Searches for Heavy Bosons Other Than Higgs Bosons

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.

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
> 406	90	[1] JODIDIO 86	ELEC	Any ζ
• • • We do not use the following data for averages, fits, limits, etc. • • •				
> 439	90	[2] BHATTACH... 93	RVUE	Z-Z' mixing
> 225	90	[3] SEVERIJNS 93	CNTR	β^+ decay
		[4] IMAZATO 92	CNTR	K^+ decay
> 475	90	[5] POLAK 92B	RVUE	μ decay
> 240	90	[6] AQUINO 91	RVUE	Neutron decay
> 496	90	[6] AQUINO 91	RVUE	Neutron and muon decay
> 700		[7] COLANGELO 91	THEO	$m_{K^0_L} - m_{K^0_S}$
> 477	90	[8] POLAK 91	RVUE	μ decay
[none 540-23000]		[9] BARBIERI 89B	ASTR	SN 1987A; light ν_R
> 300	90	[10] LANGACKER 89B	RVUE	General
> 160	90	[11] BALKE 88	CNTR	$\mu \to e\nu\overline{\nu}$
> 482	90	[1] JODIDIO 86	ELEC	$\zeta = 0$
> 800		MOHAPATRA 86	RVUE	$SU(2)_L \times SU(2)_R \times U(1)$
> 400	95	[12] STOKER 85	ELEC	Any ζ
> 475	95	[12] STOKER 85	ELEC	ζ <0.041
		[13] BERGSMA 83	CHRM	$\nu_\mu e \to \mu\nu_e$
> 380	90	[14] CARR 83	ELEC	μ^+ decay
>1600		[15] BEALL 82	THEO	$m_{K^0_L} - m_{K^0_S}$
[> 4000]		STEIGMAN 79	COSM	Nucleosynthesis; light ν_R

[1] 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^+.

[2] 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.

[3] SEVERIJNS 93 measured polarization-asymmetry correlation in ^{107}In β^+ decay. The value $R/R_0 = 0.926 \pm 0.041$ is 1.7 standard deviations away from the Standard Model expectation, giving $[m_1^2/m_2^2 + \zeta]^2 = 0.087 \pm 0.051$. The listed limit assumes zero L-R mixing.

[4] IMAZATO 92 measure positron asymmetry in $K^+ \to \mu^+\nu_\mu$ decay and obtain $\xi P_\mu > 0.990$ (90%CL). If W_R couples to $u\overline{s}$ with full weak strength (V^R_{us}=1), the result corresponds to m_{W_R} >653 GeV. See their Fig. 4 for m_{W_R} limits for general $|V^R_{us}|^2 = 1 - |V^R_{ud}|^2$.

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

[6] 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.

[7] 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.

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 Superseded by POLAK 92B.

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

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

[11] 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.

[12] 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.

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

[14] 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.

[15] BEALL 82 limit is obtained assuming that W_R contribution to K^0_L–K^0_S mass difference is smaller than the standard one, neglecting the top quark contributions. Manifest left-right symmetry assumed.

Limit on W_L-W_R Mixing Angle ζ

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
< 0.04	90	[16] MISHRA 92	CCFR	νN scattering
−0.0006 to 0.0028	90	[17] AQUINO 91	RVUE	
[none 0.00001-0.02]		[18] BARBIERI 89B	ASTR	SN 1987A
< 0.040	90	[19] JODIDIO 86	ELEC	μ decay
−0.056 to 0.040	90	[19] JODIDIO 86	ELEC	μ decay

[16] MISHRA 92 limit is from the absence of extra large-x, large-y $\overline{\nu}_\mu N \to \overline{\nu}_\mu X$ events at Tevatron, assuming left-handed ν and right-handed $\overline{\nu}$ in the neutrino beam. The result gives $\zeta^2(1-2m^2_{W_1}/m^2_{W_2}) < 0.0015$. The limit is independent of ν_R mass.

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

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

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

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

Couplings of W' to quarks and leptons are taken to be identical with those of W. The following limits are obtained from $p\overline{p} \to W'X$ with W' decaying to the mode indicated in the comments. Experiments other than ABE 91F assume no new decay channels (esp. $t\overline{b}$) are open.

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
>520	95	[20] ABE 91F	CDF	$W' \to e\nu, \mu\nu$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
>251	90	[21] ALITTI 93	UA2	$W' \to q\overline{q}$
none 260–600	95	[22] RIZZO 93	RVUE	$W' \to q\overline{q}$
none 101–158	90	[23] ALITTI 91	UA2	$W' \to q\overline{q}$
>220	90	[24] ALBAJAR 89	UA1	$W' \to e\nu$
>209	90	[25] ANSARI 87D	UA2	$W' \to e\nu$
>210	90	[26] ARNISON 86B	UA1	$W' \to e\nu$
>170	90	[27] ARNISON 83D	UA1	$W' \to e\nu$

[20] ABE 91F assume leptonic branching ratio of 1/12 for each lepton flavor. The limit from the $e\nu$ ($\mu\nu$) mode alone is 490 (435) GeV. These limits apply to W_R if $m_{\nu_R} \lesssim 15$ GeV and ν_R does not decay in the detector. Cross section limit $\sigma \cdot B <$ (1–10) pb is given for $m_{W'}$ = 100–550 GeV; see Fig. 2.

[21] ALITTI 93 search for resonances in the two-jet invariant mass. The limit assumes $\Gamma(W')/m_{W'} = \Gamma(W)/m_W$ and $B(W' \to jj) = 2/3$. This corresponds to W_R with $m_{\nu_R} > m_{W_R}$ (no leptonic decay) and $W_R \to t\overline{b}$ allowed. See their Fig. 4 for limits in the $m_{W'}$–$B(q\overline{q})$ plane.

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

[23] ALITTI 91 search is based on two-jet invariant mass spectrum, assuming $B(W' \to q\overline{q})$ = 67.6%. Limit on $\sigma \cdot B$ as a function of two-jet mass is given in Fig. 7.

[24] ALBAJAR 89 cross section limit at 630 GeV is $\sigma(W')\,B(e\nu) <$ 4.1 pb (90% CL).

[25] See Fig. 5 of ANSARI 87D for the excluded region in the $m_{W'}$–$[(g_{W'q})^2\,B(W' \to e\overline{\nu})]$ plane. Note that the quantity $(g_{W'q})^2\,B(W' \to e\overline{\nu})$ is normalized to unity for the standard W couplings.

[26] ARNISON 86B find no excess at large p_T in 148 $W \to e\nu$ events. Set limit $\sigma \times B(e\nu)$ <10 pb at CL = 90% at E_{cm} = 546 and 630 GeV.

[27] ARNISON 83D find among 47 $W \to e\nu$ candidates no event with excess p_T. Also set $\sigma \times B(e\nu)$ <30 pb with CL = 90% at E_{cm} = 540 GeV.

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

NOTE ON THE Z' SEARCHES

The mass bounds depend on the gauge group and the gauge coupling of a Z' boson. The limits listed below are not exhaustive but include only typical Z' bosons that appear frequently in the literature. The following notations are used for these Z' bosons.

$Z'_{\rm SM}$: $Z'_{\rm SM}$ is a clone of the Z and is introduced as a convenient way to gauge the limits rather than with a theoretical motivation. It is assumed to have exactly the same couplings as the Z but a different mass.

Left-right symmetric bosons: Z_{LR} is the extra neutral boson which appears in left-right symmetric models with the gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ or $SU(2)_L \times U(1)_R \times U(1)_{B-L}$, where $U(1)_R$ is the third component of $SU(2)_R$ and the weak hypercharge $Y = T_{3R} + \frac{1}{2}(B-L)$. The Z_{LR}