

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 axigluons.

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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. ● ● ●				
> 731	95	¹ ABAZOV	08P D0	$W' \rightarrow tb$
> 788	95	ABULENCIA	07K CDF	$W' \rightarrow e\nu$
none 200–610	95	² ABAZOV	06N D0	$W' \rightarrow tb$
> 800	95	ABAZOV	04C D0	$W' \rightarrow q\bar{q}$
225–536	95	³ ACOSTA	03B CDF	$W' \rightarrow tb$
none 200–480	95	⁴ AFFOLDER	02C CDF	$W' \rightarrow WZ$
> 786	95	⁵ AFFOLDER	01I CDF	$W' \rightarrow e\nu, \mu\nu$
> 660	95	⁶ ABE	00 CDF	$W' \rightarrow \mu\nu$
none 300–420	95	⁷ ABE	97G CDF	$W' \rightarrow q\bar{q}$
> 720	95	⁸ ABACHI	96C D0	$W' \rightarrow e\nu$
> 610	95	⁹ ABACHI	95E D0	$W' \rightarrow e\nu, \tau\nu$
> 652	95	¹⁰ ABE	95M CDF	$W' \rightarrow e\nu$
> 251	90	¹¹ ALITTI	93 UA2	$W' \rightarrow q\bar{q}$
none 260–600	95	¹² RIZZO	93 RVUE	$W' \rightarrow q\bar{q}$
> 220	90	¹³ ALBAJAR	89 UA1	$W' \rightarrow e\nu$
> 209	90	¹⁴ ANSARI	87D UA2	$W' \rightarrow e\nu$

¹ 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).

² 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 $M_{\nu_R} \ll M_{W'}$ ($M_{\nu_R} > M_{W'}$).

³ 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.

⁴ The quoted limit is obtained assuming $W'WZ$ coupling strength is the same as the ordinary WWZ 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.

⁵ 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.

- ⁶ ABE 00 assume that the neutrino from W' decay is stable and has a mass significantly less than $m_{W'}$.
- ⁷ ABE 97G search for new particle decaying to dijets.
- ⁸ For bounds on W_R with nonzero right-handed mass, see Fig. 5 from ABACHI 96C.
- ⁹ 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 $m_{W'}$.
- ¹⁰ ABE 95M assume that the decay $W' \rightarrow WZ$ 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.
- ¹¹ 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.
- ¹² RIZZO 93 analyses CDF limit on possible two-jet resonances. The limit is sensitive to the inclusion of the assumed K factor.
- ¹³ ALBAJAR 89 cross section limit at 630 GeV is $\sigma(W') B(e\nu) < 4.1$ pb (90% CL).
- ¹⁴ 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	¹⁵ CZAKON	99	RVUE Electroweak
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 180	90	¹⁶ MELCONIAN	07	CNTR $^{37}\text{K } \beta^+$ decay
> 290.7	90	¹⁷ SCHUMANN	07	CNTR Polarized neutron decay
[> 3300]	95	¹⁸ CYBURT	05	COSM Nucleosynthesis; light ν_R
> 310	90	¹⁹ THOMAS	01	CNTR β^+ decay
> 137	95	²⁰ ACKERSTAFF	99D	OPAL τ decay
>1400	68	²¹ BARENBOIM	98	RVUE Electroweak, Z - Z' mixing
> 549	68	²² BARENBOIM	97	RVUE μ decay
> 220	95	²³ STAHL	97	RVUE τ decay
> 220	90	²⁴ ALLET	96	CNTR β^+ decay
> 281	90	²⁵ KUZNETSOV	95	CNTR Polarized neutron decay
> 282	90	²⁶ KUZNETSOV	94B	CNTR Polarized neutron decay
> 439	90	²⁷ BHATTACH...	93	RVUE Z - Z' mixing
> 250	90	²⁸ SEVERIJNS	93	CNTR β^+ decay
		²⁹ IMAZATO	92	CNTR K^+ decay
> 475	90	³⁰ POLAK	92B	RVUE μ decay
> 240	90	³¹ AQUINO	91	RVUE Neutron decay

> 496	90	31 AQUINO	91	RVUE	Neutron and muon decay
> 700		32 COLANGELO	91	THEO	$m_{K_L^0} - m_{K_S^0}$
> 477	90	33 POLAK	91	RVUE	μ decay
[none 540–23000]		34 BARBIERI	89B	ASTR	SN 1987A; light ν_R
> 300	90	35 LANGACKER	89B	RVUE	General
> 160	90	36 BALKE	88	CNTR	$\mu \rightarrow e\nu\bar{\nu}$
> 406	90	37 JODIDIO	86	ELEC	Any ζ
> 482	90	37 JODIDIO	86	ELEC	$\zeta = 0$
> 800		MOHAPATRA	86	RVUE	$SU(2)_L \times SU(2)_R \times U(1)$
> 400	95	38 STOKER	85	ELEC	Any ζ
> 475	95	38 STOKER	85	ELEC	$\zeta < 0.041$
		39 BERGSMA	83	CHRM	$\nu_\mu e \rightarrow \mu\nu_e$
> 380	90	40 CARR	83	ELEC	μ^+ decay
>1600		41 BEALL	82	THEO	$m_{K_L^0} - m_{K_S^0}$

- ¹⁵ CZAKON 99 perform a simultaneous fit to charged and neutral sectors.
- ¹⁶ 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.
- ¹⁷ 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.
- ¹⁸ 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 $M_{W_R} > 3.3 \text{ TeV} (T_{dec} / 140 \text{ MeV})^{3/4}$.
- ¹⁹ THOMAS 01 limit is from measurement of β^+ polarization in decay of polarized ^{12}N . The listed limit assumes no mixing.
- ²⁰ ACKERSTAFF 99D limit is from τ decay parameters. Limit increase to 145 GeV for zero mixing.
- ²¹ 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.
- ²² The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L-K_S mass difference.
- ²³ STAHL 97 limit is from fit to τ -decay parameters.
- ²⁴ ALLET 96 measured polarization-asymmetry correlation in $^{12}\text{N}\beta^+$ decay. The listed limit assumes zero L - R mixing.
- ²⁵ 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.
- ²⁶ 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.
- ²⁷ 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 .
- ²⁸ 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.
- ²⁹ 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 ($V_{u\bar{s}}^R = 1$), the result corresponds to $m_{W_R} > 653$ GeV. See their Fig. 4 for m_{W_R} limits for general $|V_{u\bar{s}}^R|^2 = 1 - |V_{u\bar{d}}^R|^2$.
- ³⁰ POLAK 92B limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming $\zeta = 0$. Supersedes POLAK 91.

- 31 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.
- 32 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.
- 33 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.
- 34 BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.
- 35 LANGACKER 89B limit is for any ν_R mass (either Dirac or Majorana) and for a general class of right-handed quark mixing matrices.
- 36 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.
- 37 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^+ .
- 38 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.
- 39 BERGSMA 83 set limit $m_{W_2}/m_{W_1} > 1.9$ at CL = 90%.
- 40 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.
- 41 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	42 ACKERSTAFF 99D	OPAL	τ decay
< 0.013	90	43 CZAKON 99	RVUE	Electroweak
< 0.0333		44 BARENBOIM 97	RVUE	μ decay
< 0.04	90	45 MISHRA 92	CCFR	νN scattering
-0.0006 to 0.0028	90	46 AQUINO 91	RVUE	
[none 0.00001-0.02]		47 BARBIERI 89B	ASTR	SN 1987A
< 0.040	90	48 JODIDIO 86	ELEC	μ decay
-0.056 to 0.040	90	48 JODIDIO 86	ELEC	μ decay

- 42 ACKERSTAFF 99D limit is from τ decay parameters.
- 43 CZAKON 99 perform a simultaneous fit to charged and neutral sectors.
- 44 The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L-K_S mass difference.
- 45 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.

⁴⁶ AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right asymmetry is assumed.

⁴⁷ BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.

⁴⁸ 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
> 923	95	49 AALTONEN	07H CDF	$p\bar{p}, Z'_{SM} \rightarrow e^+e^-$
>1305	95	50 ABDALLAH	06C DLPH	e^+e^-
>1500	95	51 CHEUNG	01B RVUE	Electroweak
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 850		52 ABULENCIA	06L CDF	Repl. by AALTONEN 07H
> 825	95	53 ABULENCIA	05A CDF	$p\bar{p}; Z'_{SM} \rightarrow e^+e^-, \mu^+\mu^-$
> 399	95	54 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	55 ABBIENDI	04G OPAL	e^+e^-
> 670	95	56 ABAZOV	01B D0	$p\bar{p}, Z'_{SM} \rightarrow e^+e^-$
> 710	95	57 ABREU	00S DLPH	e^+e^-
> 898	95	58 BARATE	00I ALEP	e^+e^-
> 809	95	59 ERLER	99 RVUE	Electroweak
> 690	95	60 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	61 VILAIN	94B CHM2	$\nu_\mu e \rightarrow \nu_\mu e$ and $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
> 237	90	62 ALITTI	93 UA2	$p\bar{p}; Z'_{SM} \rightarrow q\bar{q}$
none 260–600	95	63 RIZZO	93 RVUE	$p\bar{p}; Z'_{SM} \rightarrow q\bar{q}$
> 426	90	64 ABE	90F VNS	e^+e^-

⁴⁹ AALTONEN 07H search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

⁵⁰ ABDALLAH 06C use data $\sqrt{s} = 130$ –207 GeV.

⁵¹ CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.

⁵² ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

⁵³ ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

⁵⁴ ACOSTA 05R search for resonances decaying to tau lepton pairs in $\bar{p}p$ collisions at $\sqrt{s} = 1.96$ TeV.

⁵⁵ ABBIENDI 04G give 95% CL limit on Z - Z' mixing $-0.00422 < \theta < 0.00091$. $\sqrt{s} = 91$ to 207 GeV.

⁵⁶ 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.

- 57 ABREU 00s uses LEP data at $\sqrt{s}=90$ to 189 GeV.
 58 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.
 59 ERLER 99 give 90%CL limit on the Z - Z' mixing $-0.0041 < \theta < 0.0003$. $\rho_0=1$ is assumed.
 60 ABE 97s find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s}=1.8$ TeV.
 61 VILAIN 94B assume $m_t = 150$ GeV.
 62 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.
 63 RIZZO 93 analyses CDF limit on possible two-jet resonances.
 64 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
>600	95	SCHAEL	07A ALEP	e^+e^-
>860	95	65 CHEUNG	01B RVUE	Electroweak
>630	95	66 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	67 ABDALLAH	06C DLPH	e^+e^-
>518	95	68 ABBIENDI	04G OPAL	e^+e^-
>380	95	69 ABREU	00S DLPH	e^+e^-
>436	95	70 BARATE	00i ALEP	Repl. by SCHAEL 07A
>550	95	71 CHAY	00 RVUE	Electroweak
		72 ERLER	00 RVUE	Cs
		73 CASALBUONI	99 RVUE	Cs
(> 1205)	90	74 CZAKON	99 RVUE	Electroweak
>564	95	75 ERLER	99 RVUE	Electroweak
(> 1673)	95	76 ERLER	99 RVUE	Electroweak
(> 1700)	68	77 BARENBOIM	98 RVUE	Electroweak
>244	95	78 CONRAD	98 RVUE	$\nu_\mu N$ scattering
>253	95	79 VILAIN	94B CHM2	$\nu_\mu e \rightarrow \nu_\mu e$ and $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
none 200–600	95	80 RIZZO	93 RVUE	$p\bar{p}; Z_{LR} \rightarrow q\bar{q}$
[> 2000]		WALKER	91 COSM	Nucleosynthesis; light ν_R
none 200–500		81 GRIFOLS	90 ASTR	SN 1987A; light ν_R
none 350–2400		82 BARBIERI	89B ASTR	SN 1987A; light ν_R

- 65 CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
 66 ABE 97s find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s}=1.8$ TeV.
 67 ABDALLAH 06C give 95% CL limit $|\theta| < 0.0028$. See their Fig. 14 for limit contours in the mass-mixing plane.
 68 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.

- ⁶⁹ 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.
- ⁷⁰ 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.
- ⁷¹ CHAY 00 also find $-0.0003 < \theta < 0.0019$. For g_R free, $m_{Z'} > 430$ GeV.
- ⁷² ERLER 00 discuss the possibility that a discrepancy between the observed and predicted values of $Q_W(\text{Cs})$ 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 .
- ⁷³ CASALBUONI 99 discuss the discrepancy between the observed and predicted values of $Q_W(\text{Cs})$. It is shown that the data are better described in a class of models including the Z_{LR} model.
- ⁷⁴ CZAKON 99 perform a simultaneous fit to charged and neutral sectors. Assumes manifest left-right symmetric model. Finds $|\theta| < 0.0042$.
- ⁷⁵ ERLER 99 give 90% CL limit on the Z - Z' mixing $-0.0009 < \theta < 0.0017$.
- ⁷⁶ ERLER 99 assumes 2 Higgs doublets, transforming as 10 of $SO(10)$, embedded in E_6 .
- ⁷⁷ 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.
- ⁷⁸ CONRAD 98 limit is from measurements at CCFR, assuming no Z - Z' mixing.
- ⁷⁹ VILAIN 94B assume $m_t = 150$ GeV and $\theta=0$. See Fig. 2 for limit contours in the mass-mixing plane.
- ⁸⁰ RIZZO 93 analyses CDF limit on possible two-jet resonances.
- ⁸¹ GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. A specific Higgs sector is assumed. See also GRIFOLS 90D, RIZZO 91.
- ⁸² 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
> 822	95	⁸³ AALTONEN	07H	CDF $p\bar{p}, Z'_\chi \rightarrow e^+e^-$
> 781	95	⁸⁴ ABBIENDI	04G	OPAL e^+e^-
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 680	95	SCHAEL	07A	ALEP e^+e^-
> 545	95	⁸⁵ ABDALLAH	06C	DLPH e^+e^-
> 740		⁸⁶ ABULENCIA	06L	CDF Repl. by AALTONEN 07H
> 690	95	⁸⁷ ABULENCIA	05A	CDF $p\bar{p}; Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
>2100		⁸⁸ BARGER	03B	COSM Nucleosynthesis; light ν_R
> 680	95	⁸⁹ CHEUNG	01B	RVUE Electroweak
> 440	95	⁹⁰ ABREU	00S	DLPH e^+e^-
> 533	95	⁹¹ BARATE	00I	ALEP Repl. by SCHAEL 07A
> 554	95	⁹² CHO	00	RVUE Electroweak
		⁹³ ERLER	00	RVUE Cs
		⁹⁴ ROSNER	00	RVUE Cs

> 545	95	95 ERLER	99	RVUE	Electroweak
(> 1368)	95	96 ERLER	99	RVUE	Electroweak
> 215	95	97 CONRAD	98	RVUE	$\nu_\mu N$ scattering
> 595	95	98 ABE	97S	CDF	$p\bar{p}; Z'_\chi \rightarrow e^+e^-, \mu^+\mu^-$
> 190	95	99 ARIMA	97	VNS	Bhabha scattering
> 262	95	100 VILAIN	94B	CHM2	$\nu_\mu e \rightarrow \nu_\mu e; \bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
[>1470]		101 FARAGGI	91	COSM	Nucleosynthesis; light ν_R
> 231	90	102 ABE	90F	VNS	e^+e^-
[> 1140]		103 GONZALEZ-G.	90D	COSM	Nucleosynthesis; light ν_R
[> 2100]		104 GRIFOLS	90	ASTR	SN 1987A; light ν_R

83 AALTONEN 07H search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

84 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.

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

86 ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

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

88 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.

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

90 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.

91 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.

92 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.

93 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 .

94 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 .

95 ERLER 99 give 90% CL limit on the Z - Z' mixing $-0.0020 < \theta < 0.0015$.

96 ERLER 99 assumes 2 Higgs doublets, transforming as 10 of $SO(10)$, embedded in E_6 .

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

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

99 Z - Z' mixing is assumed to be zero. $\sqrt{s} = 57.77$ GeV.

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

101 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.

102 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.

103 Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that ν_R is light ($\lesssim 1$ MeV).

104 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
>822	95	105 AALTONEN	07H	CDF $p\bar{p}, Z'_\psi \rightarrow e^+e^-$
>475	95	106 ABDALLAH	06C	DLPH e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>410	95	SCHAEL	07A	ALEP e^+e^-
>725		107 ABULENCIA	06L	CDF Repl. by AALTONEN 07H
>675	95	108 ABULENCIA	05A	CDF $p\bar{p}; Z'_\psi \rightarrow e^+e^-, \mu^+\mu^-$
>366	95	109 ABBIENDI	04G	OPAL e^+e^-
>600		110 BARGER	03B	COSM Nucleosynthesis; light ν_R
>350	95	111 ABREU	00S	DLPH e^+e^-
>294	95	112 BARATE	00I	ALEP Repl. by SCHAEL 07A
>137	95	113 CHO	00	RVUE Electroweak
>146	95	114 ERLER	99	RVUE Electroweak
> 54	95	115 CONRAD	98	RVUE $\nu_\mu N$ scattering
>590	95	116 ABE	97S	CDF $p\bar{p}; Z'_\psi \rightarrow e^+e^-, \mu^+\mu^-$
>135	95	117 VILAIN	94B	CHM2 $\nu_\mu e \rightarrow \nu_\mu e; \bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
>105	90	118 ABE	90F	VNS e^+e^-
[> 160]		119 GONZALEZ-G.	90D	COSM Nucleosynthesis; light ν_R
[> 2000]		120 GRIFOLS	90D	ASTR SN 1987A; light ν_R

105 AALTONEN 07H search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

106 ABDALLAH 06C give 95% CL limit $|\theta| < 0.0027$. See their Fig. 14 for limit contours in the mass-mixing plane.

107 ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

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

109 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.

110 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.

111 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.

112 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.

113 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.

114 ERLER 99 give 90% CL limit on the $Z-Z'$ mixing $-0.0013 < \theta < 0.0024$.

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

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

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

- 118 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.
- 119 Assumes the nucleosynthesis bound on the effective number of light neutrinos ($\delta N_\nu < 1$) and that ν_R is light ($\lesssim 1$ MeV).
- 120 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
> 891	95	121 AALTONEN	07H CDF	$p\bar{p}, Z'_\eta \rightarrow e^+e^-$
> 515	95	122 ABBIENDI	04G OPAL	e^+e^-
> 619	95	123 CHO	00 RVUE	Electroweak
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
> 350	95	SCHAEL	07A ALEP	e^+e^-
> 360	95	124 ABDALLAH	06C DLPH	e^+e^-
> 745		125 ABULENCIA	06L CDF	Repl. by AALTONEN 07H
> 720	95	126 ABULENCIA	05A CDF	$p\bar{p}; Z'_\eta \rightarrow e^+e^-, \mu^+\mu^-$
>1600		127 BARGER	03B COSM	Nucleosynthesis; light ν_R
> 310	95	128 ABREU	00S DLPH	e^+e^-
> 329	95	129 BARATE	00I ALEP	Repl. by SCHAEL 07A
> 365	95	130 ERLER	99 RVUE	Electroweak
> 87	95	131 CONRAD	98 RVUE	$\nu_\mu N$ scattering
> 620	95	132 ABE	97S CDF	$p\bar{p}; Z'_\eta \rightarrow e^+e^-, \mu^+\mu^-$
> 100	95	133 VILAIN	94B CHM2	$\nu_\mu e \rightarrow \nu_\mu e; \bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
> 125	90	134 ABE	90F VNS	e^+e^-
[> 820]		135 GONZALEZ-G.	90D COSM	Nucleosynthesis; light ν_R
[> 3300]		136 GRIFOLS	90 ASTR	SN 1987A; light ν_R
[> 1040]		135 LOPEZ	90 COSM	Nucleosynthesis; light ν_R

- 121 AALTONEN 07H search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 122 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.
- 123 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.
- 124 ABDALLAH 06C give 95% CL limit $|\theta| < 0.0092$. See their Fig. 14 for limit contours in the mass-mixing plane.
- 125 ABULENCIA 06L search for resonances decaying to e^+e^- in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 126 ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 127 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.
- 128 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.

- 129 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.
- 130 ERLER 99 give 90% CL limit on the Z - Z' mixing $-0.0062 < \theta < 0.0011$.
- 131 CONRAD 98 limit is from measurements at CCFR, assuming no Z - Z' mixing.
- 132 ABE 97S find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) < 40$ fb for $m_{Z'} > 600$ GeV at $\sqrt{s}=1.8$ TeV.
- 133 VILAIN 94B assume $m_t = 150$ GeV and $\theta=0$. See Fig. 2 for limit contours in the mass-mixing plane.
- 134 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.
- 135 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).
- 136 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. ● ● ●			
	137 AALTONEN	08Y CDF	$Z' \rightarrow t\bar{t}$
	137 ABAZOV	08AA D0	$Z' \rightarrow t\bar{t}$
	138 ABULENCIA	06M CDF	$Z' \rightarrow e\mu$
	139 ABAZOV	04A D0	Repl. by ABAZOV 08AA
	140 BARGER	03B COSM	Nucleosynthesis; light ν_R
	141 CHO	00 RVUE	E_6 -motivated
	142 CHO	98 RVUE	E_6 -motivated
	143 ABE	97G CDF	$Z' \rightarrow \bar{q}q$

- 137 Search for narrow resonance decaying to $t\bar{t}$. See their Fig. 3 for limit on $\sigma \cdot B$.
- 138 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.
- 139 Search for narrow resonance decaying to $t\bar{t}$. See their Fig. 2 for limit on $\sigma \cdot B$.
- 140 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.
- 141 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.
- 142 CHO 98 study constraints on four-Fermi contact interactions obtained from low-energy electroweak experiments, assuming no Z - Z' mixing.
- 143 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		144	MUECK	02	RVUE	Electroweak
> 3.3	95	145	CORNET	00	RVUE	$e\nu qq'$
>5000		146	DELGADO	00	RVUE	ϵ_K
> 2.6	95	147	DELGADO	00	RVUE	Electroweak
> 3.3	95	148	RIZZO	00	RVUE	Electroweak
> 2.9	95	149	MARCIANO	99	RVUE	Electroweak
> 2.5	95	150	MASIP	99	RVUE	Electroweak
> 1.6	90	151	NATH	99	RVUE	Electroweak
> 3.4	95	152	STRUMIA	99	RVUE	Electroweak

- 144 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.
- 145 Bound is derived from limits on $e\nu qq'$ contact interaction, using data from HERA and the Tevatron.
- 146 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 .
- 147 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 $Q_W(\text{Cs})$. Quoted bound assumes all Higgs bosons confined to brane; placing one Higgs doublet in the bulk lowers bound to 2.3 TeV.
- 148 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.
- 149 Bound is derived from global electroweak analysis but considering only presence of the KK W bosons.
- 150 Global electroweak analysis used to obtain bound independent of position of Higgs on brane or in bulk.
- 151 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.
- 152 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	153 ABAZOV	09 D0	Second generation
>229	95	154 ABAZOV	07J D0	Third generation
>226	95	155 ABULENCIA	06T CDF	Second generation
>256	95	156 ABAZOV	05H D0	First generation
>236	95	157 ACOSTA	05P CDF	First generation
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		158 AALTONEN	08P CDF	Third generation
>153	95	159 AALTONEN	08Z CDF	Third generation
>205	95	160 ABAZOV	08AD D0	All generations

>210	95	159	ABAZOV	08AN	D0	Third generation
>251	95	161	ABAZOV	06A	D0	Superseded by ABAZOV 09
>136	95	162	ABAZOV	06L	D0	Superseded by ABAZOV 08AD
>117	95	160	ACOSTA	05I	CDF	First generation
> 99	95	163	ABBIENDI	03R	OPAL	First generation
>100	95	163	ABBIENDI	03R	OPAL	Second generation
> 98	95	163	ABBIENDI	03R	OPAL	Third generation
> 98	95	164	ABAZOV	02	D0	All generations
>225	95	165	ABAZOV	01D	D0	First generation
> 85.8	95	166	ABBIENDI	00M	OPAL	Superseded by ABBIENDI 03R
> 85.5	95	166	ABBIENDI	00M	OPAL	Superseded by ABBIENDI 03R
> 82.7	95	166	ABBIENDI	00M	OPAL	Superseded by ABBIENDI 03R
>200	95	167	ABBOTT	00C	D0	Second generation
>123	95	168	AFFOLDER	00K	CDF	Second generation
>148	95	169	AFFOLDER	00K	CDF	Third generation
>160	95	170	ABBOTT	99J	D0	Second generation
>225	95	171	ABBOTT	98E	D0	First generation
> 94	95	172	ABBOTT	98J	D0	Third generation
>202	95	173	ABE	98S	CDF	Second generation
>242	95	174	GROSS-PILCH	98		First generation
> 99	95	175	ABE	97F	CDF	Third generation
>213	95	176	ABE	97X	CDF	First generation
> 45.5	95	177,178	ABREU	93J	DLPH	First + second generation
> 44.4	95	179	ADRIANI	93M	L3	First generation
> 44.5	95	179	ADRIANI	93M	L3	Second generation
> 45	95	179	DECAMP	92	ALEP	Third generation
none 8.9–22.6	95	180	KIM	90	AMY	First generation
none 10.2–23.2	95	180	KIM	90	AMY	Second generation
none 5–20.8	95	181	BARTEL	87B	JADE	
none 7–20.5	95	182	BEHREND	86B	CELL	

153 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.

154 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 $B(\nu b) = 1$.

155 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 $B(\mu q)$.

156 ABAZOV 05H search for scalar leptoquarks using $eejj$ 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.

157 ACOSTA 05P search for scalar leptoquarks using $eejj$, $e\nu jj$ 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.

158 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 $B(\tau b) = 1$.

159 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 $B(\tau b) = 1$.

160 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 $B(\nu q) = 1$.

- 161 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.
- 162 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 $B(\nu q) = 1$.
- 163 ABBIENDI 03R search for scalar/vector leptoquarks in e^+e^- collisions at $\sqrt{s} = 189\text{--}209$ 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.
- 164 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.
- 165 ABAZOV 01D search for scalar leptoquarks using $e\nu jj$, $eejj$, 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.
- 166 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.
- 167 ABBOTT 00C search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ 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.
- 168 AFFOLDER 00K search for scalar leptoquark using $\nu\nu cc$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. The quoted limit assumes $B(\nu c) = 1$. Bounds for vector leptoquarks are also given.
- 169 AFFOLDER 00K search for scalar leptoquark using $\nu\nu bb$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. The quoted limit assumes $B(\nu b) = 1$. Bounds for vector leptoquarks are also given.
- 170 ABBOTT 99J search for leptoquarks using $\mu\nu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ 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.
- 171 ABBOTT 98E search for scalar leptoquarks using $e\nu jj$, $eejj$, 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.
- 172 ABBOTT 98J search for charge $-1/3$ third generation scalar and vector leptoquarks in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. The quoted limit is for scalar leptoquark with $B(\nu b) = 1$.
- 173 ABE 98S search for scalar leptoquarks using $\mu\mu jj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. The limit is for $B(\mu q) = 1$. For $B(\mu q) = B(\nu q) = 0.5$, the limit is > 160 GeV.
- 174 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.
- 175 ABE 97F search for third generation scalar and vector leptoquarks in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. The quoted limit is for scalar leptoquark with $B(\tau b) = 1$.
- 176 ABE 97X search for scalar leptoquarks using $eejj$ events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.8$ TeV. The limit is for $B(eq) = 1$.
- 177 Limit is for charge $-1/3$ isospin-0 leptoquark with $B(\ell q) = 2/3$.
- 178 First and second generation leptoquarks are assumed to be degenerate. The limit is slightly lower for each generation.
- 179 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.
- 180 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.
- 181 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 $B(X \rightarrow c \bar{\nu}_\mu) + B(X \rightarrow s \mu^+) = 1$.

182 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	183 CHEKANOV 03B	ZEUS	First generation
> 73	95	184 ABREU 93J	DLPH	Second generation
• • • We do not use the following data for averages, fits, limits, etc. • • •				
		185 ABAZOV 07E	D0	Second generation
>295	95	186 AKTAS 05B	H1	First generation
		187 CHEKANOV 05A	ZEUS	Lepton-flavor violation
>197	95	188 ABBIENDI 02B	OPAL	First generation
		189 CHEKANOV 02	ZEUS	Repl. by CHEKANOV 05A
>290	95	190 ADLOFF 01C	H1	First generation
>204	95	191 BREITWEG 01	ZEUS	First generation
		192 BREITWEG 00E	ZEUS	First generation
>161	95	193 ABREU 99G	DLPH	First generation
>200	95	194 ADLOFF 99	H1	First generation
		195 DERRICK 97	ZEUS	Lepton-flavor violation
>168	95	196 DERRICK 93	ZEUS	First generation

183 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.

184 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.

185 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.

186 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.

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

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

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

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

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

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

193 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.

194 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.

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

¹⁹⁶ 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. ● ● ●				
		197 AKTAS	07A H1	Lepton-flavor violation
> 0.49	95	198 SCHAEEL	07A ALEP	$e^+e^- \rightarrow q\bar{q}$
		199 SMIRNOV	07 RVUE	$K \rightarrow e\mu, B \rightarrow e\tau$
		200 CHEKANOV	05A ZEUS	Lepton-flavor violation
> 1.7	96	201 ADLOFF	03 H1	First generation
> 46	90	202 CHANG	03 BELL	Pati-Salam type
		203 CHEKANOV	02 ZEUS	Repl. by CHEKANOV 05A
> 1.7	95	204 CHEUNG	01B RVUE	First generation
> 0.39	95	205 ACCIARRI	00P L3	$e^+e^- \rightarrow qq$
> 1.5	95	206 ADLOFF	00 H1	First generation
> 0.2	95	207 BARATE	00I ALEP	Repl. by SCHAEEL 07A
		208 BARGER	00 RVUE	Cs
		209 GABRIELLI	00 RVUE	Lepton flavor violation
> 0.74	95	210 ZARNECKI	00 RVUE	S_1 leptoquark
		211 ABBIENDI	99 OPAL	
> 19.3	95	212 ABE	98V CDF	$B_s \rightarrow e^\pm \mu^\mp$, Pati-Salam type
		213 ACCIARRI	98J L3	$e^+e^- \rightarrow q\bar{q}$
		214 ACKERSTAFF	98V OPAL	$e^+e^- \rightarrow q\bar{q}, e^+e^- \rightarrow b\bar{b}$
> 0.76	95	215 DEANDREA	97 RVUE	\tilde{R}_2 leptoquark
		216 DERRICK	97 ZEUS	Lepton-flavor violation
		217 GROSSMAN	97 RVUE	$B \rightarrow \tau^+\tau^- (X)$
		218 JADACH	97 RVUE	$e^+e^- \rightarrow q\bar{q}$
>1200		219 KUZNETSOV	95B RVUE	Pati-Salam type
		220 MIZUKOSHI	95 RVUE	Third generation scalar leptoquark
> 0.3	95	221 BHATTACH...	94 RVUE	Spin-0 leptoquark coupled to $\bar{e}_R t_L$
		222 DAVIDSON	94 RVUE	
> 18		223 KUZNETSOV	94 RVUE	Pati-Salam type
> 0.43	95	224 LEURER	94 RVUE	First generation spin-1 leptoquark
> 0.44	95	224 LEURER	94B RVUE	First generation spin-0 leptoquark
		225 MAHANTA	94 RVUE	P and T violation
> 1		226 SHANKER	82 RVUE	Nonchiral spin-0 leptoquark
> 125		226 SHANKER	82 RVUE	Nonchiral spin-1 leptoquark

¹⁹⁷ 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.

¹⁹⁸ SCHAEEL 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.

¹⁹⁹ SMIRNOV 07 obtains mass limits for the vector and scalar chiral leptoquark states from $K \rightarrow e\mu, B \rightarrow e\tau$ decays.

²⁰⁰ CHEKANOV 05 search for various leptoquarks with lepton-flavor violating couplings. See their Figs.6–10 and Tables 1–8 for detailed limits.

- 201 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.
- 202 The bound is derived from $B(B^0 \rightarrow e^\pm \mu^\mp) < 1.7 \times 10^{-7}$.
- 203 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.
- 204 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.
- 205 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.
- 206 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 $e^+ p \rightarrow e^+ X$.
- 207 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.
- 208 BARGER 00 explain the deviation of atomic parity violation in cesium atoms from prediction is explained by scalar leptoquark exchange.
- 209 GABRIELLI 00 calculate various process with lepton flavor violation in leptoquark models.
- 210 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.
- 211 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.
- 212 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).
- 213 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.
- 214 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.
- 215 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.
- 216 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.
- 217 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.
- 218 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.
- 219 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.

- 220 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.
- 221 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.
- 222 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.
- 223 KUZNETSOV 94 gives mixing independent bound of the Pati-Salam leptoquark from the cosmological limit on $\pi^0 \rightarrow \bar{\nu}\nu$.
- 224 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.
- 225 MAHANTA 94 gives bounds of P - and T -violating scalar-leptoquark couplings from atomic and molecular experiments.
- 226 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 290–420	95	227 ABE	97G CDF	E_6 diquark
none 15–31.7	95	228 ABREU	940 DLPH	SUSY E_6 diquark
227 ABE 97G search for new particle decaying to dijets.				
228 ABREU 940 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. ● ● ●				
>910	95	229 CHOUDHURY 07	RVUE	$p\bar{p} \rightarrow t\bar{t}X$
>365	95	230 DONCHESKI 98	RVUE	$\Gamma(Z \rightarrow \text{hadron})$
none 200–980	95	231 ABE	97G CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$
none 200–870	95	232 ABE	95N CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow q\bar{q}$
none 240–640	95	233 ABE	93G CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2\text{jets}$
> 50	95	234 CUYPERS	91 RVUE	$\sigma(e^+ e^- \rightarrow \text{hadrons})$
none 120–210	95	235 ABE	90H CDF	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2\text{jets}$
> 29		236 ROBINETT	89 THEO	Partial-wave unitarity
none 150–310	95	237 ALBAJAR	88B UA1	$p\bar{p} \rightarrow g_A X, g_A \rightarrow 2\text{jets}$
> 20		BERGSTROM	88 RVUE	$p\bar{p} \rightarrow \gamma X$ via $g_A g$
> 9		238 CUYPERS	88 RVUE	Υ decay
> 25		239 DONCHESKI	88B RVUE	Υ decay

- 229 CHOUDHURY 07 limit is from the $t\bar{t}$ production cross section measured at CDF.
 230 DONCHESKI 98 compare α_s derived from low-energy data and that from $\Gamma(Z \rightarrow \text{hadrons})/\Gamma(Z \rightarrow \text{leptons})$.
 231 ABE 97G search for new particle decaying to dijets.
 232 ABE 95N assume axigluons decaying to quarks in the Standard Model only.
 233 ABE 93G assume $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 10$.
 234 CUYPERS 91 compare α_s measured in Υ decay and that from R at PEP/PETRA energies.
 235 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.
 236 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.
 237 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.
 238 CUYPERS 88 requires $\Gamma(\Upsilon \rightarrow g g_A) < \Gamma(\Upsilon \rightarrow g g g)$. A similar result is obtained by DONCHESKI 88.
 239 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. ● ● ●				
		240 BARATE	98U ALEP	$X^0 \rightarrow \ell\bar{\ell}, q\bar{q}, g g, \gamma\gamma, \nu\bar{\nu}$
		241 ACCIARRI	97Q L3	$X^0 \rightarrow$ invisible particle(s)
		242 ACTON	93E OPAL	$X^0 \rightarrow \gamma\gamma$
		243 ABREU	92D DLPH	$X^0 \rightarrow$ hadrons
		244 ADRIANI	92F L3	$X^0 \rightarrow$ hadrons
		245 ACTON	91 OPAL	$X^0 \rightarrow$ anything
$< 1.1 \times 10^{-4}$	95	246 ACTON	91B OPAL	$X^0 \rightarrow e^+ e^-$
$< 9 \times 10^{-5}$	95	246 ACTON	91B OPAL	$X^0 \rightarrow \mu^+ \mu^-$
$< 1.1 \times 10^{-4}$	95	246 ACTON	91B OPAL	$X^0 \rightarrow \tau^+ \tau^-$
$< 2.8 \times 10^{-4}$	95	247 ADEVA	91D L3	$X^0 \rightarrow e^+ e^-$
$< 2.3 \times 10^{-4}$	95	247 ADEVA	91D L3	$X^0 \rightarrow \mu^+ \mu^-$
$< 4.7 \times 10^{-4}$	95	248 ADEVA	91D L3	$X^0 \rightarrow$ hadrons
$< 8 \times 10^{-4}$	95	249 AKRAWY	90J OPAL	$X^0 \rightarrow$ hadrons

- 240 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.
 241 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} .
 242 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.
 243 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 .

- 244 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.
- 245 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.
- 246 ACTON 91B limits are for $m_{X^0} = 60-85$ GeV.
- 247 ADEVA 91D limits are for $m_{X^0} = 30-89$ GeV.
- 248 ADEVA 91D limits are for $m_{X^0} = 30-86$ GeV.
- 249 AKRAWY 90J give $\Gamma(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow \text{hadrons}) < 1.9$ MeV (95%CL) for $m_{X^0} = 32-80$ 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		250 ODAKA	89 VNS	$\Gamma(X^0 \rightarrow e^+ e^-)$. $B(X^0 \rightarrow \text{had.}) \gtrsim 0.2$ MeV
>45	95	251 DERRICK	86 HRS	$\Gamma(X^0 \rightarrow e^+ e^-) = 6$ MeV
>46.6	95	252 ADEVA	85 MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-) = 10$ keV
>48	95	252 ADEVA	85 MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-) = 4$ MeV
		253 BERGER	85B PLUT	
none 39.8-45.5		254 ADEVA	84 MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-) = 10$ keV
>47.8	95	254 ADEVA	84 MRKJ	$\Gamma(X^0 \rightarrow e^+ e^-) = 4$ MeV
none 39.8-45.2		254 BEHREND	84C CELL	
>47	95	254 BEHREND	84C CELL	$\Gamma(X^0 \rightarrow e^+ e^-) = 4$ MeV

- 250 ODAKA 89 looked for a narrow or wide scalar resonance in $e^+ e^- \rightarrow \text{hadrons}$ at $E_{\text{cm}} = 55.0-60.8$ GeV.
- 251 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.
- 252 ADEVA 85 first limit is from 2γ , $\mu^+ \mu^-$, hadrons assuming X^0 is a scalar. Second limit is from $e^+ e^-$ channel. $E_{\text{cm}} = 40-47$ GeV. Supersedes ADEVA 84.
- 253 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.
- 254 ADEVA 84 and BEHREND 84C have $E_{\text{cm}} = 39.8-45.5$ GeV. MARK-J searched X^0 in $e^+ e^- \rightarrow \text{hadrons}$, 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 $m_{X^0} > E_{\text{cm}}$. 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
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$<10^3$	95	255 ABE	93C VNS	$\Gamma(ee)$
$<(0.4-10)$	95	256 ABE	93C VNS	$f = \gamma\gamma$
$<(0.3-5)$	95	257,258 ABE	93D TOPZ	$f = \gamma\gamma$
$<(2-12)$	95	257,258 ABE	93D TOPZ	$f = \text{hadrons}$
$<(4-200)$	95	258,259 ABE	93D TOPZ	$f = ee$
$<(0.1-6)$	95	258,259 ABE	93D TOPZ	$f = \mu\mu$
$<(0.5-8)$	90	260 STERNER	93 AMY	$f = \gamma\gamma$
255 Limit is for $\Gamma(X^0 \rightarrow e^+e^-) m_{X^0} = 56-63.5$ GeV for $\Gamma(X^0) = 0.5$ GeV.				
256 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.				
257 Limit is for $m_{X^0} = 57.2-60$ GeV.				
258 Limit is valid for $\Gamma(X^0) \ll 100$ MeV. See paper for limits for $\Gamma = 1$ GeV and those for $J = 2$ resonances.				
259 Limit is for $m_{X^0} = 56.6-60$ GeV.				
260 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 $e\rho$ Collisions

VALUE	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	261 CHEKANOV	02B ZEUS	$X \rightarrow jj$
261 CHEKANOV 02B search for photoproduction of X decaying into dijets in $e\rho$ 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
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
<2.6	95	262 ACTON	93E OPAL	$m_{X^0} = 60 \pm 1$ GeV
<2.9	95	BUSKULIC	93F ALEP	$m_{X^0} \sim 60$ GeV
262 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
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	263 ABBIENDI	03D OPAL	$X^0 \rightarrow \gamma\gamma$
	264 ABREU	00Z DLPH	X^0 decaying invisibly
	265 ADAM	96C DLPH	X^0 decaying invisibly

- 263 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.
- 264 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.
- 265 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. ● ● ●				
$<3.7 \times 10^{-6}$	95	266 ABREU	96T DLPH	$f=e,\mu,\tau; F=\gamma\gamma$
		267 ABREU	96T DLPH	$f=\nu; F=\gamma\gamma$
		268 ABREU	96T DLPH	$f=q; F=\gamma\gamma$
$<6.8 \times 10^{-6}$	95	267 ACTON	93E OPAL	$f=e,\mu,\tau; F=\gamma\gamma$
$<5.5 \times 10^{-6}$	95	267 ACTON	93E OPAL	$f=q; F=\gamma\gamma$
$<3.1 \times 10^{-6}$	95	267 ACTON	93E OPAL	$f=\nu; F=\gamma\gamma$
$<6.5 \times 10^{-6}$	95	267 ACTON	93E OPAL	$f=e,\mu; F=\ell\bar{\ell}, q\bar{q}, \nu\bar{\nu}$
$<7.1 \times 10^{-6}$	95	267 BUSKULIC	93F ALEP	$f=e,\mu; F=\ell\bar{\ell}, q\bar{q}, \nu\bar{\nu}$
		269 ADRIANI	92F L3	$f=q; F=\gamma\gamma$

- 266 ABREU 96T obtain limit as a function of m_{X^0} . See their Fig. 6.
- 267 Limit is for m_{X^0} around 60 GeV.
- 268 ABREU 96T obtain limit as a function of m_{X^0} . See their Fig. 15.
- 269 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. ● ● ●			
	270 ABE	97W CDF	$X^0 \rightarrow b\bar{b}$

- 270 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	271	BALEST	95	CLE2	$\Upsilon(1S) \rightarrow X^0 \gamma,$ $m_{X^0} < 5 \text{ GeV}$
$< 3 \times 10^{-5}$ – 6×10^{-3}	90	272	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	273	ANTREASYAN 90C		CBAL	$\Upsilon(1S) \rightarrow X^0 \gamma,$ $m_{X^0} < 7.2 \text{ GeV}$
		274	ALBRECHT	89	ARG	

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

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

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

274 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 $m_{X^0} < 3.5 \text{ GeV}$.

REFERENCES FOR Searches for Heavy Bosons Other Than Higgs Bosons

ABAZOV	09	PL B671 224	V.M. Abazov <i>et al.</i>	(D0 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.)
ABULENCIA	06M	PRL 96 211802	A. Abulencia <i>et al.</i>	(CDF Collab.)
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.)
ACOSTA	05I	PR D71 112001	D. Acosta <i>et al.</i>	(CDF Collab.)
ACOSTA	05P	PR D72 051107R	D. Acosta <i>et al.</i>	(CDF Collab.)
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.)
CYBURT	05	ASP 23 313	R.H. Cyburt <i>et al.</i>	
ABAZOV	04A	PRL 92 221801	V.M. Abazov <i>et al.</i>	(D0 Collab.)
ABAZOV	04C	PR D69 111101R	V.M. Abazov <i>et al.</i>	(D0 Collab.)
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.)
ABAZOV	01D	PR D64 092004	V.M. Abazov <i>et al.</i>	(D0 Collab.)
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.)
ABREU	00Z	EPJ C17 53	P. Abreu <i>et al.</i>	(DELPHI Collab.)
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.)
AFFOLDER	00K	PRL 85 2056	T. Affolder <i>et al.</i>	(CDF Collab.)
BARATE	00I	EPJ C12 183	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARGER	00	PL B480 149	V. Barger, K. Cheung	
BREITWEG	00E	EPJ C16 253	J. Breitweg <i>et al.</i>	(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 <i>et al.</i>	(OPAL Collab.)
ABBOTT	99J	PRL 83 2896	B. Abbott <i>et al.</i>	(D0 Collab.)
ABREU	99G	PL B446 62	P. Abreu <i>et al.</i>	(DELPHI Collab.)
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	
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 <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.)
BARATE	98U	EPJ C4 571	R. Barate <i>et al.</i>	(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-PILCHER	98	hep-ex/9810015	C. Grosso-Pilcher, G. Landsberg, M. Paterno	
ABE	97F	PRL 78 2906	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	97G	PR D55 R5263	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	97S	PRL 79 2192	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	97W	PRL 79 3819	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	97X	PRL 79 4327	F. Abe <i>et al.</i>	(CDF Collab.)
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.)
BARENBOIM	97	PR D55 4213	G. Barenboim <i>et al.</i>	(VALE, IFIC)
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.)
ABE	95N	PRL 74 3538	F. Abe <i>et al.</i>	(CDF Collab.)
BALEST	95	PR D51 2053	R. Balest <i>et al.</i>	(CLEO Collab.)
KUZNETSOV	95	PRL 75 794	I.A. Kuznetsov <i>et al.</i>	(PNPI, KIAE, HARV+)
KUZNETSOV	95B	PAN 58 2113	A.V. Kuznetsov, N.V. Mikheev	(YARO)
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+)
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 <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. 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)
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)