ -decay parameters.
- ²⁶ ALLET 96 measured polarization-asymmetry correlation in $^{12}\text{N} \beta^+$ decay. The listed limit assumes zero L - R mixing.
- ²⁷ 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.
- ²⁸ 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.
- ²⁹ 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 .
- ³⁰ SEVERIJNS 93 measured polarization-asymmetry correlation in $^{107}\text{In} \beta^+$ decay. The listed limit assumes zero L - R mixing. Value quoted here is from SEVERIJNS 94 erratum.
- ³¹ 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 $u\bar{s}$ with full weak strength ($V_{us}^R = 1$), the result corresponds to $m_{W_R} > 653$ GeV. See their Fig. 4 for m_{W_R} limits for general $|V_{us}^R|^2 = 1 - |V_{ud}^R|^2$.

- 32 POLAK 92B limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming $\zeta=0$. Supersedes POLAK 91.
- 33 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.
- 34 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.
- 35 POLAK 91 limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming $\zeta=0$. Superseded by POLAK 92B.
- 36 BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.
- 37 LANGACKER 89B limit is for any ν_R mass (either Dirac or Majorana) and for a general class of right-handed quark mixing matrices.
- 38 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.
- 39 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^+ .
- 40 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.
- 41 BERGSMA 83 set limit $m_{W_2}/m_{W_1} > 1.9$ at CL = 90%.
- 42 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.
- 43 BEALL 82 limit is obtained assuming that W_R contribution to $K_L^0-K_S^0$ 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. ● ● ●				
< 0.022	90	MACDONALD 08	TWST	$\mu \rightarrow e \nu \bar{\nu}$
< 0.12	95	44 ACKERSTAFF 99D	OPAL	τ decay
< 0.013	90	45 CZAKON 99	RVUE	Electroweak
< 0.0333		46 BARENBOIM 97	RVUE	μ decay
< 0.04	90	47 MISHRA 92	CCFR	νN scattering
-0.0006 to 0.0028	90	48 AQUINO 91	RVUE	
[none 0.00001-0.02]		49 BARBIERI 89B	ASTR	SN 1987A
< 0.040	90	50 JODIDIO 86	ELEC	μ decay
-0.056 to 0.040	90	50 JODIDIO 86	ELEC	μ decay

- 44 ACKERSTAFF 99D limit is from τ decay parameters.
 45 CZAKON 99 perform a simultaneous fit to charged and neutral sectors.
 46 The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L-K_S mass difference.
 47 MISHRA 92 limit is from the absence of extra large- x , large- y $\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu X$ events at Tevatron, assuming left-handed ν and right-handed $\bar{\nu}$ in the neutrino beam. The result gives $\zeta^2(1-2m_{W_1}^2/m_{W_2}^2) < 0.0015$. The limit is independent of ν_R mass.
 48 AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right asymmetry is assumed.
 49 BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.
 50 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.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>1030	95	51 AALTONEN	09V CDF	$p\bar{p}; Z'_{SM} \rightarrow \mu^+ \mu^-$
>1305	95	52 ABDALLAH	06C DLPH	$e^+ e^-$
>1500	95	53 CHEUNG	01B RVUE	Electroweak
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
none 320–740	95	54 AALTONEN	09AC CDF	$Z' \rightarrow q\bar{q}$
> 963	95	55 AALTONEN	09T CDF	$p\bar{p}; Z'_{SM} \rightarrow e^+ e^-$
>1403	95	56 ERLER	09 RVUE	Electroweak
> 923	95	55 AALTONEN	07H CDF	Repl. by AALTONEN 09T
> 850		55 ABULENCIA	06L CDF	Repl. by AALTONEN 07H
> 825	95	57 ABULENCIA	05A CDF	$p\bar{p}; Z'_{SM} \rightarrow e^+ e^-, \mu^+ \mu^-$
> 399	95	58 ACOSTA	05R CDF	$\bar{p}p; Z'_{SM} \rightarrow \tau^+ \tau^-$
none 400–640	95	ABAZOV	04C D0	$p\bar{p}; Z'_{SM} \rightarrow q\bar{q}$
>1018	95	59 ABBIENDI	04G OPAL	$e^+ e^-$
> 670	95	60 ABAZOV	01B D0	$p\bar{p}; Z'_{SM} \rightarrow e^+ e^-$
> 710	95	61 ABREU	00S DLPH	$e^+ e^-$
> 898	95	62 BARATE	00I ALEP	$e^+ e^-$
> 809	95	63 ERLER	99 RVUE	Electroweak
> 690	95	64 ABE	97S CDF	$p\bar{p}; Z'_{SM} \rightarrow e^+ e^-, \mu^+ \mu^-$
> 490	95	ABACHI	96D D0	$p\bar{p}; Z'_{SM} \rightarrow e^+ e^-$
> 398	95	65 VILAIN	94B CHM2	$\nu_\mu e \rightarrow \nu_\mu e$ and $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
> 237	90	66 ALITTI	93 UA2	$p\bar{p}; Z'_{SM} \rightarrow q\bar{q}$
none 260–600	95	67 RIZZO	93 RVUE	$p\bar{p}; Z'_{SM} \rightarrow q\bar{q}$
> 426	90	68 ABE	90F VNS	$e^+ e^-$

- 51 AALTONEN 09V search for resonances decaying to $\mu^+\mu^-$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 52 ABDALLAH 06C use data $\sqrt{s} = 130\text{--}207$ GeV.
- 53 CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
- 54 AALTONEN 09AC search for new particle decaying to dijets.
- 55 AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 56 ERLER 09 give 95% CL limit on the Z - Z' mixing $-0.0026 < \theta < 0.0006$.
- 57 ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 58 ACOSTA 05R search for resonances decaying to tau lepton pairs in $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV.
- 59 ABBIENDI 04G give 95% CL limit on Z - Z' mixing $-0.00422 < \theta < 0.00091$. $\sqrt{s} = 91$ to 207 GeV.
- 60 ABAZOV 01B search for resonances in $p\bar{p} \rightarrow e^+e^-$ at $\sqrt{s}=1.8$ TeV. They find $\sigma \cdot B(Z' \rightarrow ee) < 0.06$ pb for $M_{Z'} > 500$ GeV.
- 61 ABREU 00S uses LEP data at $\sqrt{s}=90$ to 189 GeV.
- 62 BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s}=90$ to 183 GeV. Assume $\theta=0$. Bounds in the mass-mixing plane are shown in their Figure 18.
- 63 ERLER 99 give 90%CL limit on the Z - Z' mixing $-0.0041 < \theta < 0.0003$. $\rho_0=1$ is assumed.
- 64 ABE 97S find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s}= 1.8$ TeV.
- 65 VILAIN 94B assume $m_t = 150$ GeV.
- 66 ALITTI 93 search for resonances in the two-jet invariant mass. The limit assumes $B(Z' \rightarrow q\bar{q})=0.7$. See their Fig. 5 for limits in the $m_{Z'}-B(q\bar{q})$ plane.
- 67 RIZZO 93 analyses CDF limit on possible two-jet resonances.
- 68 ABE 90F use data for R , $R_{\ell\ell}$, and $A_{\ell\ell}$. They fix $m_W = 80.49 \pm 0.43 \pm 0.24$ GeV and $m_Z = 91.13 \pm 0.03$ 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
>998	95	69 ERLER	09 RVUE	Electroweak
>600	95	SCHAEL	07A ALEP	e^+e^-
>630	95	70 ABE	97S CDF	$p\bar{p}; Z'_{LR} \rightarrow e^+e^-, \mu^+\mu^-$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>455	95	71 ABDALLAH	06C DLPH	e^+e^-
>518	95	72 ABBIENDI	04G OPAL	e^+e^-
>860	95	73 CHEUNG	01B RVUE	Electroweak
>380	95	74 ABREU	00S DLPH	e^+e^-
>436	95	75 BARATE	00I ALEP	Repl. by SCHAEL 07A
>550	95	76 CHAY	00 RVUE	Electroweak
		77 ERLER	00 RVUE	Cs
		78 CASALBUONI	99 RVUE	Cs
(> 1205)	90	79 CZAKON	99 RVUE	Electroweak

>564	95	80 ERLER	99 RVUE	Electroweak
(> 1673)	95	81 ERLER	99 RVUE	Electroweak
(> 1700)	68	82 BARENBOIM	98 RVUE	Electroweak
>244	95	83 CONRAD	98 RVUE	$\nu_\mu N$ scattering
>253	95	84 VILAIN	94B CHM2	$\nu_\mu e \rightarrow \nu_\mu e$ and $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
none 200–600	95	85 RIZZO	93 RVUE	$p\bar{p}; Z_{LR} \rightarrow q\bar{q}$
[> 2000]		WALKER	91 COSM	Nucleosynthesis; light ν_R
none 200–500		86 GRIFOLS	90 ASTR	SN 1987A; light ν_R
none 350–2400		87 BARBIERI	89B ASTR	SN 1987A; light ν_R

- 69 ERLER 09 give 95% CL limit on the Z - Z' mixing $-0.0013 < \theta < 0.0006$.
- 70 ABE 97s find $\sigma(Z') \times B(e^+ e^-, \mu^+ \mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s} = 1.8$ TeV.
- 71 ABDALLAH 06c give 95% CL limit $|\theta| < 0.0028$. See their Fig. 14 for limit contours in the mass-mixing plane.
- 72 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.
- 73 CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
- 74 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.
- 75 BARATE 00i search for deviations in cross section and asymmetries in $e^+ e^- \rightarrow$ fermions at $\sqrt{s} = 90$ to 183 GeV. Assume $\theta = 0$. Bounds in the mass-mixing plane are shown in their Figure 18.
- 76 CHAY 00 also find $-0.0003 < \theta < 0.0019$. For g_R free, $m_{Z'} > 430$ GeV.
- 77 ERLER 00 discuss the possibility that a discrepancy between the observed and predicted values of $Q_W(C_s)$ 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 .
- 78 CASALBUONI 99 discuss the discrepancy between the observed and predicted values of $Q_W(C_s)$. It is shown that the data are better described in a class of models including the Z_{LR} model.
- 79 CZAKON 99 perform a simultaneous fit to charged and neutral sectors. Assumes manifest left-right symmetric model. Finds $|\theta| < 0.0042$.
- 80 ERLER 99 give 90% CL limit on the Z - Z' mixing $-0.0009 < \theta < 0.0017$.
- 81 ERLER 99 assumes 2 Higgs doublets, transforming as 10 of $SO(10)$, embedded in E_6 .
- 82 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.
- 83 CONRAD 98 limit is from measurements at CCFR, assuming no Z - Z' mixing.
- 84 VILAIN 94B assume $m_t = 150$ GeV and $\theta = 0$. See Fig. 2 for limit contours in the mass-mixing plane.
- 85 RIZZO 93 analyses CDF limit on possible two-jet resonances.
- 86 GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. A specific Higgs sector is assumed. See also GRIFOLS 90D, RIZZO 91.
- 87 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 $SO(10) \rightarrow SU(5) \times U(1)_\chi$. $g_\chi = e/\cos\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho = 1$ but with no further constraints on the Higgs sector. Values in parentheses assume stronger constraint on the Higgs sector motivated by superstring models. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
> 892	95	88 AALTONEN	09V CDF	$p\bar{p}; Z'_\chi \rightarrow \mu^+ \mu^-$
> 1141	95	89 ERLER	09 RVUE	Electroweak
> 781	95	90 ABBIENDI	04G OPAL	$e^+ e^-$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 862	95	91 AALTONEN	09T CDF	$p\bar{p}, Z'_\chi \rightarrow e^+ e^-$
> 822	95	91 AALTONEN	07H CDF	Repl. by AALTONEN 09T
> 680	95	SCHAEL	07A ALEP	$e^+ e^-$
> 545	95	92 ABDALLAH	06C DLPH	$e^+ e^-$
> 740		91 ABULENCIA	06L CDF	Repl. by AALTONEN 07H
> 690	95	93 ABULENCIA	05A CDF	$p\bar{p}; Z'_\chi \rightarrow e^+ e^-, \mu^+ \mu^-$
>2100		94 BARGER	03B COSM	Nucleosynthesis; light ν_R
> 680	95	95 CHEUNG	01B RVUE	Electroweak
> 440	95	96 ABREU	00S DLPH	$e^+ e^-$
> 533	95	97 BARATE	00I ALEP	Repl. by SCHAEL 07A
> 554	95	98 CHO	00 RVUE	Electroweak
		99 ERLER	00 RVUE	Cs
		100 ROSNER	00 RVUE	Cs
> 545	95	101 ERLER	99 RVUE	Electroweak
(> 1368)	95	102 ERLER	99 RVUE	Electroweak
> 215	95	103 CONRAD	98 RVUE	$\nu_\mu N$ scattering
> 595	95	104 ABE	97S CDF	$p\bar{p}; Z'_\chi \rightarrow e^+ e^-, \mu^+ \mu^-$
> 190	95	105 ARIMA	97 VNS	Bhabha scattering
> 262	95	106 VILAIN	94B CHM2	$\nu_\mu e \rightarrow \nu_\mu e; \bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
[>1470]		107 FARAGGI	91 COSM	Nucleosynthesis; light ν_R
> 231	90	108 ABE	90F VNS	$e^+ e^-$
[> 1140]		109 GONZALEZ-G.	90D COSM	Nucleosynthesis; light ν_R
[> 2100]		110 GRIFOLS	90 ASTR	SN 1987A; light ν_R

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

89 ERLER 09 give 95% CL limit on the Z - Z' mixing $-0.0016 < \theta < 0.0006$.

90 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.

91 AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to $e^+ e^-$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

92 ABDALLAH 06C give 95% CL limit $|\theta| < 0.0031$. See their Fig. 14 for limit contours in the mass-mixing plane.

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

94 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.

- ⁹⁵ CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
- ⁹⁶ ABREU 00S give 95% CL limit on Z - Z' mixing $|\theta| < 0.0017$. See their Fig. 6 for the limit contour in the mass-mixing plane. $\sqrt{s}=90$ to 189 GeV.
- ⁹⁷ BARATE 00I search for deviations in cross section and asymmetries in $e^+ e^- \rightarrow$ fermions at $\sqrt{s}=90$ to 183 GeV. Assume $\theta=0$. Bounds in the mass-mixing plane are shown in their Figure 18.
- ⁹⁸ 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.
- ⁹⁹ ERLER 00 discuss the possibility that a discrepancy between the observed and predicted values of $Q_W(C_s)$ 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 .
- ¹⁰⁰ ROSNER 00 discusses the possibility that a discrepancy between the observed and predicted values of $Q_W(C_s)$ is due to the exchange of Z' . The data are better described in a certain class of the Z' models including Z_χ .
- ¹⁰¹ ERLER 99 give 90% CL limit on the Z - Z' mixing $-0.0020 < \theta < 0.0015$.
- ¹⁰² ERLER 99 assumes 2 Higgs doublets, transforming as 10 of $SO(10)$, embedded in E_6 .
- ¹⁰³ CONRAD 98 limit is from measurements at CCFR, assuming no Z - Z' mixing.
- ¹⁰⁴ ABE 97S find $\sigma(Z') \times B(e^+ e^-, \mu^+ \mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s}=1.8$ TeV.
- ¹⁰⁵ Z - Z' mixing is assumed to be zero. $\sqrt{s}=57.77$ GeV.
- ¹⁰⁶ VILAIN 94B assume $m_t = 150$ GeV and $\theta=0$. See Fig. 2 for limit contours in the mass-mixing plane.
- ¹⁰⁷ 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.
- ¹⁰⁸ 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.
- ¹⁰⁹ Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that ν_R is light ($\lesssim 1$ MeV).
- ¹¹⁰ 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 $E_6 \rightarrow SO(10) \times U(1)_\psi$. $g_\psi = e/\cos\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho=1$ but with no further constraints on the Higgs sector. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>878	95	111 AALTONEN	09V CDF	$p\bar{p}; Z'_\psi \rightarrow \mu^+ \mu^-$
>475	95	112 ABDALLAH	06C DLPH	$e^+ e^-$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
>851	95	113 AALTONEN	09T CDF	$p\bar{p}; Z'_\psi \rightarrow e^+ e^-$
>147	95	114 ERLER	09 RVUE	Electroweak
>822	95	113 AALTONEN	07H CDF	Repl. by AALTONEN 09T
>410	95	SCHAEEL	07A ALEP	$e^+ e^-$
>725		113 ABULENCIA	06L CDF	Repl. by AALTONEN 07H
>675	95	115 ABULENCIA	05A CDF	$p\bar{p}; Z'_\psi \rightarrow e^+ e^-, \mu^+ \mu^-$
>366	95	116 ABBIENDI	04G OPAL	$e^+ e^-$
>600		117 BARGER	03B COSM	Nucleosynthesis; light ν_R
>350	95	118 ABREU	00S DLPH	$e^+ e^-$

- | | | | | | | |
|----------|----|-----|-------------|-----|------|--|
| >294 | 95 | 119 | BARATE | 00I | ALEP | Repl. by SCHAELE 07A |
| >137 | 95 | 120 | CHO | 00 | RVUE | Electroweak |
| >146 | 95 | 121 | ERLER | 99 | RVUE | Electroweak |
| > 54 | 95 | 122 | CONRAD | 98 | RVUE | $\nu_\mu N$ scattering |
| >590 | 95 | 123 | ABE | 97S | CDF | $p\bar{p}; Z'_\psi \rightarrow e^+e^-, \mu^+\mu^-$ |
| >135 | 95 | 124 | VILAIN | 94B | CHM2 | $\nu_\mu e \rightarrow \nu_\mu e; \bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$ |
| >105 | 90 | 125 | ABE | 90F | VNS | e^+e^- |
| [> 160] | | 126 | GONZALEZ-G. | 90D | COSM | Nucleosynthesis; light ν_R |
| [> 2000] | | 127 | GRIFOLS | 90D | ASTR | SN 1987A; light ν_R |
- 111 AALTONEN 09V search for resonances decaying to $\mu^+\mu^-$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 112 ABDALLAH 06C give 95% CL limit $|\theta| < 0.0027$. See their Fig. 14 for limit contours in the mass-mixing plane.
- 113 AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 114 ERLER 09 give 95% CL limit on the Z - Z' mixing $-0.0018 < \theta < 0.0009$.
- 115 ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 116 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.
- 117 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.
- 118 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.
- 119 BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at $\sqrt{s} = 90$ to 183 GeV. Assume $\theta = 0$. Bounds in the mass-mixing plane are shown in their Figure 18.
- 120 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.
- 121 ERLER 99 give 90% CL limit on the Z - Z' mixing $-0.0013 < \theta < 0.0024$.
- 122 CONRAD 98 limit is from measurements at CCFR, assuming no Z - Z' mixing.
- 123 ABE 97S find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s} = 1.8$ TeV.
- 124 VILAIN 94B assume $m_t = 150$ GeV and $\theta = 0$. See Fig. 2 for limit contours in the mass-mixing plane.
- 125 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.
- 126 Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that ν_R is light ($\lesssim 1$ MeV).
- 127 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
> 904	95	128 AALTONEN	09V CDF	$p\bar{p}; Z'_\eta \rightarrow \mu^+\mu^-$
> 515	95	129 ABBIENDI	04G OPAL	e^+e^-
> 619	95	130 CHO	00 RVUE	Electroweak

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

> 877	95	131	AALTONEN	09T	CDF	$p\bar{p}, Z'_\eta \rightarrow e^+e^-$
> 427	95	132	ERLER	09	RVUE	Electroweak
> 891	95	131	AALTONEN	07H	CDF	Repl. by AALTONEN 09T
> 350	95		SCHAEL	07A	ALEP	e^+e^-
> 360	95	133	ABDALLAH	06C	DLPH	e^+e^-
> 745		131	ABULENCIA	06L	CDF	Repl. by AALTONEN 07H
> 720	95	134	ABULENCIA	05A	CDF	$p\bar{p}; Z'_\eta \rightarrow e^+e^-, \mu^+\mu^-$
>1600		135	BARGER	03B	COSM	Nucleosynthesis; light ν_R
> 310	95	136	ABREU	00S	DLPH	e^+e^-
> 329	95	137	BARATE	00I	ALEP	Repl. by SCHAEL 07A
> 365	95	138	ERLER	99	RVUE	Electroweak
> 87	95	139	CONRAD	98	RVUE	$\nu_\mu N$ scattering
> 620	95	140	ABE	97S	CDF	$p\bar{p}; Z'_\eta \rightarrow e^+e^-, \mu^+\mu^-$
> 100	95	141	VILAIN	94B	CHM2	$\nu_\mu e \rightarrow \nu_\mu e; \bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
> 125	90	142	ABE	90F	VNS	e^+e^-
[> 820]		143	GONZALEZ-G.	90D	COSM	Nucleosynthesis; light ν_R
[> 3300]		144	GRIFOLS	90	ASTR	SN 1987A; light ν_R
[> 1040]		143	LOPEZ	90	COSM	Nucleosynthesis; light ν_R

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

129 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.

130 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.

131 AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

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

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

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

135 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.

136 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.

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

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

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

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

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

142 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.

143 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).

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

Limits for other Z'

VALUE (GeV)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
145	AALTONEN 08D	CDF	$Z' \rightarrow t\bar{t}$
145	AALTONEN 08Y	CDF	$Z' \rightarrow t\bar{t}$
145	ABAZOV 08AA	D0	$Z' \rightarrow t\bar{t}$
146	ABULENCIA 06M	CDF	$Z' \rightarrow e\mu$
147	ABAZOV 04A	D0	Repl. by ABAZOV 08AA
148	BARGER 03B	COSM	Nucleosynthesis; light ν_R
149	CHO 00	RVUE	E_6 -motivated
150	CHO 98	RVUE	E_6 -motivated
151	ABE 97G	CDF	$Z' \rightarrow \bar{q}q$

- 145 Search for narrow resonance decaying to $t\bar{t}$. See their Fig. 3 for limit on $\sigma \cdot B$.
- 146 ABULENCIA 06M search for new particle with lepton flavor violating decay at $\sqrt{s} = 1.96$ TeV. See their Fig. 4 for an exclusion plot on a mass-coupling plane.
- 147 Search for narrow resonance decaying to $t\bar{t}$. See their Fig. 2 for limit on $\sigma \cdot B$.
- 148 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.
- 149 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.
- 150 CHO 98 study constraints on four-Fermi contact interactions obtained from low-energy electroweak experiments, assuming no Z - Z' mixing.
- 151 Search for Z' decaying to dijets at $\sqrt{s}=1.8$ TeV. For Z' with electromagnetic strength coupling, no bound is obtained.

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		152 MUECK	02	RVUE Electroweak
> 3.3	95	153 CORNET	00	RVUE $e\nu qq'$
>5000		154 DELGADO	00	RVUE ϵ_K
> 2.6	95	155 DELGADO	00	RVUE Electroweak
> 3.3	95	156 RIZZO	00	RVUE Electroweak
> 2.9	95	157 MARCIANO	99	RVUE Electroweak
> 2.5	95	158 MASIP	99	RVUE Electroweak
> 1.6	90	159 NATH	99	RVUE Electroweak
> 3.4	95	160 STRUMIA	99	RVUE Electroweak

- 152 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.
- 153 Bound is derived from limits on $e\nu qq'$ contact interaction, using data from HERA and the Tevatron.

- 154 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 .
- 155 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.
- 156 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.
- 157 Bound is derived from global electroweak analysis but considering only presence of the KK W bosons.
- 158 Global electroweak analysis used to obtain bound independent of position of Higgs on brane or in bulk.
- 159 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.
- 160 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
>316	95	161 ABAZOV	09 D0	Second generation
>299	95	162 ABAZOV	09AF D0	First generation
>229	95	163 ABAZOV	07J D0	Third generation
>226	95	164 ABULENCIA	06T CDF	Second generation
>236	95	165 ACOSTA	05P CDF	First generation
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		166 AALTONEN	08P CDF	Third generation
>153	95	167 AALTONEN	08Z CDF	Third generation
>205	95	168 ABAZOV	08AD D0	All generations
>210	95	167 ABAZOV	08AN D0	Third generation
>251	95	169 ABAZOV	06A D0	Superseded by ABAZOV 09
>136	95	170 ABAZOV	06L D0	Superseded by ABAZOV 08AD
>256	95	171 ABAZOV	05H D0	First generation
>117	95	168 ACOSTA	05I CDF	First generation
> 99	95	172 ABBIENDI	03R OPAL	First generation
>100	95	172 ABBIENDI	03R OPAL	Second generation
> 98	95	172 ABBIENDI	03R OPAL	Third generation
> 98	95	173 ABAZOV	02 D0	All generations
>225	95	174 ABAZOV	01D D0	First generation
> 85.8	95	175 ABBIENDI	00M OPAL	Superseded by ABBIENDI 03R
> 85.5	95	175 ABBIENDI	00M OPAL	Superseded by ABBIENDI 03R
> 82.7	95	175 ABBIENDI	00M OPAL	Superseded by ABBIENDI 03R
>200	95	176 ABBOTT	00C D0	Second generation
>123	95	177 AFFOLDER	00K CDF	Second generation
>148	95	178 AFFOLDER	00K CDF	Third generation
>160	95	179 ABBOTT	99J D0	Second generation
>225	95	180 ABBOTT	98E D0	First generation

> 94	95	181	ABBOTT	98J	D0	Third generation
>202	95	182	ABE	98S	CDF	Second generation
>242	95	183	GROSS-PILCH	98		First generation
> 99	95	184	ABE	97F	CDF	Third generation
>213	95	185	ABE	97X	CDF	First generation
> 45.5	95	186,187	ABREU	93J	DLPH	First + second generation
> 44.4	95	188	ADRIANI	93M	L3	First generation
> 44.5	95	188	ADRIANI	93M	L3	Second generation
> 45	95	188	DECAMP	92	ALEP	Third generation
none 8.9–22.6	95	189	KIM	90	AMY	First generation
none 10.2–23.2	95	189	KIM	90	AMY	Second generation
none 5–20.8	95	190	BARTEL	87B	JADE	
none 7–20.5	95	191	BEHREND	86B	CELL	

- 161 ABAZOV 09 search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV. The limit above assumes $B(\mu q) = 1$. For $B(\mu q) = 0.5$, the limit becomes 270 GeV.
- 162 ABAZOV 09AF search for scalar leptoquarks using $e e jj$ and $e\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV. The limit above assumes $B(eq) = 1$. For $B(eq) = 0.5$ the bound becomes 284 GeV.
- 163 ABAZOV 07J search for pair productions of scalar leptoquark state decaying to νb in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV. The limit above assumes $B(\nu b) = 1$.
- 164 ABULENCIA 06T search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV. The quoted limit assumes $B(\mu q) = 1$. For $B(\mu q) = 0.5$ or 0.1, the bound becomes 208 GeV or 143 GeV, respectively. See their Fig. 4 for the exclusion limit as a function of $B(\mu q)$.
- 165 ACOSTA 05P search for scalar leptoquarks using $e e jj$, $e\nu jj$ events in $\bar{p}p$ collisions at $E_{\text{cm}} = 1.96$ TeV. The limit above assumes $B(eq) = 1$. For $B(eq) = 0.5$ and 0.1, the bound becomes 205 GeV and 145 GeV, respectively.
- 166 AALTONEN 08P search for vector leptoquarks using $\tau^+\tau^- b\bar{b}$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV. Assuming Yang-Mills (minimal) couplings, the mass limit is >317 GeV (251 GeV) at 95% CL for $B(\tau b) = 1$.
- 167 Search for pair production of scalar leptoquark state decaying to τb in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV. The limit above assumes $B(\tau b) = 1$.
- 168 Search for scalar leptoquarks using $\nu\nu jj$ events in $\bar{p}p$ collisions at $E_{\text{cm}} = 1.96$ TeV. The limit above assumes $B(\nu q) = 1$.
- 169 ABAZOV 06A search for scalar leptoquarks using $\mu\mu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV and at 1.96 TeV. The limit above assumes $B(\mu q) = 1$. For $B(\mu q) = 0.5$, the limit becomes 204 GeV.
- 170 ABAZOV 06L search for scalar leptoquarks using $\nu\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV and at 1.96 TeV. The limit above assumes $B(\nu q) = 1$.
- 171 ABAZOV 05H search for scalar leptoquarks using $e e jj$ and $e\nu jj$ events in $\bar{p}p$ collisions at $E_{\text{cm}} = 1.8$ TeV and 1.96 TeV. The limit above assumes $B(eq) = 1$. For $B(eq) = 0.5$ the bound becomes 234 GeV.
- 172 ABBIENDI 03R search for scalar/vector leptoquarks in e^+e^- collisions at $\sqrt{s} = 189$ –209 GeV. The quoted limits are for charge $-4/3$ isospin 0 scalar-leptoquark with $B(\ell q) = 1$. See their table 12 for other cases.
- 173 ABAZOV 02 search for scalar leptoquarks using $\nu\nu jj$ events in $\bar{p}p$ collisions at $E_{\text{cm}} = 1.8$ TeV. The bound holds for all leptoquark generations. Vector leptoquarks are likewise constrained to lie above 200 GeV.
- 174 ABAZOV 01D search for scalar leptoquarks using $e\nu jj$, $e e jj$, and $\nu\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ 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.

- 175 **ABBIENDI 00M** search for scalar/vector leptoquarks in e^+e^- collisions at $\sqrt{s}=183$ GeV. The quoted limits are for charge $-4/3$ isospin 0 scalar-leptoquarks with $B(\ell q)=1$. See their Table 8 and Figs. 6–9 for other cases.
- 176 **ABBOTT 00C** search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The limit above assumes $B(\mu q)=1$. For $B(\mu q)=0.5$ and 0, the bound becomes 180 and 79 GeV respectively. Bounds for vector leptoquarks are also given.
- 177 **AFFOLDER 00K** search for scalar leptoquark using $\nu\nu cc$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The quoted limit assumes $B(\nu c)=1$. Bounds for vector leptoquarks are also given.
- 178 **AFFOLDER 00K** search for scalar leptoquark using $\nu\nu bb$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The quoted limit assumes $B(\nu b)=1$. Bounds for vector leptoquarks are also given.
- 179 **ABBOTT 99J** search for leptoquarks using $\mu\nu jj$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The quoted limit is for a scalar leptoquark with $B(\mu q) = B(\nu q) = 0.5$. Limits on vector leptoquarks range from 240 to 290 GeV.
- 180 **ABBOTT 98E** search for scalar leptoquarks using $e\nu jj$, $eejj$, and $\nu\nu jj$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The limit above assumes $B(eq)=1$. For $B(eq)=0.5$ and 0, the bound becomes 204 and 79 GeV, respectively.
- 181 **ABBOTT 98J** search for charge $-1/3$ third generation scalar and vector leptoquarks in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The quoted limit is for scalar leptoquark with $B(\nu b)=1$.
- 182 **ABE 98S** search for scalar leptoquarks using $\mu\mu jj$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The limit is for $B(\mu q)=1$. For $B(\mu q)=B(\nu q)=0.5$, the limit is > 160 GeV.
- 183 **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.
- 184 **ABE 97F** search for third generation scalar and vector leptoquarks in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The quoted limit is for scalar leptoquark with $B(\tau b)=1$.
- 185 **ABE 97X** search for scalar leptoquarks using $eejj$ events in $p\bar{p}$ collisions at $E_{cm}=1.8$ TeV. The limit is for $B(eq)=1$.
- 186 Limit is for charge $-1/3$ isospin-0 leptoquark with $B(\ell q) = 2/3$.
- 187 First and second generation leptoquarks are assumed to be degenerate. The limit is slightly lower for each generation.
- 188 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.
- 189 **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 $u \bar{\nu}$ ($s \mu^+$ and $c \bar{\nu}$). See paper for limits for specific branching ratios.
- 190 **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 $B(X \rightarrow c \bar{\nu}_\mu) + B(X \rightarrow s \mu^+) = 1$.
- 191 **BEHREND 86B** assumed that a charge $2/3$ spinless leptoquark, χ , decays either into $s \mu^+$ or $c \bar{\nu}$: $B(\chi \rightarrow s \mu^+) + B(\chi \rightarrow c \bar{\nu}) = 1$.

MASS LIMITS for Leptoquarks from Single Production

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

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>298	95	192 CHEKANOV	03B ZEUS	First generation
> 73	95	193 ABREU	93J DLPH	Second generation

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

		194	ABAZOV	07E	D0	Second generation
>295	95	195	AKTAS	05B	H1	First generation
		196	CHEKANOV	05A	ZEUS	Lepton-flavor violation
>197	95	197	ABBIENDI	02B	OPAL	First generation
		198	CHEKANOV	02	ZEUS	Repl. by CHEKANOV 05A
>290	95	199	ADLOFF	01C	H1	First generation
>204	95	200	BREITWEG	01	ZEUS	First generation
		201	BREITWEG	00E	ZEUS	First generation
>161	95	202	ABREU	99G	DLPH	First generation
>200	95	203	ADLOFF	99	H1	First generation
		204	DERRICK	97	ZEUS	Lepton-flavor violation
>168	95	205	DERRICK	93	ZEUS	First generation

192 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.

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

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

195 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.

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

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

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

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

200 See their Fig. 14 for limits in the mass-coupling plane.

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

202 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.

203 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.

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

205 DERRICK 93 search for single leptoquark production in ep collisions with the decay $e q$ 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

<u>VALUE (TeV)</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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• • • We do not use the following data for averages, fits, limits, etc. • • •

		206	AKTAS	07A	H1	Lepton-flavor violation
>	0.49	95	207 SCHAEL	07A	ALEP	$e^+e^- \rightarrow q\bar{q}$
			208 SMIRNOV	07	RVUE	$K \rightarrow e\mu, B \rightarrow e\tau$
			209 CHEKANOV	05A	ZEUS	Lepton-flavor violation
>	1.7	96	210 ADLOFF	03	H1	First generation
>	46	90	211 CHANG	03	BELL	Pati-Salam type
			212 CHEKANOV	02	ZEUS	Repl. by CHEKANOV 05A
>	1.7	95	213 CHEUNG	01B	RVUE	First generation
>	0.39	95	214 ACCIARRI	00P	L3	$e^+e^- \rightarrow qq$
>	1.5	95	215 ADLOFF	00	H1	First generation
>	0.2	95	216 BARATE	00I	ALEP	Repl. by SCHAEL 07A
			217 BARGER	00	RVUE	Cs
			218 GABRIELLI	00	RVUE	Lepton flavor violation
>	0.74	95	219 ZARNECKI	00	RVUE	S_1 leptoquark
			220 ABBIENDI	99	OPAL	
>	19.3	95	221 ABE	98V	CDF	$B_s \rightarrow e^\pm \mu^\mp$, Pati-Salam type
			222 ACCIARRI	98J	L3	$e^+e^- \rightarrow q\bar{q}$
			223 ACKERSTAFF	98V	OPAL	$e^+e^- \rightarrow q\bar{q}, e^+e^- \rightarrow b\bar{b}$
>	0.76	95	224 DEANDREA	97	RVUE	\tilde{R}_2 leptoquark
			225 DERRICK	97	ZEUS	Lepton-flavor violation
			226 GROSSMAN	97	RVUE	$B \rightarrow \tau^+\tau^- (X)$
			227 JADACH	97	RVUE	$e^+e^- \rightarrow q\bar{q}$
>1200			228 KUZNETSOV	95B	RVUE	Pati-Salam type
			229 MIZUKOSHI	95	RVUE	Third generation scalar leptoquark
>	0.3	95	230 BHATTACH...	94	RVUE	Spin-0 leptoquark coupled to $\bar{e}_R t_L$
			231 DAVIDSON	94	RVUE	
>	18		232 KUZNETSOV	94	RVUE	Pati-Salam type
>	0.43	95	233 LEURER	94	RVUE	First generation spin-1 leptoquark
>	0.44	95	233 LEURER	94B	RVUE	First generation spin-0 leptoquark
			234 MAHANTA	94	RVUE	P and T violation
>	1		235 SHANKER	82	RVUE	Nonchiral spin-0 leptoquark
>	125		235 SHANKER	82	RVUE	Nonchiral spin-1 leptoquark

206 AKTAS 07A search for lepton-flavor violation in ep collision. See their Tables 4–7 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks.

207 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.

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

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

210 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.

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

212 CHEKANOV 02 search for lepton-flavor violation in ep collisions. See their Tables 1–4 for limits on lepton-flavor violating and four-fermion interactions induced by various leptoquarks.

213 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.

- 214 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.
- 215 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 $e^+ p \rightarrow e^+ X$.
- 216 BARATE 00I search for deviations in cross section and jet-charge asymmetry in $e^+ e^- \rightarrow \bar{q}q$ 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.
- 217 BARGER 00 explain the deviation of atomic parity violation in cesium atoms from prediction is explained by scalar leptoquark exchange.
- 218 GABRIELLI 00 calculate various process with lepton flavor violation in leptoquark models.
- 219 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.
- 220 ABBIENDI 99 limits are from $e^+ e^- \rightarrow q\bar{q}$ cross section at 130–136, 161–172, 183 GeV. See their Fig. 8 and Fig. 9 for limits in mass-coupling plane.
- 221 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).
- 222 ACCIARRI 98J limit is from $e^+ e^- \rightarrow q\bar{q}$ 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.
- 223 ACKERSTAFF 98V limits are from $e^+ e^- \rightarrow q\bar{q}$ and $e^+ e^- \rightarrow b\bar{b}$ 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.
- 224 DEANDREA 97 limit is for \tilde{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.
- 225 DERRICK 97 search for lepton-flavor violation in $e p$ collision. See their Tables 2–5 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks.
- 226 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.
- 227 JADACH 97 limit is from $e^+ e^- \rightarrow q\bar{q}$ 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.
- 228 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.
- 229 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.
- 230 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 $\bar{e}_L t_R$, $\bar{\mu} t$, and $\bar{\tau} t$, see Fig. 2 in BHATTACHARYYA 94B erratum and Fig. 3.
- 231 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.
- 232 KUZNETSOV 94 gives mixing independent bound of the Pati-Salam leptoquark from the cosmological limit on $\pi^0 \rightarrow \bar{\nu}\nu$.

- 233 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.
- 234 MAHANTA 94 gives bounds of P - and T -violating scalar-leptoquark couplings from atomic and molecular experiments.
- 235 From $(\pi \rightarrow e\nu)/(\pi \rightarrow \mu\nu)$ ratio. SHANKER 82 assumes the leptoquark induced four-fermion coupling $4g^2/M^2 (\bar{\nu}_{eL} u_R) (\bar{d}_L e_R)$ with $g=0.004$ for spin-0 leptoquark and $g^2/M^2 (\bar{\nu}_{eL} \gamma_\mu u_L) (\bar{d}_R \gamma^\mu e_R)$ with $g \simeq 0.6$ for spin-1 leptoquark.

MASS LIMITS for Diquarks

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
none 290–630	95	236 AALTONEN	09AC CDF	E_6 diquark
none 290–420	95	237 ABE	97G CDF	E_6 diquark
none 15–31.7	95	238 ABREU	94O DLPH	SUSY E_6 diquark
236 AALTONEN 09AC search for new narrow resonance decaying to dijets.				
237 ABE 97G search for new particle decaying to dijets.				
238 ABREU 94O limit is from $e^+ e^- \rightarrow \bar{c} \bar{s} c s$. Range extends up to 43 GeV if diquarks are degenerate in mass.				

MASS LIMITS for g_A (axigluon)

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
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
none 260–1250	95	239 AALTONEN	09AC CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$
>910	95	240 CHOUDHURY	07 RVUE	$p\bar{p} \rightarrow t\bar{t} X$
>365	95	241 DONCHESKI	98 RVUE	$\Gamma(Z \rightarrow \text{hadron})$
none 200–980	95	242 ABE	97G CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$
none 200–870	95	243 ABE	95N CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow q\bar{q}$
none 240–640	95	244 ABE	93G CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$
> 50	95	245 CUYPERS	91 RVUE	$\sigma(e^+ e^- \rightarrow \text{hadrons})$
none 120–210	95	246 ABE	90H CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$
> 29		247 ROBINETT	89 THEO	Partial-wave unitarity
none 150–310	95	248 ALBAJAR	88B UA1	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$
> 20		BERGSTROM	88 RVUE	$p\bar{p} \rightarrow \Upsilon X$ via $g_A g$
> 9		249 CUYPERS	88 RVUE	Υ decay
> 25		250 DONCHESKI	88B RVUE	Υ decay
239 AALTONEN 09AC search for new narrow resonance decaying to dijets.				
240 CHOUDHURY 07 limit is from the $t\bar{t}$ production cross section measured at CDF.				
241 DONCHESKI 98 compare α_s derived from low-energy data and that from $\Gamma(Z \rightarrow \text{hadrons})/\Gamma(Z \rightarrow \text{leptons})$.				
242 ABE 97G search for new particle decaying to dijets.				
243 ABE 95N assume axigluons decaying to quarks in the Standard Model only.				
244 ABE 93G assume $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 10$.				
245 CUYPERS 91 compare α_s measured in Υ decay and that from R at PEP/PETRA energies.				

- 246 ABE 90H assumes $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 5$ ($\Gamma(g_A) = 0.09m_{g_A}$). For $N = 10$, the excluded region is reduced to 120–150 GeV.
- 247 ROBINETT 89 result demands partial-wave unitarity of $J = 0$ $t\bar{t} \rightarrow t\bar{t}$ scattering amplitude and derives a limit $m_{g_A} > 0.5 m_t$. Assumes $m_t > 56$ GeV.
- 248 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.
- 249 CUYPERS 88 requires $\Gamma(\Upsilon \rightarrow g g_A) < \Gamma(\Upsilon \rightarrow g g g)$. A similar result is obtained by DONCHESKI 88.
- 250 DONCHESKI 88B requires $\Gamma(\Upsilon \rightarrow g q\bar{q})/\Gamma(\Upsilon \rightarrow g g g) < 0.25$, where the former decay proceeds via axigluon exchange. A more conservative estimate of < 0.5 leads to $m_{g_A} > 21$ GeV.

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. ● ● ●				
		251 BARATE	98U ALEP	$X^0 \rightarrow \ell\bar{\ell}, q\bar{q}, g g, \gamma\gamma, \nu\bar{\nu}$
		252 ACCIARRI	97Q L3	$X^0 \rightarrow$ invisible particle(s)
		253 ACTON	93E OPAL	$X^0 \rightarrow \gamma\gamma$
		254 ABREU	92D DLPH	$X^0 \rightarrow$ hadrons
		255 ADRIANI	92F L3	$X^0 \rightarrow$ hadrons
		256 ACTON	91 OPAL	$X^0 \rightarrow$ anything
$< 1.1 \times 10^{-4}$	95	257 ACTON	91B OPAL	$X^0 \rightarrow e^+ e^-$
$< 9 \times 10^{-5}$	95	257 ACTON	91B OPAL	$X^0 \rightarrow \mu^+ \mu^-$
$< 1.1 \times 10^{-4}$	95	257 ACTON	91B OPAL	$X^0 \rightarrow \tau^+ \tau^-$
$< 2.8 \times 10^{-4}$	95	258 ADEVA	91D L3	$X^0 \rightarrow e^+ e^-$
$< 2.3 \times 10^{-4}$	95	258 ADEVA	91D L3	$X^0 \rightarrow \mu^+ \mu^-$
$< 4.7 \times 10^{-4}$	95	259 ADEVA	91D L3	$X^0 \rightarrow$ hadrons
$< 8 \times 10^{-4}$	95	260 AKRAWY	90J OPAL	$X^0 \rightarrow$ hadrons

- 251 BARATE 98U obtain limits on $B(Z \rightarrow \gamma X^0)B(X^0 \rightarrow \ell\bar{\ell}, q\bar{q}, g g, \gamma\gamma, \nu\bar{\nu})$. See their Fig. 17.
- 252 See Fig. 4 of ACCIARRI 97Q for the upper limit on $B(Z \rightarrow \gamma X^0; E_\gamma > E_{\min})$ as a function of E_{\min} .
- 253 ACTON 93E give $\sigma(e^+ e^- \rightarrow X^0 \gamma) \cdot B(X^0 \rightarrow \gamma\gamma) < 0.4$ pb (95%CL) for $m_{X^0} = 60 \pm 2.5$ GeV. If the process occurs via s-channel γ exchange, the limit translates to $\Gamma(X^0) \cdot B(X^0 \rightarrow \gamma\gamma)^2 < 20$ MeV for $m_{X^0} = 60 \pm 1$ GeV.
- 254 ABREU 92D give $\sigma_Z \cdot B(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow \text{hadrons}) < (3-10)$ pb for $m_{X^0} = 10-78$ GeV. A very similar limit is obtained for spin-1 X^0 .
- 255 ADRIANI 92F search for isolated γ in hadronic Z decays. The limit $\sigma_Z \cdot B(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow \text{hadrons}) < (2-10)$ pb (95%CL) is given for $m_{X^0} = 25-85$ GeV.
- 256 ACTON 91 searches for $Z \rightarrow Z^* X^0$, $Z^* \rightarrow e^+ e^-, \mu^+ \mu^-,$ or $\nu\bar{\nu}$. Excludes any new scalar X^0 with $m_{X^0} < 9.5$ GeV/c if it has the same coupling to $Z Z^*$ as the MSM Higgs boson.
- 257 ACTON 91B limits are for $m_{X^0} = 60-85$ GeV.
- 258 ADEVA 91D limits are for $m_{X^0} = 30-89$ GeV.

259 ADEVA 91D limits are for $m_{X^0} = 30\text{--}86$ GeV.

260 AKRAWY 90J give $\Gamma(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow \text{hadrons}) < 1.9$ MeV (95%CL) for $m_{X^0} = 32\text{--}80$ GeV. We divide by $\Gamma(Z) = 2.5$ GeV to get product of branching ratios. For nonresonant transitions, the limit is $B(Z \rightarrow \gamma q\bar{q}) < 8.2$ 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
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• • • We do not use the following data for averages, fits, limits, etc. • • •

none 55–61		261 ODAKA	89 VNS	$\Gamma(X^0 \rightarrow e^+e^-)$. $B(X^0 \rightarrow \text{had.}) \gtrsim 0.2$ MeV
>45	95	262 DERRICK	86 HRS	$\Gamma(X^0 \rightarrow e^+e^-) = 6$ MeV
>46.6	95	263 ADEVA	85 MRKJ	$\Gamma(X^0 \rightarrow e^+e^-) = 10$ keV
>48	95	263 ADEVA	85 MRKJ	$\Gamma(X^0 \rightarrow e^+e^-) = 4$ MeV
		264 BERGER	85B PLUT	
none 39.8–45.5		265 ADEVA	84 MRKJ	$\Gamma(X^0 \rightarrow e^+e^-) = 10$ keV
>47.8	95	265 ADEVA	84 MRKJ	$\Gamma(X^0 \rightarrow e^+e^-) = 4$ MeV
none 39.8–45.2		265 BEHREND	84C CELL	
>47	95	265 BEHREND	84C CELL	$\Gamma(X^0 \rightarrow e^+e^-) = 4$ MeV

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

262 DERRICK 86 found no deviation from the Standard Model Bhabha scattering at $E_{\text{cm}} = 29$ GeV and set limits on the possible scalar boson e^+e^- coupling. See their figure 4 for excluded region in the $\Gamma(X^0 \rightarrow e^+e^-) - m_{X^0}$ 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.

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

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

265 ADEVA 84 and BEHREND 84C have $E_{\text{cm}} = 39.8\text{--}45.5$ GeV. MARK-J searched X^0 in $e^+e^- \rightarrow \text{hadrons}, 2\gamma, \mu^+\mu^-, e^+e^-$ 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 $m_X > E_{\text{cm}}$. 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
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$<10^3$	95	266	ABE	93C	VNS	$\Gamma(ee)$
$<(0.4-10)$	95	267	ABE	93C	VNS	$f = \gamma\gamma$
$<(0.3-5)$	95	268,269	ABE	93D	TOPZ	$f = \gamma\gamma$
$<(2-12)$	95	268,269	ABE	93D	TOPZ	$f = \text{hadrons}$
$<(4-200)$	95	269,270	ABE	93D	TOPZ	$f = ee$
$<(0.1-6)$	95	269,270	ABE	93D	TOPZ	$f = \mu\mu$
$<(0.5-8)$	90	271	STERNER	93	AMY	$f = \gamma\gamma$

²⁶⁶ Limit is for $\Gamma(X^0 \rightarrow e^+e^-)$ $m_{X^0} = 56-63.5$ GeV for $\Gamma(X^0) = 0.5$ GeV.

²⁶⁷ Limit is for $m_{X^0} = 56-61.5$ GeV and is valid for $\Gamma(X^0) \ll 100$ MeV. See their Fig. 5 for limits for $\Gamma = 1,2$ GeV.

²⁶⁸ Limit is for $m_{X^0} = 57.2-60$ GeV.

²⁶⁹ Limit is valid for $\Gamma(X^0) \ll 100$ MeV. See paper for limits for $\Gamma = 1$ GeV and those for $J = 2$ resonances.

²⁷⁰ Limit is for $m_{X^0} = 56.6-60$ GeV.

²⁷¹ STERNER 93 limit is for $m_{X^0} = 57-59.6$ GeV and is valid for $\Gamma(X^0) < 100$ MeV. See their Fig. 2 for limits for $\Gamma = 1,3$ GeV.

Search for X^0 Resonance in $e p$ Collisions

VALUE	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

²⁷² CHEKANOV 02B ZEUS $X \rightarrow jj$

²⁷² CHEKANOV 02B search for photoproduction of X decaying into dijets in $e p$ collisions. See their Fig. 5 for the limit on the photoproduction cross section.

Search for X^0 Resonance in Two-Photon Process

The limit is for $\Gamma(X^0) \cdot B(X^0 \rightarrow \gamma\gamma)^2$. Spin 0 is assumed for X^0 .

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

<2.6 95 ²⁷³ ACTON 93E OPAL $m_{X^0} = 60 \pm 1$ GeV

<2.9 95 BUSKULIC 93F ALEP $m_{X^0} \sim 60$ GeV

²⁷³ ACTON 93E limit for a $J = 2$ resonance is 0.8 MeV.

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

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

²⁷⁴ ABBIENDI 03D OPAL $X^0 \rightarrow \gamma\gamma$

²⁷⁵ ABREU 00Z DLPH X^0 decaying invisibly

²⁷⁶ ADAM 96C DLPH X^0 decaying invisibly

- 274 ABBIENDI 03D measure the $e^+e^- \rightarrow \gamma\gamma\gamma$ cross section at $\sqrt{s}=181\text{--}209$ GeV. The upper bound on the production cross section, $\sigma(e^+e^- \rightarrow X^0\gamma)$ times the branching ratio for $X^0 \rightarrow \gamma\gamma$, is less than 0.03 pb at 95%CL for X^0 masses between 20 and 180 GeV. See their Fig. 9b for the limits in the mass-cross section plane.
- 275 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.
- 276 ADAM 96C is from the single photon production cross at $\sqrt{s}=130, 136$ GeV. The upper bound is less than 3 pb for X^0 masses between 60 and 130 GeV. See their Fig. 5 for the exact bound on the cross section $\sigma(e^+e^- \rightarrow \gamma X^0)$.

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

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		277 ABREU	96T DLPH	$f=e,\mu,\tau; F=\gamma\gamma$
$<3.7 \times 10^{-6}$	95	278 ABREU	96T DLPH	$f=\nu; F=\gamma\gamma$
		279 ABREU	96T DLPH	$f=q; F=\gamma\gamma$
$<6.8 \times 10^{-6}$	95	278 ACTON	93E OPAL	$f=e,\mu,\tau; F=\gamma\gamma$
$<5.5 \times 10^{-6}$	95	278 ACTON	93E OPAL	$f=q; F=\gamma\gamma$
$<3.1 \times 10^{-6}$	95	278 ACTON	93E OPAL	$f=\nu; F=\gamma\gamma$
$<6.5 \times 10^{-6}$	95	278 ACTON	93E OPAL	$f=e,\mu; F=\ell\bar{\ell}, q\bar{q}, \nu\bar{\nu}$
$<7.1 \times 10^{-6}$	95	278 BUSKULIC	93F ALEP	$f=e,\mu; F=\ell\bar{\ell}, q\bar{q}, \nu\bar{\nu}$
		280 ADRIANI	92F L3	$f=q; F=\gamma\gamma$

- 277 ABREU 96T obtain limit as a function of m_{X^0} . See their Fig. 6.
- 278 Limit is for m_{X^0} around 60 GeV.
- 279 ABREU 96T obtain limit as a function of m_{X^0} . See their Fig. 15.
- 280 ADRIANI 92F give $\sigma_Z \cdot B(Z \rightarrow q\bar{q}X^0) \cdot B(X^0 \rightarrow \gamma\gamma) < (0.75\text{--}1.5)$ pb (95%CL) for $m_{X^0} = 10\text{--}70$ GeV. The limit is 1 pb at 60 GeV.

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

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	281 ABE	97W CDF	$X^0 \rightarrow b\bar{b}$

- 281 ABE 97W search for X^0 production associated with W in $p\bar{p}$ collisions at $E_{\text{cm}}=1.8$ TeV. The 95%CL upper limit on the production cross section times the branching ratio for $X^0 \rightarrow b\bar{b}$ 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} .

Heavy Particle Production in Quarkonium Decays

Limits are for branching ratios to modes shown.

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				

$< 1.5 \times 10^{-5}$	90	282	BALEST	95	CLE2	$\Upsilon(1S) \rightarrow X^0 \gamma,$ $m_{X^0} < 5 \text{ GeV}$
$< 3 \times 10^{-5}$ – 6×10^{-3}	90	283	BALEST	95	CLE2	$\Upsilon(1S) \rightarrow X^0 \bar{X}^0 \gamma,$ $m_{X^0} < 3.9 \text{ GeV}$
$< 5.6 \times 10^{-5}$	90	284	ANTREASYAN 90C		CBAL	$\Upsilon(1S) \rightarrow X^0 \gamma,$ $m_{X^0} < 7.2 \text{ GeV}$
		285	ALBRECHT	89	ARG	

282 BALEST 95 two-body limit is for pseudoscalar X^0 . The limit becomes $< 10^{-4}$ for $m_{X^0} < 7.7 \text{ GeV}$.

283 BALEST 95 three-body limit is for phase-space photon energy distribution and angular distribution same as for $\Upsilon \rightarrow gg\gamma$.

284 ANTREASYAN 90C assume that X^0 does not decay in the detector.

285 ALBRECHT 89 give limits for $B(\Upsilon(1S), \Upsilon(2S) \rightarrow X^0 \gamma) \cdot B(X^0 \rightarrow \pi^+ \pi^-, K^+ K^-, p \bar{p})$ for $m_{X^0} < 3.5 \text{ GeV}$.

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AALTONEN	09AC	PR D79 112002	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09T	PRL 102 031801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	09V	PRL 102 091805	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	09	PL B671 224	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	09AF	PL B681 224	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ERLER	09	JHEP 0908 017	J. Erler <i>et al.</i>	
AALTONEN	08D	PR D77 051102R	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08P	PR D77 091105R	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08Y	PRL 100 231801	T. Aaltonen <i>et al.</i>	(CDF Collab.)
AALTONEN	08Z	PRL 101 071802	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	08AA	PL B668 98	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08AD	PL B668 357	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08AN	PRL 101 241802	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08C	PRL 100 031804	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	08P	PRL 100 211803	V.M. Abazov <i>et al.</i>	(D0 Collab.)
MACDONALD	08	PR D78 032010	R.P. MacDonald <i>et al.</i>	(TWIST Collab.)
AALTONEN	07H	PRL 99 171802	T. Aaltonen <i>et al.</i>	(CDF Collab.)
ABAZOV	07E	PL B647 74	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	07J	PRL 99 061801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABULENCIA	07K	PR D75 091101R	A. Abulencia <i>et al.</i>	(CDF Collab.)
AKTAS	07A	EPJ C52 833	A. Aktas <i>et al.</i>	(H1 Collab.)
CHOUDHURY	07	PL B657 69	D. Choudhury <i>et al.</i>	
MELCONIAN	07	PL B649 370	D. Melconian <i>et al.</i>	(TRIUMF)
SCHAEEL	07A	EPJ C49 411	S. Schaeel <i>et al.</i>	(ALEPH Collab.)
SCHUMANN	07	PRL 99 191803	M. Schumann <i>et al.</i>	(HEID, ILLG, KARL+)
SMIRNOV	07	MPL A22 2353	A.D. Smirnov	
ABAZOV	06A	PL B636 183	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	06L	PL B640 230	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	06N	PL B641 423	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABDALLAH	06C	EPJ C45 589	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ABULENCIA	06L	PRL 96 211801	A. Abulencia <i>et al.</i>	(CDF Collab.)
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ABULENCIA	06T	PR D73 051102R	A. Abulencia <i>et al.</i>	(CDF Collab.)
ABAZOV	05H	PR D71 071104R	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABULENCIA	05A	PRL 95 252001	A. Abulencia <i>et al.</i>	(CDF Collab.)
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ACOSTA	05R	PRL 95 131801	D. Acosta <i>et al.</i>	(CDF Collab.)
AKTAS	05B	PL B629 9	A. Aktas <i>et al.</i>	(H1 Collab.)
CHEKANOV	05	PL B610 212	S. Chekanov <i>et al.</i>	(HERA ZEUS Collab.)
CHEKANOV	05A	EPJ C44 463	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
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ABBIENDI	04G	EPJ C33 173	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	03D	EPJ C26 331	G. Abbiendi <i>et al.</i>	(OPAL Collab.)

ABBIENDI	03R	EPJ C31 281	G. Abbiendi <i>et al.</i>	(OPAL)
ACOSTA	03B	PRL 90 081802	D. Acosta <i>et al.</i>	(CDF Collab.)
ADLOFF	03	PL B568 35	C. Adloff <i>et al.</i>	(H1 Collab.)
BARGER	03B	PR D67 075009	V. Barger, P. Langacker, H. Lee	
CHANG	03	PR D68 111101R	M.-C. Chang <i>et al.</i>	(BELLE Collab.)
CHEKANOV	03B	PR D68 052004	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
ABAZOV	02	PRL 88 191801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABBIENDI	02B	PL B526 233	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
AFFOLDER	02C	PRL 88 071806	T. Affolder <i>et al.</i>	(CDF Collab.)
CHEKANOV	02	PR D65 092004	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
CHEKANOV	02B	PL B531 9	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
MUECK	02	PR D65 085037	A. Mueck, A. Pilaftsis, R. Rueckl	
ABAZOV	01B	PRL 87 061802	V.M. Abazov <i>et al.</i>	(D0 Collab.)
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ADLOFF	01C	PL B523 234	C. Adloff <i>et al.</i>	(H1 Collab.)
AFFOLDER	01I	PRL 87 231803	T. Affolder <i>et al.</i>	(CDF Collab.)
BREITWEG	01	PR D63 052002	J. Breitweg <i>et al.</i>	(ZEUS Collab.)
CHEUNG	01B	PL B517 167	K. Cheung	
THOMAS	01	NP A694 559	E. Thomas <i>et al.</i>	
ABBIENDI	00M	EPJ C13 15	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	00C	PRL 84 2088	B. Abbott <i>et al.</i>	(D0 Collab.)
ABE	00	PRL 84 5716	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	00S	PL B485 45	P. Abreu <i>et al.</i>	(DELPHI Collab.)
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ACCIARRI	00P	PL B489 81	M. Acciarri <i>et al.</i>	(L3 Collab.)
ADLOFF	00	PL B479 358	C. Adloff <i>et al.</i>	(H1 Collab.)
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BARATE	00I	EPJ C12 183	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARGER	00	PL B480 149	V. Barger, K. Cheung	
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ABBIENDI	99	EPJ C6 1	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	99J	PRL 83 2896	B. Abbott <i>et al.</i>	(D0 Collab.)
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ACKERSTAFF	99D	EPJ C8 3	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ADLOFF	99	EPJ C11 447	C. Adloff <i>et al.</i>	(H1 Collab.)
Also		EPJ C14 553 (erratum)	C. Adloff <i>et al.</i>	(H1 Collab.)
CASALBUONI	99	PL B460 135	R. Casalbuoni <i>et al.</i>	
CZAKON	99	PL B458 355	M. Czakon, J. Gluza, M. Zralek	
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MARCIANO	99	PR D60 093006	W. Marciano	
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STRUMIA	99	PL B466 107	A. Strumia	
ABBOTT	98E	PRL 80 2051	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	98J	PRL 81 38	B. Abbott <i>et al.</i>	(D0 Collab.)
ABE	98S	PRL 81 4806	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	98V	PRL 81 5742	F. Abe <i>et al.</i>	(CDF Collab.)
ACCIARRI	98J	PL B433 163	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACKERSTAFF	98V	EPJ C2 441	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
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ABE	97G	PR D55 R5263	F. Abe <i>et al.</i>	(CDF Collab.)
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ABE	97W	PRL 79 3819	F. Abe <i>et al.</i>	(CDF Collab.)
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ACCIARRI	97Q	PL B412 201	M. Acciarri <i>et al.</i>	(L3 Collab.)
ARIMA	97	PR D55 19	T. Arima <i>et al.</i>	(VENUS Collab.)

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DEANDREA	97	PL B409 277	A. Deandrea	(MARS)
DERRICK	97	ZPHY C73 613	M. Derrick <i>et al.</i>	(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 <i>et al.</i>	(D0 Collab.)
ABACHI	96D	PL B385 471	S. Abachi <i>et al.</i>	(D0 Collab.)
ABREU	96T	ZPHY C72 179	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ADAM	96C	PL B380 471	W. Adam <i>et al.</i>	(DELPHI Collab.)
AID	96B	PL B369 173	S. Aid <i>et al.</i>	(H1 Collab.)
ALLET	96	PL B383 139	M. Allet <i>et al.</i>	(VILL, LEUV, LOUV, WISC)
ABACHI	95E	PL B358 405	S. Abachi <i>et al.</i>	(D0 Collab.)
ABE	95M	PRL 74 2900	F. Abe <i>et al.</i>	(CDF Collab.)
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KUZNETSOV	95B	PAN 58 2113	A.V. Kuznetsov, N.V. Mikheev	(YARO)
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MIZUKOSHI	95	NP B443 20	J.K. Mizukoshi, O.J.P. Eboli, M.C. Gonzalez-Garcia	
ABREU	94O	ZPHY C64 183	P. Abreu <i>et al.</i>	(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 <i>et al.</i>	(PNPI, KIAE, HARV+)
		Translated from ZETFP 60 311.		
LEURER	94	PR D50 536	M. Leurer	(REHO)
LEURER	94B	PR D49 333	M. Leurer	(REHO)
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MAHANTA	94	PL B337 128	U. Mahanta	(MEHTA)
SEVERIJNS	94	PRL 73 611 (erratum)	N. Severijns <i>et al.</i>	(LOUV, WISC, LEUV+)
VILAIN	94B	PL B332 465	P. Vilain <i>et al.</i>	(CHARM II Collab.)
ABE	93C	PL B302 119	K. Abe <i>et al.</i>	(VENUS Collab.)
ABE	93D	PL B304 373	T. Abe <i>et al.</i>	(TOPAZ Collab.)
ABE	93G	PRL 71 2542	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	93J	PL B316 620	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACTON	93E	PL B311 391	P.D. Acton <i>et al.</i>	(OPAL Collab.)
ADRIANI	93M	PRPL 236 1	O. Adriani <i>et al.</i>	(L3 Collab.)
ALITTI	93	NP B400 3	J. Alitti <i>et al.</i>	(UA2 Collab.)
BHATTACH...	93	PR D47 R3693	G. Bhattacharyya <i>et al.</i>	(CALC, JADA, ICTP+)
BUSKULIC	93F	PL B308 425	D. Buskulic <i>et al.</i>	(ALEPH Collab.)
DERRICK	93	PL B306 173	M. Derrick <i>et al.</i>	(ZEUS Collab.)
RIZZO	93	PR D48 4470	T.G. Rizzo	(ANL)
SEVERIJNS	93	PRL 70 4047	N. Severijns <i>et al.</i>	(LOUV, WISC, LEUV+)
Also		PRL 73 611 (erratum)	N. Severijns <i>et al.</i>	(LOUV, WISC, LEUV+)
STERNER	93	PL B303 385	K.L. Sterner <i>et al.</i>	(AMY Collab.)
ABREU	92D	ZPHY C53 555	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ADRIANI	92F	PL B292 472	O. Adriani <i>et al.</i>	(L3 Collab.)
DECAMP	92	PRPL 216 253	D. Decamp <i>et al.</i>	(ALEPH Collab.)
IMAZATO	92	PRL 69 877	J. Imazato <i>et al.</i>	(KEK, INUS, TOKY+)
MISHRA	92	PRL 68 3499	S.R. Mishra <i>et al.</i>	(COLU, CHIC, FNAL+)
POLAK	92B	PR D46 3871	J. Polak, M. Zralek	(SILES)
ACTON	91	PL B268 122	D.P. Acton <i>et al.</i>	(OPAL Collab.)
ACTON	91B	PL B273 338	D.P. Acton <i>et al.</i>	(OPAL Collab.)
ADEVA	91D	PL B262 155	B. Adeva <i>et al.</i>	(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 <i>et al.</i>	(HSCA, OSU, CHIC+)
ABE	90F	PL B246 297	K. Abe <i>et al.</i>	(VENUS Collab.)
ABE	90H	PR D41 1722	F. Abe <i>et al.</i>	(CDF Collab.)
AKRAWY	90J	PL B246 285	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)
ANTREASYAN	90C	PL B251 204	D. Antreasyan <i>et al.</i>	(Crystal Ball Collab.)
GONZALEZ-G...	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 <i>et al.</i>	(AMY Collab.)
LOPEZ	90	PL B241 392	J.L. Lopez, D.V. Nanopoulos	(TAMU)
ALBAJAR	89	ZPHY C44 15	C. Albajar <i>et al.</i>	(UA1 Collab.)
ALBRECHT	89	ZPHY C42 349	H. Albrecht <i>et al.</i>	(ARGUS Collab.)
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 <i>et al.</i>	(VENUS Collab.)
ROBINETT	89	PR D39 834	R.W. Robinett	(PSU)
ALBAJAR	88B	PL B209 127	C. Albajar <i>et al.</i>	(UA1 Collab.)
BAGGER	88	PR D37 1188	J. Bagger, C. Schmidt, S. King	(HARV, BOST)
BALKE	88	PR D37 587	B. Balke <i>et al.</i>	(LBL, UCB, COLO, NWES+)
BERGSTROM	88	PL B212 386	L. Bergstrom	(STOH)
CUYPERS	88	PRL 60 1237	F. Cuyppers, 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)
ANSARI	87D	PL B195 613	R. Ansari <i>et al.</i>	(UA2 Collab.)
BARTEL	87B	ZPHY C36 15	W. Bartel <i>et al.</i>	(JADE Collab.)
BEHREND	86B	PL B178 452	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
DERRICK	86	PL 166B 463	M. Derrick <i>et al.</i>	(HRS Collab.)
Also		PR D34 3286	M. Derrick <i>et al.</i>	(HRS Collab.)
JODIDIO	86	PR D34 1967	A. Jodidio <i>et al.</i>	(LBL, NWES, TRIU)
Also		PR D37 237 (erratum)	A. Jodidio <i>et al.</i>	(LBL, NWES, TRIU)
MOHAPATRA	86	PR D34 909	R.N. Mohapatra	(UMD)
ADEVA	85	PL 152B 439	B. Adeva <i>et al.</i>	(Mark-J Collab.)
BERGER	85B	ZPHY C27 341	C. Berger <i>et al.</i>	(PLUTO Collab.)
STOKER	85	PRL 54 1887	D.P. Stoker <i>et al.</i>	(LBL, NWES, TRIU)
ADEVA	84	PRL 53 134	B. Adeva <i>et al.</i>	(Mark-J Collab.)
BEHREND	84C	PL 140B 130	H.J. Behrend <i>et al.</i>	(CELLO Collab.)
BERGSMA	83	PL 122B 465	F. Bergsma <i>et al.</i>	(CHARM Collab.)
CARR	83	PRL 51 627	J. Carr <i>et al.</i>	(LBL, NWES, TRIU)
BEALL	82	PRL 48 848	G. Beall, M. Bander, A. Soni	(UCI, UCLA)
SHANKER	82	NP B204 375	O. Shanker	(TRIU)