[154] 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)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[155] LEURER	93	RVUE	FCNC
>350	[156] DESHPANDE	83	RVUE	Pati-Salam X-boson
> 1	[157] SHANKER	82	RVUE	PS leptoquark
>125	[157] SHANKER	82	RVUE	Vector-leptoquark

[155] LEURER 93 gives bounds for generation-changing couplings of scalar leptoquark from K^0-$\overline{K}^0$, D^0-$\overline{D}^0$, B^0-$\overline{B}^0$ mixing. See her Fig. 1.
[156] DESHPANDE 83 used upper limit on $K^0_L \rightarrow \mu e$ decay with renormalization-group equations to estimate coupling at the heavy boson mass. See also DIMOPOULOS 81.
[157] From $(\pi \rightarrow e\nu)/(\pi \rightarrow \mu\nu)$ ratio.

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 240–640	95	[158] ABE	93G	CDF	$p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2jets
>50	95	[159] CUYPERS	91	RVUE	$\sigma(e^+e^- \rightarrow$ hadrons)
none 120–210	95	[160] ABE	90H	CDF	$p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2jets
>29		[161] ROBINETT	89	THEO	Partial-wave unitarity
none 150–310	95	[162] ALBAJAR	88B	UA1	$p\overline{p} \rightarrow g_A X$, $g_A \rightarrow$ 2jets
>20		BERGSTROM	88	RVUE	$p\overline{p} \rightarrow \Upsilon X$ via $g_A g$
> 9		[163] CUYPERS	88	RVUE	Υ decay
>25		[164] DONCHESKI	88B	RVUE	Υ decay

[158] ABE 93G assume $\Gamma(g_A) = N\alpha_s m_{g_A}/6$ with $N = 10$.
[159] CUYPERS 91 compare α_s measured in Υ decay and that from R at PEP/PETRA energies.
[160] 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.
[161] ROBINETT 89 result demands partial-wave unitarity of $J = 0$ $t\overline{t} \rightarrow t\overline{t}$ scattering amplitude and derives a limit $m_{g_A} > 0.5\ m_t$. Assumes $m_t > 56$ GeV.
[162] 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.
[163] CUYPERS 88 requires $\Gamma(\Upsilon \rightarrow g g_A) < \Gamma(\Upsilon \rightarrow ggg)$. A similar result is obtained by DONCHESKI 88.
[164] DONCHESKI 88B requires $\Gamma(\Upsilon \rightarrow g q\overline{q})/\Gamma(\Upsilon \rightarrow ggg) < 0.25$, 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, or a photon pair 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. • • •					
		[165] ACTON	93E	OPAL	$X^0 \rightarrow \gamma\gamma$
		[166] ABREU	92D	DLPH	$X^0 \rightarrow$ hadrons
		[167] ADRIANI	92F	L3	$X^0 \rightarrow$ hadrons
		[168] ACTON	91	OPAL	$X^0 \rightarrow$ anything
$<1.1 \times 10^{-4}$	95	[169] ACTON	91B	OPAL	$X^0 \rightarrow e^+e^-$
$<9 \times 10^{-5}$	95	[169] ACTON	91B	OPAL	$X^0 \rightarrow \mu^+\mu^-$
$<1.1 \times 10^{-4}$	95	[169] ACTON	91B	OPAL	$X^0 \rightarrow \tau^+\tau^-$
$<2.8 \times 10^{-4}$	95	[170] ADEVA	91D	L3	$X^0 \rightarrow e^+e^-$
$<2.3 \times 10^{-4}$	95	[170] ADEVA	91D	L3	$X^0 \rightarrow \mu^+\mu^-$
$<4.7 \times 10^{-4}$	95	[171] ADEVA	91D	L3	$X^0 \rightarrow$ hadrons
$<8 \times 10^{-4}$	95	[172] AKRAWY	90J	OPAL	$X^0 \rightarrow$ hadrons

[165] 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.
[166] ABREU 92D give $\sigma_Z \cdot B(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow$ hadrons) $<$(3–10) pb for $m_{X^0} =$ 10–78 GeV. A very similar limit is obtained for spin-1 X^0.
[167] ADRIANI 92F search for isolated γ in hadronic Z decays. The limit $\sigma_Z \cdot B(Z \rightarrow \gamma X^0) \cdot B(X^0 \rightarrow$ hadrons) $<$(2–10) pb (95%CL) is given for $m_{X^0} =$ 25–85 GeV.
[168] ACTON 91 searches for $Z \rightarrow Z^* X^0$, $Z^* \rightarrow e^+e^-$, $\mu^+\mu^-$, or $\nu\overline{\nu}$. Excludes any new scalar X^0 with $m_{X^0} < 9.5$ GeV/c if it has the same coupling to ZZ^* as the MSM Higgs boson.
[169] ACTON 91B limits are for $m_{X^0} =$ 60–85 GeV.
[170] ADEVA 91D limits are for $m_{X^0} =$ 30–89 GeV.
[171] ADEVA 91D limits are for $m_{X^0} =$ 30–86 GeV.
[172] AKRAWY 90J give $\Gamma(Z \rightarrow \gamma X^0)\cdot B(X^0 \rightarrow$ 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 $B(Z \rightarrow \gamma q\overline{q}) < 8.2$ MeV assuming three-body phase space distribution.

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

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 55–61		[173] ODAKA	89	VNS	$\Gamma(X^0 \rightarrow e^+e^-)\cdot B(X^0 \rightarrow$ hadrons) $\gtrsim$ 0.2 MeV
>45	95	[174] DERRICK	86	HRS	$\Gamma(X^0 \rightarrow e^+e^-)$=6 MeV
>46.6	95	[175] ADEVA	85	MRKJ	$\Gamma(X^0 \rightarrow e^+e^-)$=10 keV
>48	95	[175] ADEVA	85	MRKJ	$\Gamma(X^0 \rightarrow e^+e^-)$=4 MeV
		[176] BERGER	85B	PLUT	
none 39.8–45.5		[177] ADEVA	84	MRKJ	$\Gamma(X^0 \rightarrow e^+e^-)$=10 keV
>47.8	95	[177] ADEVA	84	MRKJ	$\Gamma(X^0 \rightarrow e^+e^-)$=4 MeV
none 39.8–45.2		[177] BEHREND	84C	CELL	
>47	95	[177] BEHREND	84C	CELL	$\Gamma(X^0 \rightarrow e^+e^-)$=4 MeV

[173] ODAKA 89 looked for a narrow or wide scalar resonance in $e^+e^- \rightarrow$ hadrons at E_{cm} = 55.0–60.8 GeV.
[174] DERRICK 86 found no deviation from the Standard Model Bhabha scattering at E_{cm}= 29 GeV and set limits on the possible scalar boson e^+e^- coupling. See their figure 4 for excluded region in the $\Gamma(X^0 \rightarrow e^+e^-)$-$m_{X^0}$ plane. Electronic chiral invariance requires a parity doublet of X^0, in which case the limit applies for $\Gamma(X^0 \rightarrow e^+e^-) =$ 3 MeV.
[175] ADEVA 85 first limit is from 2γ, $\mu^+\mu^-$, hadrons assuming X^0 is a scalar. Second limit is from e^+e^- channel. E_{cm} = 40–47 GeV. Supersedes ADEVA 84.
[176] BERGER 85B looked for effect of spin-0 boson exchange in $e^+e^- \rightarrow e^+e^-$ and $\mu^+\mu^-$ at E_{cm} = 34.7 GeV. See Fig. 5 for excluded region in the $m_{X^0} - \Gamma(X^0)$ plane.
[177] ADEVA 84 and BEHREND 84C have E_{cm} = 39.8–45.5 GeV. MARK-J searched X^0 in $e^+e^- \rightarrow$ hadrons, 2γ, $\mu^+\mu^-$, e^+e^- and CELLO in the same channels plus τ pair. No narrow or broad X^0 is found in the energy range. They also searched for the effect of X^0 with $m_X > E_{cm}$. The second limits are from Bhabha data and for spin-0 singlet. The same limits apply for $\Gamma(X^0 \rightarrow e^+e^-) = 2$ MeV if X^0 is a spin-0 doublet. The second limit of BEHREND 84C was read off from their figure 2. The original papers also list limits in other channels.

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

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

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<10^3$	95	[178] ABE	93C	VNS	$\Gamma(ee)$
<(0.4–10)	95	[179] ABE	93C	VNS	$f = \gamma\gamma$
<(0.3–5)	95	[180,181] ABE	93D	TOPZ	$f = \gamma\gamma$
<(2–12)	95	[180,181] ABE	93D	TOPZ	$f =$ hadrons
<(4–200)	95	[181,182] ABE	93D	TOPZ	$f = ee$
<(0.1–6)	95	[181,182] ABE	93D	TOPZ	$f = \mu\mu$
<(0.5–8)	90	[183] STERNER	93	AMY	$f = \gamma\gamma$

[178] Limit is for $\Gamma(X^0 \rightarrow e^+e^-)$ m_{X^0} = 56–63.5 GeV for $\Gamma(X^0) = 0.5$ GeV.
[179] Limit is for m_{X^0} = 56–61.5 GeV and is valid for $\Gamma(X^0) \ll 100$ MeV. See their Fig. 5 for limits for Γ = 1,2 GeV.
[180] Limit is for m_{X^0} = 57.2–60 GeV.
[181] Limit is valid for $\Gamma(X^0) \ll 100$ MeV. See paper for limits for Γ = 1 GeV and those for $J = 2$ resonances.
[182] Limit is for m_{X^0} = 56.6–60 GeV.
[183] STERNER 93 limit is for m_{X^0} = 57–59.6 GeV and is valid for $\Gamma(X^0)$<100 MeV. See their Fig. 2 for limits for Γ = 1,3 GeV.

Search for X^0 Resonance in 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	[184] ACTON	93E	OPAL	m_{X^0}=60 ± 1 GeV
<2.9	95	BUSKULIC	93F	ALEP	$m_{X^0} \sim 60$ GeV

[184] ACTON 93E limit for a $J = 2$ resonance is 0.8 MeV.

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

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

VALUE (MeV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.8 \times 10^{-6}$	95	[185] ACTON	93E	OPAL	f=e,μ,τ; F=$\gamma\gamma$
$<5.5 \times 10^{-6}$	95	[185] ACTON	93E	OPAL	f=q; F=$\gamma\gamma$
$<3.1 \times 10^{-6}$	95	[185] ACTON	93E	OPAL	f=ν; F=$\gamma\gamma$
$<6.5 \times 10^{-6}$	95	[185] ACTON	93E	OPAL	f=e,μ; F=$\ell\overline{\ell}$, $q\overline{q}$, $\nu\overline{\nu}$
$<7.1 \times 10^{-6}$	95	[185] BUSKULIC	93F	ALEP	f=e,μ; F=$\ell\overline{\ell}$, $q\overline{q}$, $\nu\overline{\nu}$
		[186] ADRIANI	92F	L3	f=q; F=$\gamma\gamma$