W

$J = 1$

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W MASS

To obtain the world average, common systematics between experiments are properly taken into account. The procedure for averaging the LEP data is given in the note LEPEWWG/MASS/2002-01 (March 11, 2002), accessible at http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg_2002/. The LEP average W mass based on published results is 80.400 ± 0.056 GeV. The combined $p\overline{p}$ collider data yields an average W mass of 80.454 ± 0.059 GeV (ABAZOV 04D).

OUR FIT uses these average LEP and $p\overline{p}$ collider W mass values together with the Z mass, the W to Z mass ratio, and mass difference measurements.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
80.425± 0.038 OUR FIT					
80.41 ± 0.41 ±0.13	1101	[1] ABBIENDI	03C	OPAL	E_{cm}^{ee}= 183–207 GeV
80.483± 0.084	49247	[2] ABAZOV	02D	D0	$E_{cm}^{p\overline{p}}$= 1.8 TeV
80.432± 0.066±0.045	2789	[3] ABBIENDI	01F	OPAL	E_{cm}^{ee}= 161+172+183 +189 GeV
80.359± 0.074±0.049	3077	[4] ABREU	01K	DLPH	E_{cm}^{ee}= 161+172+183 +189 GeV
80.433± 0.079	53841	[5] AFFOLDER	01E	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV
80.418± 0.061±0.047	2977	[6] BARATE	00T	ALEP	E_{cm}^{ee}= 161+172+183 +189 GeV
80.61 ± 0.15	801	[7] ACCIARRI	99	L3	E_{cm}^{ee}= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
80.3 ± 2.1 ± 1.2 ± 1.0	645	[8] CHEKANOV	02C	ZEUS	$e^- p \to \nu_e$ X, $\sqrt{s}$= 318 GeV
79.9 ± 2.2 ±2.3	700	[9] ADLOFF	01A	H1	$e^- p \to \nu_e$ X, $\sqrt{s} \approx$ 320 GeV
80.482± 0.091	45394	[10] ABBOTT	00	D0	Repl. by ABAZOV 02D
80.9 ± 3.7 ±3.7	700	[11] ADLOFF	00B	H1	$e^+ p \to \overline{\nu}_e$ X, $\sqrt{s} \approx$ 300 GeV
$81.4^{+2.7}_{-2.6}$ ± $2.0^{+3.3}_{-3.0}$	1086	[12] BREITWEG	00D	ZEUS	$e^+ p \to \overline{\nu}_e$ X, $\sqrt{s} \approx$ 300 GeV
80.38 ± 0.12 ±0.05	701	[13] ABBIENDI	99C	OPAL	Repl. by ABBIENDI 01F
80.270± 0.137±0.048	809	[14] ABREU	99T	DLPH	Repl. by ABREU 01K
80.423± 0.112±0.054	812	[15] BARATE	99	ALEP	Repl. by BARATE 00T
$80.80 \pm {}^{0.48}_{0.42}$ ±0.03	20	[16] ACCIARRI	97	L3	Repl. by ACCIARRI 99
$80.5 \pm {}^{1.4}_{2.4}$ ±0.3	94	[17] ACCIARRI	97M	L3	Repl. by ACCIARRI 99
$80.71 \pm {}^{0.34}_{0.35}$ ±0.09	101	[18] ACCIARRI	97S	L3	Repl. by ACCIARRI 99

80.41	± 0.18		8986	[19] ABE	95P	CDF	Repl. by AFFOLDER 01E
80.84	± 0.22	±0.83	2065	[20] ALITTI	92B	UA2	See W/Z ratio below
80.79	± 0.31	±0.84		[21] ALITTI	90B	UA2	$E_{cm}^{p\overline{p}}$ = 546,630 GeV
80.0	± 3.3	±2.4	22	[22] ABE	89I	CDF	$E_{cm}^{p\overline{p}}$ = 1.8 TeV
82.7	± 1.0	±2.7	149	[23] ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$ = 546,630 GeV
81.8	$^{+\ 6.0}_{-\ 5.3}$	±2.6	46	[24] ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$ = 546,630 GeV
89	± 3	±6	32	[25] ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$ = 546,630 GeV
81.	± 5.		6	ARNISON	83	UA1	E_{cm}^{ee} = 546 GeV
80.	$^{+10.}_{-\ 6.}$		4	BANNER	83B	UA2	Repl. by ALITTI 90B

[1] ABBIENDI 03C determine the mass of the W boson using fully leptonic decays $W^+W^- \to \ell\nu_\ell\ell'\nu_{\ell'}$. They use the measured energies of the charged leptons and an approximate kinematic reconstruction of the event (both neutrinos are assumed in the same plane as the charged leptons) to get a W pseudo-mass. All these variables are combined in a simultaneous maximum likelihood fit. The systematic error is dominated by the uncertainty on the lepton energy.

[2] ABAZOV 02D improve the measurement of the W-boson mass including $W \to e\nu_e$ events in which the electron is close to a boundary of a central electromagnetic calorimeter module. Properly combining the results obtained by fitting $m_T(W)$, $p_T(e)$, and $p_T(\nu)$, this sample provides a mass value of 80.574 ± 0.405 GeV. The value reported here is a combination of this measurement with all previous DØ W-boson mass measurements.

[3] ABBIENDI 01F obtain this value properly combining results obtained from a direct W mass reconstruction at 172, 183, and 189 GeV with that from measurement of the W-pair production cross section at 161 GeV. The systematic error includes ±0.017 GeV due to LEP energy uncertainty and ±0.028 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[4] ABREU 01K obtain this value properly combining results obtained from a direct W mass reconstruction at 172, 183, and 189 GeV with those from measurements of W-pair production cross sections at 161, 172, and 183 GeV. The systematic error includes ±0.017 GeV due to the beam energy uncertainty and ±0.033 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[5] AFFOLDER 01E fit the transverse mass spectrum of 30115 $W \to e\nu_e$ events (M_W = 80.473 ± 0.065 ± 0.092 GeV) and of 14740 $W \to \mu\nu_\mu$ events (M_W = 80.465 ± 0.100 ± 0.103 GeV) obtained in the run IB (1994-95). Combining the electron and muon results, accounting for correlated uncertainties, yields M_W = 80.470 ± 0.089 GeV. They combine this value with their measurement of ABE 95P reported in run IA (1992-93) to obtain the quoted value.

[6] BARATE 00T obtain this value properly combining results obtained from a direct W mass reconstruction at 172, 183, and 189 GeV with those from measurements of W-pair production cross sections at 161 and 172 GeV. The systematic error includes ±0.017 GeV due to LEP energy uncertainty and ±0.019 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[7] ACCIARRI 99 obtain this value properly combining results obtained from a direct W mass reconstruction at 172 and 183 GeV with those from the measurements of the total W-pair production cross sections at 161 and 172 GeV. The value of the mass obtained from the direct reconstruction at 172 and 183 GeV is $M(W)$= 80.58 ± 0.14 ± 0.08 GeV.

[8] CHEKANOV 02C fit the Q^2 dependence ($200 < Q^2 < 60000$ GeV^2) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.

[9] ADLOFF 01A fit the Q^2 dependence ($150 < Q^2 < 30000$ GeV^2) of the charged-current double-differential cross sections with a propagator mass fit. The second error includes 2.1 GeV due to the theoretical uncertainties.

[10] ABBOTT 00 use $W \to e\nu_e$ events to measure the W mass with a fit to the transverse mass distribution. The result quoted here corresponds to electrons detected both in the forward and in the central calorimeters for the data recorded in 1992–1995. For the large rapidity electrons recorded in 1994–1995, the analysis combines results obtained from m_T, $p_T(e)$, and $p_T(\nu)$.

[11] ADLOFF 00B fit the Q^2 dependence ($300 < Q^2 < 15000$ GeV^2) of the charged-current double-differential cross sections with a propagator mass fit. The second error is due to the theoretical uncertainties.

[12] BREITWEG 00D fit the Q^2 dependence ($200 < Q^2 < 22500$ GeV^2) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.

[13] ABBIENDI 99C obtain this value properly combining results from a direct W mass reconstruction at 172 and 183 GeV with that from the measurement of the total W-pair production cross section at 161 GeV. The systematic error includes an uncertainty of ± 0.02 GeV due to the possible color-reconnection and Bose-Einstein effects in the purely hadronic final states and an uncertainty of ± 0.02 GeV due to the beam energy.

[14] ABREU 99T obtain this value properly combining results obtained from a direct W mass reconstruction at 172 and 183 GeV with those from measurement of W-pair production cross sections at 161, 172, and 183 GeV. The systematic error includes ± 0.021 GeV due to the beam energy uncertainty and ± 0.030 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[15] BARATE 99 obtain this value properly combining results from a direct W mass reconstruction at 172 and 183 GeV with those from the measurements of the total W-pair production cross sections at 161 and 172 GeV. The systematic error includes ± 0.023 GeV due to LEP energy uncertainty and ± 0.021 GeV due to theory uncertainty on account of possible color reconnection and Bose-Einstein correlations.

[16] ACCIARRI 97 derive this value from their measured W-W production cross section $\sigma_{WW} = 2.89^{+0.81}_{-0.70} \pm 0.14$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy. Statistical and systematic errors are added in quadrature and the last error of ± 0.03 GeV arises from the beam energy uncertainty. The same result is given by a fit of the production cross sections to the data.

[17] ACCIARRI 97M derive this value from their measured WW production cross section $\sigma_{WW} = 12.27^{+1.41}_{-1.32} \pm 0.23$ pb using the Standard Model dependence of σ_{WW} on M_W at the given c.m. energy. Combining with ACCIARRI 97 authors find $M(W) = 80.78^{+0.45}_{-0.41} \pm 0.03$ GeV where the last error is due to beam energy uncertainty.

[18] ACCIARRI 97S obtain this value from a fit to the reconstructed W mass distribution. The W width was taken as its Standard Model value at the fitted W mass. When both W mass and width are varied they obtain $M(W) = 80.72^{+0.31}_{-0.33} \pm 0.09$ GeV. The systematic error includes ± 0.03 GeV due to the beam energy uncertainty and ± 0.05 GeV due to the possible color reconnection and Bose-Einstein effects in the purely hadronic final state. Combining with ACCIARRI 97 and ACCIARRI 97M authors find: $M(W) = 80.75^{+0.26}_{-0.27} \pm 0.03$ (LEP) GeV.

[19] ABE 95P use 3268 $W \to \mu\nu_\mu$ events to find $M = 80.310 \pm 0.205 \pm 0.130$ GeV and 5718 $W \to e\nu_e$ events to find $M = 80.490 \pm 0.145 \pm 0.175$ GeV. The result given here combines these while accounting for correlated uncertainties.

[20] ALITTI 92B result has two contributions to the systematic error (± 0.83); one (± 0.81) cancels in m_W/m_Z and one (± 0.17) is noncancelling. These were added in quadrature. We choose the ALITTI 92B value without using the LEP m_Z value, because we perform our own combined fit.

[21] There are two contributions to the systematic error (± 0.84): one (± 0.81) which cancels in m_W/m_Z and one (± 0.21) which is non-cancelling. These were added in quadrature.

[22] ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.

[23] ALBAJAR 89 result is from a total sample of 299 $W \to e\nu$ events.

[24] ALBAJAR 89 result is from a total sample of 67 $W \to \mu\nu$ events.

[25] ALBAJAR 89 result is from $W \to \tau\nu$ events.

W/Z MASS RATIO

The fit uses the W and Z mass, mass difference, and mass ratio measurements.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.88197±0.00042 OUR FIT					
0.8821 ±0.0011 ±0.0008	28323	[26] ABBOTT	98N	D0	$E_{cm}^{p\overline{p}}$= 1.8 TeV
0.88114±0.00154±0.00252	5982	[27] ABBOTT	98P	D0	$E_{cm}^{p\overline{p}}$= 1.8 TeV
0.8813 ±0.0036 ±0.0019	156	[28] ALITTI	92B	UA2	$E_{cm}^{p\overline{p}}$= 630 GeV

[26] ABBOTT 98N obtain this from a study of 28323 $W \to e\nu_e$ and 3294 $Z \to e^+e^-$ decays. Of this latter sample, 2179 events are used to calibrate the electron energy scale.
[27] ABBOTT 98P obtain this from a study of 5982 $W \to e\nu_e$ events. The systematic error includes an uncertainty of ±0.00175 due to the electron energy scale.
[28] Scale error cancels in this ratio.

$m_Z - m_W$

The fit uses the W and Z mass, mass difference, and mass ratio measurements.

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10.763±0.038 OUR FIT				
10.4 ±1.4 ±0.8	ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
11.3 ±1.3 ±0.9	ANSARI	87	UA2	$E_{cm}^{p\overline{p}}$= 546,630 GeV

$m_{W^+} - m_{W^-}$

Test of CPT invariance.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
−0.19±0.58	1722	ABE	90G	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV

W WIDTH

The CDF and DØ widths labelled "extracted value" are obtained by measuring $R = [\sigma(W)/\sigma(Z)]\ [\Gamma(W \to \ell\nu_\ell)]/(\mathrm{B}(Z \to \ell\ell)\Gamma(W))$ where the bracketed quantities can be calculated with plausible reliability. $\Gamma(W)$ is then extracted by using a value of $\mathrm{B}(Z \to \ell\ell)$ measured at LEP. The UA1 and UA2 widths used $R = [\sigma(W)/\sigma(Z)]\ [\Gamma(W \to \ell\nu_\ell)/\Gamma(Z \to \ell\ell)]\ \Gamma(Z)/\Gamma(W)$ and the measured value of $\Gamma(Z)$. The Standard Model prediction is 2.0921 ± 0.0025 GeV (see Review on "Electroweak model and constraints on new physics" in this Edition).

To obtain OUR FIT, the correlation between systematics within LEP experiments and within Tevatron experiments is properly taken into account as given in the LEP note LEPEWWG/MASS/2002-01 (http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg_2002/) and the combined Tevatron paper of ABAZOV 04D. The respective average values (2.17 ± 0.12 GeV from LEP and 2.115 ± 0.105 GeV from Tevatron)

yield an average W width of 2.139 ± 0.079 GeV coming from direct measurements. ABAZOV 04D also determine the average extracted W width using CDF and DØ data to obtain a value of 2.141 ± 0.057 GeV.

They further combine the Tevatron direct and extracted W widths to obtain an average Tevatron width of 2.135 ± 0.050 GeV. Finally combining this with the LEP W width and the extracted W width values from UA1 and UA2 one obtains the quoted value.

VALUE (GeV)	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.138±0.044 OUR FIT						
$2.23\ ^{+0.15}_{-0.14}\ \pm0.10$		294	[29] ABAZOV	02E	D0	Direct meas.
2.04 ±0.16 ±0.09		2756	[30] ABBIENDI	01F	OPAL	E^{ee}_{cm}= 172+183 +189 GeV
2.266±0.176±0.076		3005	[31] ABREU	01K	DLPH	E^{ee}_{cm}= 183+189 GeV
2.152±0.066		79176	[32] ABBOTT	00B	D0	Extracted value
2.05 ±0.10 ±0.08		662	[33] AFFOLDER	00M	CDF	Direct meas.
2.24 ±0.20 ±0.13		1711	[34] BARATE	00T	ALEP	E^{ee}_{cm}= 189 GeV
1.97 ±0.34 ±0.17		687	[35] ACCIARRI	99	L3	E^{ee}_{cm}= 172+183 GeV
2.064±0.060±0.059			[36] ABE	95W	CDF	Extracted value
$2.10\ ^{+0.14}_{-0.13}\ \pm0.09$		3559	[37] ALITTI	92	UA2	Extracted value
$2.18\ ^{+0.26}_{-0.24}\ \pm0.04$			[38] ALBAJAR	91	UA1	Extracted value
• • • We do not use the following data for averages, fits, limits, etc. • • •						
1.84 ±0.32 ±0.20		674	[39] ABBIENDI	99C	OPAL	Repl. by ABBIENDI 01F
2.044±0.097		11858	[40] ABBOTT	99H	D0	Repl. by ABBOTT 00B
2.48 ±0.40 ±0.10		737	[41] ABREU	99T	DLPH	Repl. by ABREU 01K
$2.126^{+0.052}_{-0.048}\pm0.035$			[42] BARATE	99I	ALEP	E^{ee}_{cm}= 161+172+183 GeV
$1.74\ ^{+0.88}_{-0.78}\ \pm0.25$		101	[43] ACCIARRI	97S	L3	Repl. by ACCIARRI 99
2.11 ±0.28 ±0.16		58	[44] ABE	95C	CDF	Repl. by AFFOLDER 00M
2.30 ±0.19 ±0.06			[45] ALITTI	90C	UA2	Extracted value
$2.8\ ^{+1.4}_{-1.5}\ \pm1.3$		149	[46] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
<7	90	119	APPEL	86	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV
<6.5	90	86	[47] ARNISON	86	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[29] ABAZOV 02E obtain this result fitting the high-end tail (90–200 GeV) of the transverse-mass spectrum in semileptonic $W \to e\nu_e$ decays.

[30] ABBIENDI 01F obtain this value from a fit to the reconstructed W mass distribution using data at 172, 183, and 189 GeV. The systematic error includes ±0.010 GeV due to LEP energy uncertainty and ±0.078 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[31] ABREU 01K obtain this value properly combining results obtained at 183 and 189 GeV using $WW \to \ell\overline{\nu}_\ell q\overline{q}$ and $WW \to q\overline{q}q\overline{q}$ decays. The systematic error includes an

uncertainty of ± 0.052 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[32] ABBOTT 00B measure $R = 10.43 \pm 0.27$ for the $W \to e\nu_e$ decay channel. They use the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $\Gamma(W \to e\nu_e)$ and the world average for $B(Z \to ee)$. The value quoted here is obtained combining this result (2.169 ± 0.070 GeV) with that of ABBOTT 99H.

[33] AFFOLDER 00M fit the high transverse mass (100–200 GeV) $W \to e\nu_e$ and $W \to \mu\nu_\mu$ events to obtain $\Gamma(W) = 2.04 \pm 0.11(\text{stat}) \pm 0.09(\text{syst})$ GeV. This is combined with the earlier CDF measurement (ABE 95C) to obtain the quoted result.

[34] BARATE 00T obtain this value using $WW \to q\overline{q}q\overline{q}$, $WW \to e\nu_e q\overline{q}$, and $WW \to \mu\nu_\mu q\overline{q}$ decays. The systematic error includes ± 0.015 GeV due to LEP energy uncertainty and ± 0.080 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[35] ACCIARRI 99 obtain this value from a fit to the reconstructed W mass distribution using data at 172 and 183 GeV.

[36] ABE 95W measured $R = 10.90 \pm 0.32 \pm 0.29$. They use $m_W = 80.23 \pm 0.18$ GeV, $\sigma(W)/\sigma(Z) = 3.35 \pm 0.03$, $\Gamma(W \to e\nu) = 225.9 \pm 0.9$ MeV, $\Gamma(Z \to e^+e^-) = 83.98 \pm 0.18$ MeV, and $\Gamma(Z) = 2.4969 \pm 0.0038$ GeV.

[37] ALITTI 92 measured $R = 10.4^{+0.7}_{-0.6} \pm 0.3$. The values of $\sigma(Z)$ and $\sigma(W)$ come from $O(\alpha_s^2)$ calculations using $m_W = 80.14 \pm 0.27$ GeV, and $m_Z = 91.175 \pm 0.021$ GeV along with the corresponding value of $\sin^2\theta_W = 0.2274$. They use $\sigma(W)/\sigma(Z) = 3.26 \pm 0.07 \pm 0.05$ and $\Gamma(Z) = 2.487 \pm 0.010$ GeV.

[38] ALBAJAR 91 measured $R = 9.5^{+1.1}_{-1.0}$ (stat. + syst.). $\sigma(W)/\sigma(Z)$ is calculated in QCD at the parton level using $m_W = 80.18 \pm 0.28$ GeV and $m_Z = 91.172 \pm 0.031$ GeV along with $\sin^2\theta_W = 0.2322 \pm 0.0014$. They use $\sigma(W)/\sigma(Z) = 3.23 \pm 0.05$ and $\Gamma(Z) = 2.498 \pm 0.020$ GeV. This measurement is obtained combining both the electron and muon channels.

[39] ABBIENDI 99C obtain this value from a fit to the reconstructed W mass distribution using data at 172 and 183 GeV. The systematic error includes an uncertainty of ± 0.12 GeV due to the possible color-reconnection and Bose-Einstein effects in the purely hadronic final states and an uncertainty of ± 0.01 GeV due to the beam energy.

[40] ABBOTT 99H measure $R = 10.90 \pm 0.52$ combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$, $B(Z \to \ell\ell)$, and $\Gamma(W \to \ell\nu_\ell)$.

[41] ABREU 99T obtain this value using $WW \to \ell\overline{\nu}_\ell q\overline{q}$ and $WW \to q\overline{q}q\overline{q}$ events. The systematic error includes an uncertainty of ± 0.080 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

[42] BARATE 99I obtain this result with a fit to the WW measured cross sections at 161, 172, and 183 GeV. The theoretical prediction takes into account the sensitivity to the W total width.

[43] ACCIARRI 97S obtain this value from a fit to the reconstructed W mass distribution.

[44] ABE 95C use the tail of the transverse mass distribution of $W \to e\nu_e$ decays.

[45] ALITTI 90C used the same technique as described for ABE 90. They measured $R = 9.38^{+0.82}_{-0.72} \pm 0.25$, obtained $\Gamma(W)/\Gamma(Z) = 0.902 \pm 0.074 \pm 0.024$. Using $\Gamma(Z) = 2.546 \pm 0.032$ GeV, they obtained the $\Gamma(W)$ value quoted above and the limits $\Gamma(W) < 2.56$ (2.64) GeV at the 90% (95%) CL. $E_{\text{cm}}^{p\overline{p}} = 546{,}630$ GeV.

[46] ALBAJAR 89 result is from a total sample of 299 $W \to e\nu$ events.

[47] If systematic error is neglected, result is $2.7^{+1.4}_{-1.5}$ GeV. This is enhanced subsample of 172 total events.

W^+ DECAY MODES

W^- modes are charge conjugates of the modes below.

	Mode		Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\ell^+\nu$	[a]	(10.80 ± 0.09) %	
Γ_2	$e^+\nu$		(10.75 ± 0.13) %	
Γ_3	$\mu^+\nu$		(10.57 ± 0.15) %	
Γ_4	$\tau^+\nu$		(11.25 ± 0.20) %	
Γ_5	hadrons		(67.60 ± 0.27) %	
Γ_6	$\pi^+\gamma$		$< 8 \times 10^{-5}$	95%
Γ_7	$D_s^+\gamma$		$< 1.3 \times 10^{-3}$	95%
Γ_8	cX		(33.4 ± 2.6) %	
Γ_9	$c\overline{s}$		$(31\ ^{+13}_{-11})$ %	
Γ_{10}	invisible	[b]	(1.4 ± 2.8) %	

[a] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[b] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

W PARTIAL WIDTHS

Γ(invisible) Γ_{10}

This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
$\mathbf{30^{+52}_{-48} \pm 33}$	[48] BARATE	99I	ALEP	E_{cm}^{ee} = 161+172+183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[49] BARATE	99L	ALEP	E_{cm}^{ee} = 161+172+183 GeV

[48] BARATE 99I measure this quantity using the dependence of the total cross section σ_{WW} upon a change in the total width. The fit is performed to the WW measured cross sections at 161, 172, and 183 GeV. This partial width is < 139 MeV at 95%CL.

[49] BARATE 99L use W-pair production to search for effectively invisible W decays, tagging with the decay of the other W boson to Standard Model particles. The partial width for effectively invisible decay is < 27 MeV at 95%CL.

W BRANCHING RATIOS

Overall fits are performed to determine the branching ratios of the W. LEP averages on $W \to e\nu_e$, $W \to \mu\nu_\mu$, and $W \to \tau\nu_\tau$, and their correlations are first obtained by combining results from the four experiments taking properly into account the common systematics. The procedure is described in the note LEPEWWG/XSEC/2001-02, 30 March 2001, at http://lepewwg.web.cern.ch/LEPEWWG/lepww/4f/PDG01. The LEP average values so obtained, using published data, are given in the note LEPEWWG/XSEC/2005-01 accessible at http://lepewwg.web.cern.ch/

LEPEWWG/lepww/4f/PDG05/. These results, together with results from the $p\overline{p}$ colliders are then used in fits to obtain the world average W branching ratios. A first fit determines three individual leptonic branching ratios, B($W \to e\nu_e$), B($W \to \mu\nu_\mu$), and B($W \to \tau\nu_\tau$). This fit has a $\chi^2 = 4.7$ for 10 degrees of freedom. A second fit assumes lepton universality and determines the leptonic branching ratio B($W \to \ell\nu_\ell$) and the hadronic branching ratio is derived as B($W \to$ hadrons) = 1–3 B($W \to \ell\nu$). This fit has a χ^2=11.3 for 12 degrees of freedom.

The LEP $W \to \ell\nu$ data are obtained by the Collaborations using individual leptonic channels and are, therefore, not included in the overall fits to avoid double counting.

$\Gamma(\ell^+\nu)/\Gamma_{\text{total}}$ Γ_1/Γ

ℓ indicates average over e, μ, and τ modes, not sum over modes.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1080±0.0009 OUR FIT					
0.1085±0.0014±0.0008	13600	ABDALLAH	04G	DLPH	E_{cm}^{ee} = 161–209 GeV
0.1083±0.0014±0.0010	11246	ACHARD	04J	L3	E_{cm}^{ee} = 161–209 GeV
0.1096±0.0012±0.0005	16116	SCHAEL	04A	ALEP	E_{cm}^{ee}= 183–209 GeV
0.1056±0.0020±0.0009	5778	ABBIENDI,G	00	OPAL	E_{cm}^{ee}= 161+172+183 +189 GeV
0.1102±0.0052	11858	[50] ABBOTT	99H	D0	$E_{\text{cm}}^{p\overline{p}}$= 1.8 TeV
0.104 ±0.008	3642	[51] ABE	92I	CDF	$E_{\text{cm}}^{p\overline{p}}$= 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.1071±0.0024±0.0014	4843	ABREU	00K	DLPH	Repl. by ABDALLAH 04G
0.1060±0.0023±0.0011	5328	ACCIARRI	00V	L3	Repl. by ACHARD 04J
0.1101±0.0022±0.0011	5258	BARATE	00J	ALEP	Repl. by SCHAEL 04A
0.107 ±0.004 ±0.002	1440	ABBIENDI	99D	OPAL	Repl. by ABBIENDI,G 00

[50] ABBOTT 99H measure $R \equiv [\sigma_W$ B($W \to \ell\nu_\ell$)]/[σ_Z B($Z \to \ell\ell$)] = 10.90 ± 0.52 combining electron and muon channels. They use M_W = 80.39 ± 0.06 GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and B($Z \to \ell\ell$).

[51] $1216 \pm 38^{+27}_{-31}$ $W \to \mu\nu$ events from ABE 92I and 2426 $W \to e\nu$ events of ABE 91C. ABE 92I give the inverse quantity as 9.6 ± 0.7 and we have inverted.

$\Gamma(e^+\nu)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1075±0.0013 OUR FIT					
0.1061±0.0028		[52] ABAZOV	04D	TEVA	$E_{\text{cm}}^{p\overline{p}}$= 1.8 TeV
0.1055±0.0031±0.0014	1804	ABDALLAH	04G	DLPH	E_{cm}^{ee} = 161–209 GeV
0.1078±0.0029±0.0013	1576	ACHARD	04J	L3	E_{cm}^{ee} = 161–209 GeV
0.1078±0.0027±0.0010	2142	SCHAEL	04A	ALEP	E_{cm}^{ee}= 183–209 GeV
0.1046±0.0042±0.0014	801	ABBIENDI,G	00	OPAL	E_{cm}^{ee}= 161+172+183 +189 GeV
0.10 ±0.014 $^{+0.02}_{-0.03}$	248	[53] ANSARI	87C	UA2	$E_{\text{cm}}^{p\overline{p}}$= 546,630 GeV

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

0.1044 ± 0.0015 ± 0.0028	67318	[54] ABBOTT	00B	D0	Repl. by ABAZOV 04D
0.1018 ± 0.0054 ± 0.0026	527	ABREU	00K	DLPH	Repl. by ABDALLAH 04G
0.1077 ± 0.0045 ± 0.0016	715	ACCIARRI	00V	L3	Repl. by ACHARD 04J
0.1135 ± 0.0046 ± 0.0017	720	BARATE	00J	ALEP	Repl. by SCHAEL 04A
0.117 ± 0.009 ± 0.002	224	ABBIENDI	99D	OPAL	Repl. by ABBIENDI,G 00
0.1094 ± 0.0033 ± 0.0031		[55] ABE	95W	CDF	Repl. by ABAZOV 04D
seen	119	APPEL	86	UA2	$E_{cm}^{p\overline{p}}$ = 546,630 GeV
seen	172	ARNISON	86	UA1	$E_{cm}^{p\overline{p}}$ = 546,630 GeV

[52] ABAZOV 04D take into account all correlations to properly combine the CDF (ABE 95W) and DØ (ABBOTT 00B) measurements of the ratio R in the electron channel. The ratio R is defined as $[\sigma_W \cdot B(W \to e\nu_e)] / [\sigma_Z \cdot B(Z \to ee)]$. The combination gives $R^{Tevatron} = 10.59 \pm 0.23$. σ_W / σ_Z is calculated at next–to–next–to–leading order (3.360 ± 0.051). The branching fraction $B(Z \to ee)$ is taken from this *Review* as (3.363 ± 0.004)%.

[53] The first error was obtained by adding the statistical and systematic experimental uncertainties in quadrature. The second error reflects the dependence on theoretical prediction of total W cross section: $\sigma(546\text{ GeV}) = 4.7^{+1.4}_{-0.7}$ nb and $\sigma(630\text{ GeV}) = 5.8^{+1.8}_{-1.0}$ nb. See ALTARELLI 85B.

[54] ABBOTT 00B measure $R \equiv [\sigma_W B(W \to e\nu_e)]/[\sigma_Z B(Z \to ee)] = 10.43 \pm 0.27$ for the $W \to e\nu_e$ decay channel. They use the SM theoretical prediction for $\sigma(W)/\sigma(Z)$ and the world average for $B(Z \to ee)$.

[55] ABE 95W result is from a measurement of $\sigma B(W \to e\nu)/\sigma B(Z \to e^+e^-) = 10.90 \pm 0.32 \pm 0.29$, the theoretical prediction for the cross section ratio, the experimental knowledge of $\Gamma(Z \to e^+e^-) = 83.98 \pm 0.18$ MeV, and $\Gamma(Z) = 2.4969 \pm 0.0038$ GeV.

$\Gamma(\mu^+\nu)/\Gamma_{total}$ Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1057 ± 0.0015 OUR FIT					
0.1065 ± 0.0026 ± 0.0008	1998	ABDALLAH	04G	DLPH	E_{cm}^{ee} = 161–209 GeV
0.1003 ± 0.0029 ± 0.0012	1423	ACHARD	04J	L3	E_{cm}^{ee} = 161–209 GeV
0.1087 ± 0.0025 ± 0.0008	2216	SCHAEL	04A	ALEP	E_{cm}^{ee} = 183–209 GeV
0.1050 ± 0.0041 ± 0.0012	803	ABBIENDI,G	00	OPAL	E_{cm}^{ee} = 161+172+183 +189 GeV
0.10 ± 0.01	1216	[56] ABE	92I	CDF	$E_{cm}^{p\overline{p}}$ = 1.8 TeV

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

0.1092 ± 0.0048 ± 0.0012	649	ABREU	00K	DLPH	Repl. by ABDALLAH 04G
0.0990 ± 0.0046 ± 0.0015	617	ACCIARRI	00V	L3	Repl. by ACHARD 04J
0.1110 ± 0.0044 ± 0.0016	710	BARATE	00J	ALEP	Repl. by SCHAEL 04A
0.102 ± 0.008 ± 0.002	193	ABBIENDI	99D	OPAL	Repl. by ABBIENDI,G 00

[56] ABE 92I quote the inverse quantity as 9.9 ± 1.2 which we have inverted.

$\Gamma(\tau^+\nu)/\Gamma_{\text{total}}$ Γ_4/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.1125±0.0020 OUR FIT					
0.1146±0.0039±0.0019	2034	ABDALLAH	04G	DLPH	E_{cm}^{ee} = 161–209 GeV
0.1189±0.0040±0.0020	1375	ACHARD	04J	L3	E_{cm}^{ee} = 161–209 GeV
0.1125±0.0032±0.0020	2070	SCHAEL	04A	ALEP	E_{cm}^{ee}= 183–209 GeV
0.1075±0.0052±0.0021	794	ABBIENDI,G	00	OPAL	E_{cm}^{ee}= 161+172+183 +189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.1105±0.0075±0.0032	579	ABREU	00K	DLPH	Repl. by ABDALLAH 04G
0.1124±0.0062±0.0022	536	ACCIARRI	00V	L3	Repl. by ACHARD 04J
0.1051±0.0055±0.0022	607	BARATE	00J	ALEP	Repl. by SCHAEL 04A
0.101 ±0.010 ±0.003	183	ABBIENDI	99D	OPAL	Repl. by ABBIENDI,G 00

$\Gamma(\text{hadrons})/\Gamma_{\text{total}}$ Γ_5/Γ

OUR FIT value is obtained by a fit to the lepton branching ratio data assuming lepton universality.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.6760±0.0027 OUR FIT					
0.6745±0.0041±0.0024	13600	ABDALLAH	04G	DLPH	E_{cm}^{ee} = 161–209 GeV
0.6750±0.0042±0.0030	11246	ACHARD	04J	L3	E_{cm}^{ee} = 161–209 GeV
0.6713±0.0037±0.0015	16116	SCHAEL	04A	ALEP	E_{cm}^{ee}= 183–209 GeV
0.6832±0.0061±0.0028	5778	ABBIENDI,G	00	OPAL	E_{cm}^{ee}= 161+172+183 +189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.6789±0.0073±0.0043	4843	ABREU	00K	DLPH	Repl. by ABDALLAH 04G
0.6820±0.0068±0.0033	5328	ACCIARRI	00V	L3	Repl. by ACHARD 04J
0.6697±0.0065±0.0032	5258	BARATE	00J	ALEP	Repl. by SCHAEL 04A
0.679 ±0.012 ±0.005	1440	ABBIENDI	99D	OPAL	Repl. by ABBIENDI,G 00

$\Gamma(\mu^+\nu)/\Gamma(e^+\nu)$ Γ_3/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.983±0.018 OUR FIT					
0.89 ±0.10	13k	[57] ABACHI	95D	D0	$E_{\text{cm}}^{p\overline{p}}$= 1.8 TeV
1.02 ±0.08	1216	[58] ABE	92I	CDF	$E_{\text{cm}}^{p\overline{p}}$= 1.8 TeV
1.00 ±0.14 ±0.08	67	ALBAJAR	89	UA1	$E_{\text{cm}}^{p\overline{p}}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$1.24\ ^{+0.6}_{-0.4}$	14	ARNISON	84D	UA1	Repl. by ALBAJAR 89

[57] ABACHI 95D obtain this result from the measured $\sigma_W \text{B}(W \to \mu\nu)$= 2.09 ± 0.23 ± 0.11 nb and $\sigma_W \text{B}(W \to e\nu)$= 2.36 ± 0.07 ± 0.13 nb in which the first error is the combined statistical and systematic uncertainty, the second reflects the uncertainty in the luminosity.

[58] ABE 92I obtain $\sigma_W \text{B}(W \to \mu\nu)$= 2.21 ± 0.07 ± 0.21 and combine with ABE 91C $\sigma_W \text{B}((W \to e\nu))$ to give a ratio of the couplings from which we derive this measurement.

$\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.046±0.023 OUR FIT					
0.961±0.061	980	[59] ABBOTT	00D	D0	$E_{cm}^{p\overline{p}}$= 1.8 TeV
0.94 ±0.14	179	[60] ABE	92E	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[61] ALITTI	92F	UA2	$E_{cm}^{p\overline{p}}$= 630 GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89	UA1	$E_{cm}^{p\overline{p}}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.995±0.112±0.083	198	ALITTI	91C	UA2	Repl. by ALITTI 92F
1.02 ±0.20 ±0.10	32	ALBAJAR	87	UA1	Repl. by ALBAJAR 89

[59] ABBOTT 00D measure $\sigma_W \times B(W \to \tau\nu_\tau) = 2.22 \pm 0.09 \pm 0.10 \pm 0.10$ nb. Using the ABBOTT 00B result $\sigma_W \times B(W \to e\nu_e) = 2.31 \pm 0.01 \pm 0.05 \pm 0.10$ nb, they quote the ratio of the couplings from which we derive this measurement.

[60] ABE 92E use two procedures for selecting $W \to \tau\nu_\tau$ events. The missing E_T trigger leads to $132 \pm 14 \pm 8$ events and the τ trigger to $47 \pm 9 \pm 4$ events. Proper statistical and systematic correlations are taken into account to arrive at $\sigma B(W \to \tau\nu) = 2.05 \pm 0.27$ nb. Combined with ABE 91C result on $\sigma B(W \to e\nu)$, ABE 92E quote a ratio of the couplings from which we derive this measurement.

[61] This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

$\Gamma(\pi^+\gamma)/\Gamma(e^+\nu)$ Γ_6/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
< 7 × 10^{-4}	95	ABE	98H	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV
< 4.9 × 10^{-3}	95	[62] ALITTI	92D	UA2	$E_{cm}^{p\overline{p}}$= 630 GeV
<58 × 10^{-3}	95	[63] ALBAJAR	90	UA1	$E_{cm}^{p\overline{p}}$= 546, 630 GeV

[62] ALITTI 92D limit is 3.8×10^{-3} at 90%CL.

[63] ALBAJAR 90 obtain < 0.048 at 90%CL.

$\Gamma(D_s^+\gamma)/\Gamma(e^+\nu)$ Γ_7/Γ_2

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<1.2 × 10^{-2}	95	ABE	98P	CDF	$E_{cm}^{p\overline{p}}$= 1.8 TeV

$\Gamma(cX)/\Gamma(\text{hadrons})$ Γ_8/Γ_5

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.49 ±0.04 OUR AVERAGE					
0.481±0.042±0.032	3005	[64] ABBIENDI	00V	OPAL	E_{cm}^{ee}= 183 + 189 GeV
0.51 ±0.05 ±0.03	746	[65] BARATE	99M	ALEP	E_{cm}^{ee}= 172 + 183 GeV

[64] ABBIENDI 00V tag $W \to cX$ decays using measured jet properties, lifetime information, and leptons produced in charm decays. From this result, and using the additional measurements of $\Gamma(W)$ and $B(W \to \text{hadrons})$, $|V_{cs}|$ is determined to be $0.969 \pm 0.045 \pm 0.036$.

[65] BARATE 99M tag c jets using a neural network algorithm. From this measurement $|V_{cs}|$ is determined to be $1.00 \pm 0.11 \pm 0.07$.

$R_{cs} = \Gamma(c\bar{s})/\Gamma(\text{hadrons})$ Γ_9/Γ_5

VALUE	DOCUMENT ID		TECN	COMMENT
$0.46^{+0.18}_{-0.14} \pm 0.07$	[66] ABREU	98N	DLPH	$E_{cm}^{ee} = 161+172$ GeV

[66] ABREU 98N tag c and s jets by identifying a charged kaon as the highest momentum particle in a hadronic jet. They also use a lifetime tag to independently identify a c jet, based on the impact parameter distribution of charged particles in a jet. From this measurement $|V_{cs}|$ is determined to be $0.94^{+0.32}_{-0.26} \pm 0.13$.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC W DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_{\pi^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
15.70 ± 0.35	[67] ABREU,P	00F	DLPH	$E_{cm}^{ee} = 189$ GeV

[67] ABREU,P 00F measure $\langle N_{\pi^\pm} \rangle = 31.65 \pm 0.48 \pm 0.76$ and $15.51 \pm 0.38 \pm 0.40$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_{K^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.20 ± 0.19	[68] ABREU,P	00F	DLPH	$E_{cm}^{ee} = 189$ GeV

[68] ABREU,P 00F measure $\langle N_{K^\pm} \rangle = 4.38 \pm 0.42 \pm 0.12$ and $2.23 \pm 0.32 \pm 0.17$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_p \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.92 ± 0.14	[69] ABREU,P	00F	DLPH	$E_{cm}^{ee} = 189$ GeV

[69] ABREU,P 00F measure $\langle N_p \rangle = 1.82 \pm 0.29 \pm 0.16$ and $0.94 \pm 0.23 \pm 0.06$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_{\text{charged}} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
19.41 ± 0.15 OUR AVERAGE				
19.44 ± 0.17	[70] ABREU,P	00F	DLPH	$E_{cm}^{ee} = 183+189$ GeV
$19.3 \pm 0.3 \pm 0.3$	[71] ABBIENDI	99N	OPAL	$E_{cm}^{ee} = 183$ GeV
19.23 ± 0.74	[72] ABREU	98C	DLPH	$E_{cm}^{ee} = 172$ GeV

[70] ABREU,P 00F measure $\langle N_{\text{charged}} \rangle = 39.12 \pm 0.33 \pm 0.36$ and $38.11 \pm 0.57 \pm 0.44$ in the fully hadronic final states at 189 and 183 GeV respectively, and $\langle N_{\text{charged}} \rangle = 19.49 \pm 0.31 \pm 0.27$ and $19.78 \pm 0.49 \pm 0.43$ in the semileptonic final states. The value quoted is a weighted average without assuming any correlations.

[71] ABBIENDI 99N use the final states $W^+W^- \to q\bar{q}\ell\bar{\nu}_\ell$ to derive this value.

[72] ABREU 98C combine results from both the fully hadronic as well semileptonic WW final states after demonstrating that the W decay charged multiplicity is independent of the topology within errors.

TRIPLE GAUGE COUPLINGS (TGC'S)

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Δg_1^Z

OUR FIT below is obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$= 0.016^{+0.022}_{-0.019}$ OUR FIT					
$0.001 \pm 0.027 \pm 0.013$	9310	[73] SCHAEL	05A	ALEP	$E_{cm}^{ee} = 183$–209 GeV
$-0.013^{+0.034}_{-0.033}$	9800	[74] ABBIENDI	04D	OPAL	$E_{cm}^{ee} = 183$–209 GeV
$-0.034^{+0.034}_{-0.032} \pm 0.015$	8325	[75] ACHARD	04D	L3	$E_{cm}^{ee} = 161$–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-0.02 \pm 0.07 \pm 0.01$	2114	[76] ABREU	01I	DLPH	$E_{cm}^{ee} = 183+189$ GeV
	331	[77] ABBOTT	99I	D0	$E_{cm}^{p\overline{p}} = 1.8$ TeV

[73] SCHAEL 05A study single–photon, single–W, and WW–pair production from 183 to 209 GeV. The result quoted here is derived from the WW–pair production sample. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[74] ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.077 < \Delta g_1^Z < 0.054$.

[75] ACHARD 04D study WW–pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained from the WW–pair production sample including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[76] ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^- and $We\nu_e$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $-0.16 < \Delta g_1^Z < 0.13$.

[77] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \to$ dilepton, $WW/WZ \to e\nu jj$, $WW/WZ \to \mu\nu jj$, and $WZ \to$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.37 < \Delta g_1^Z < 0.57$, fixing λ_Z=$\Delta\kappa_Z$ =0 and assuming Standard Model values for the $WW\gamma$ couplings.

$\Delta\kappa_\gamma$

OUR FIT below is obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$= 0.027^{+0.044}_{-0.045}$ OUR FIT					
$-0.029 \pm 0.055 \pm 0.030$	10689	[78] SCHAEL	05A	ALEP	$E_{cm}^{ee} = 183$–209 GeV
$-0.12^{+0.09}_{-0.08}$	9800	[79] ABBIENDI	04D	OPAL	$E_{cm}^{ee} = 183$–209 GeV
$0.013^{+0.067}_{-0.064} \pm 0.026$	10575	[80] ACHARD	04D	L3	$E_{cm}^{ee} = 161$–209 GeV

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

0.25	$^{+0.21}_{-0.20}$ ±0.06	2298	[81] ABREU	01I	DLPH	E_{cm}^{ee} = 183+189 GeV	
			[82] BREITWEG	00	ZEUS	$e^+ p \to e^+ W^\pm X$, $\sqrt{s} \approx$ 300 GeV	
−0.08	±0.34	331	[83] ABBOTT	99I	D0	$E_{cm}^{p\overline{p}}$ = 1.8 TeV	

[78] SCHAEL 05A study single–photon, single–W, and WW–pair production from 183 to 209 GeV. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[79] ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.27 < \Delta\kappa_\gamma < 0.07$.

[80] ACHARD 04D study WW–pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[81] ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $-0.13 < \Delta\kappa_\gamma < 0.68$.

[82] BREITWEG 00 search for W production in events with large hadronic p_T. For p_T >20 GeV, the upper limit on the cross section gives the 95%CL limit $-4.7 < \Delta\kappa_\gamma < 1.5$ (for λ_γ=0).

[83] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \to$ dilepton, $WW/WZ \to e\nu jj$, $WW/WZ \to \mu\nu jj$, and $WZ \to$ trilepton data samples. For Λ = 2.0 TeV, the 95%CL limits are $-0.25 < \Delta\kappa_\gamma < 0.39$.

λ_γ

OUR FIT below is obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc).

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$= 0.028^{+0.020}_{-0.021}$ OUR FIT				
$-0.012 \pm 0.027 \pm 0.011$	10689	[84] SCHAEL	05A ALEP	E_{cm}^{ee} = 183–209 GeV
$-0.060^{+0.034}_{-0.033}$	9800	[85] ABBIENDI	04D OPAL	E_{cm}^{ee} = 183–209 GeV
$-0.021^{+0.035}_{-0.034} \pm 0.017$	10575	[86] ACHARD	04D L3	E_{cm}^{ee} = 161–209 GeV

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

0.05	±0.09 ±0.01	2298	[87] ABREU	01I	DLPH	E_{cm}^{ee} = 183+189 GeV
			[88] BREITWEG	00	ZEUS	$e^+ p \to e^+ W^\pm X$, $\sqrt{s} \approx$ 300 GeV
0.00	$^{+0.10}_{-0.09}$	331	[89] ABBOTT	99I	D0	$E_{cm}^{p\overline{p}}$ = 1.8 TeV

[84] SCHAEL 05A study single–photon, single–W, and WW–pair production from 183 to 209 GeV. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[85] ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.13 < \lambda_\gamma < 0.01$.

[86] ACHARD 04D study WW–pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[87] ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $-0.11 < \lambda_\gamma < 0.23$.

[88] BREITWEG 00 search for W production in events with large hadronic p_T. For p_T >20 GeV, the upper limit on the cross section gives the 95%CL limit $-3.2 < \lambda_\gamma < 3.2$ (for $\Delta\kappa_\gamma$=0).

[89] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \to$ dilepton, $WW/WZ \to e\nu jj$, $WW/WZ \to \mu\nu jj$, and $WZ \to$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.18 < \lambda_\gamma < 0.19$.

$\Delta\kappa_Z$

This coupling is CP-conserving (C- and P- separately conserving).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{-0.076^{+0.059}_{-0.056}\pm0.024}$	7171	[90] ACHARD		04D L3	$E^{ee}_{\rm cm}$ = 189–209 GeV

[90] ACHARD 04D study WW–pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW–pair production sample. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

λ_Z

This coupling is CP-conserving (C- and P- separately conserving).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{=0.088^{+0.060}_{-0.057}\pm0.023}$	7171	[91] ACHARD		04D L3	$E^{ee}_{\rm cm}$ = 189–209 GeV

[91] ACHARD 04D study WW–pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW–pair production sample. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

Δg_5^Z

This coupling is CP-conserving but C- and P-violating.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$=0.07\pm0.09$ OUR AVERAGE		Error includes scale factor of 1.1.			
$-0.04^{+0.13}_{-0.12}$	9800	[92] ABBIENDI		04D OPAL	$E^{ee}_{\rm cm}$= 183–209 GeV
$0.00\pm0.13\pm0.05$	7171	[93] ACHARD		04D L3	$E^{ee}_{\rm cm}$ = 189–209 GeV
$-0.44^{+0.23}_{-0.22}\pm0.12$	1154	[94] ACCIARRI		99Q L3	$E^{ee}_{\rm cm}$= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
-0.16 ± 0.23		[95] EBOLI		00 THEO	LEP1, SLC+ Tevatron

[92] ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.28 < \Delta g_5^Z < 0.21$.

[93] ACHARD 04D study WW–pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained

using the WW–pair production sample. Each parameter is determined from a single–parameter fit in which the other parameters assume their Standard Model values.

[94] ACCIARRI 99Q study W-pair, single-W, and single photon events.

[95] EBOLI 00 extract this indirect value of the coupling studying the non-universal one-loop contributions to the experimental value of the $Z \to b\overline{b}$ width (Λ=1 TeV is assumed).

g_4^Z

This coupling is CP-violating (C-violating and P-conserving).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.02^{+0.32}_{-0.33}$	1065	[96] ABBIENDI	01H	OPAL	$E_{\rm cm}^{ee}$= 189 GeV

[96] ABBIENDI 01H study W-pair events, with one leptonically and one hadronically decaying W. The coupling is extracted using information from the W production angle together with decay angles from the leptonically decaying W.

$\widetilde{\kappa}_Z$

This coupling is CP-violating (C-conserving and P-violating).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.20^{+0.10}_{-0.07}$	1065	[97] ABBIENDI	01H	OPAL	$E_{\rm cm}^{ee}$= 189 GeV

[97] ABBIENDI 01H study W-pair events, with one leptonically and one hadronically decaying W. The coupling is extracted using information from the W production angle together with decay angles from the leptonically decaying W.

$\widetilde{\lambda}_Z$

This coupling is CP-violating (C-conserving and P-violating).

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.18^{+0.24}_{-0.16}$	1065	[98] ABBIENDI	01H	OPAL	$E_{\rm cm}^{ee}$= 189 GeV

[98] ABBIENDI 01H study W-pair events, with one leptonically and one hadronically decaying W. The coupling is extracted using information from the W production angle together with decay angles from the leptonically decaying W.

W ANOMALOUS MAGNETIC MOMENT

The full magnetic moment is given by $\mu_W = e(1+\kappa+\lambda)/2m_W$. In the Standard Model, at tree level, $\kappa = 1$ and $\lambda = 0$. Some papers have defined $\Delta\kappa = 1-\kappa$ and assume that $\lambda = 0$. Note that the electric quadrupole moment is given by $-e(\kappa-\lambda)/m_W^2$. A description of the parameterization of these moments and additional references can be found in HAGIWARA 87 and BAUR 88. The parameter Λ appearing in the theoretical limits below is a regularization cutoff which roughly corresponds to the energy scale where the structure of the W boson becomes manifest.

VALUE ($e/2m_W$)	EVTS	DOCUMENT ID		TECN	COMMENT
$2.22^{+0.20}_{-0.19}$	2298	[99] ABREU	01I	DLPH	$E_{\rm cm}^{ee}$= 183+189 GeV

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

[100]	ABE	95G	CDF
[101]	ALITTI	92C	UA2
[102]	SAMUEL	92	THEO
[103]	SAMUEL	91	THEO
[104]	GRIFOLS	88	THEO
[105]	GROTCH	87	THEO
[106]	VANDERBIJ	87	THEO
[107]	GRAU	85	THEO
[108]	SUZUKI	85	THEO
[109]	HERZOG	84	THEO

[99] ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV to determine Δg_1^Z, $\Delta\kappa_\gamma$, and λ_γ. $\Delta\kappa_\gamma$ and λ_γ are simultaneously floated in the fit to determine μ_W.

[100] ABE 95G report $-1.3 < \kappa < 3.2$ for λ=0 and $-0.7 < \lambda < 0.7$ for κ=1 in $p\overline{p} \rightarrow\ e\nu_e\gamma X$ and $\mu\nu_\mu\gamma X$ at $\sqrt{s} = 1.8$ TeV.

[101] ALITTI 92C measure $\kappa = 1^{+2.6}_{-2.2}$ and $\lambda = 0^{+1.7}_{-1.8}$ in $p\overline{p} \rightarrow\ e\nu\gamma + X$ at $\sqrt{s} = 630$ GeV. At 95%CL they report $-3.5 < \kappa < 5.9$ and $-3.6 < \lambda < 3.5$.

[102] SAMUEL 92 use preliminary CDF and UA2 data and find $-2.4 < \kappa < 3.7$ at 96%CL and $-3.1 < \kappa < 4.2$ at 95%CL respectively. They use data for $W\gamma$ production and radiative W decay.

[103] SAMUEL 91 use preliminary CDF data for $p\overline{p} \rightarrow\ W\gamma X$ to obtain $-11.3 \leq \Delta\kappa \leq 10.9$. Note that their $\kappa = 1-\Delta\kappa$.

[104] GRIFOLS 88 uses deviation from ρ parameter to set limit $\Delta\kappa \lesssim 65\ (M_W^2/\Lambda^2)$.

[105] GROTCH 87 finds the limit $-37 < \Delta\kappa < 73.5$ (90% CL) from the experimental limits on $e^+e^- \rightarrow\ \nu\overline{\nu}\gamma$ assuming three neutrino generations and $-19.5 < \Delta\kappa < 56$ for four generations. Note their $\Delta\kappa$ has the opposite sign as our definition.

[106] VANDERBIJ 87 uses existing limits to the photon structure to obtain $|\Delta\kappa| < 33\ (m_W/\Lambda)$. In addition VANDERBIJ 87 discusses problems with using the ρ parameter of the Standard Model to determine $\Delta\kappa$.

[107] GRAU 85 uses the muon anomaly to derive a coupled limit on the anomalous magnetic dipole and electric quadrupole (λ) moments $1.05 > \Delta\kappa\ \ln(\Lambda/m_W) + \lambda/2 > -2.77$. In the Standard Model $\lambda = 0$.

[108] SUZUKI 85 uses partial-wave unitarity at high energies to obtain $|\Delta\kappa| \lesssim 190\ (m_W/\Lambda)^2$. From the anomalous magnetic moment of the muon, SUZUKI 85 obtains $|\Delta\kappa| \lesssim 2.2/\ln(\Lambda/m_W)$. Finally SUZUKI 85 uses deviations from the ρ parameter and obtains a very qualitative, order-of-magnitude limit $|\Delta\kappa| \lesssim 150\ (m_W/\Lambda)^4$ if $|\Delta\kappa| \ll 1$.

[109] HERZOG 84 consider the contribution of W-boson to muon magnetic moment including anomalous coupling of $WW\gamma$. Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV.

ANOMALOUS W/Z QUARTIC COUPLINGS

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a_0/Λ^2, a_c/Λ^2, a_n/Λ^2

Using the $WW\gamma$ final state, the LEP combined 95% CL limits on the anomalous contributions to the $WW\gamma\gamma$ and $WWZ\gamma$ vertices (as of summer 2003) are given below:

(See P. Wells, "Experimental Tests of the Standard Model," Int. Europhysics Conference on High-Energy Physics, Aachen, Germany, 17–23 July 2003)

$-0.02 < a_0^W/\Lambda^2 < 0.02$ GeV^{-2},
$-0.05 < a_c^W/\Lambda^2 < 0.03$ GeV^{-2},
$-0.15 < a_n/\Lambda^2 < 0.15$ GeV^{-2}.

VALUE	DOCUMENT ID	TECN

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

[110]	ABBIENDI	04B	OPAL
[111]	ABBIENDI	04L	OPAL
[112]	HEISTER	04A	ALEP
[113]	ABDALLAH	03I	DLPH
[114]	ACHARD	02F	L3

[110] ABBIENDI 04B select 187 $e^+e^- \to W^+W^-\gamma$ events in the C.M. energy range 180–209 GeV, where E_γ >2.5 GeV, the photon has a polar angle $|\cos\theta_\gamma| < 0.975$ and is well isolated from the nearest jet and charged lepton, and the effective masses of both fermion-antifermion systems agree with the W mass within 3 Γ_W. The measured differential cross section as a function of the photon energy and photon polar angle is used to extract the 95% CL limits: -0.020 GeV^{-2} $< a_0/\Lambda^2 < 0.020$ GeV^{-2}, -0.053 GeV^{-2} $< a_c/\Lambda^2 < 0.037$ GeV^{-2} and -0.16 GeV^{-2} $< a_n/\Lambda^2 < 0.15$ GeV^{-2}.

[111] ABBIENDI 04L select 20 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+e^- \to q\overline{q}\gamma\gamma$ events in the energy range 130–209 GeV. These samples are used to constrain possible anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ quartic couplings. Further combining with the $W^+W^-\gamma$ sample of ABBIENDI 04B the following one–parameter 95% CL limits are obtained: -0.007 $< a_0^Z/\Lambda^2 <$ 0.023 GeV^{-2}, -0.029 $< a_c^Z/\Lambda^2 <$ 0.029 GeV^{-2}, -0.020 $< a_0^W/\Lambda^2 <$ 0.020 GeV^{-2}, -0.052 $< a_c^W/\Lambda^2 <$ 0.037 GeV^{-2}.

[112] In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon–photon acoplanarity is required to be $> 5^\circ$, $E_\gamma/\sqrt{s} > 0.025$ (the more energetic photon having energy $> 0.2\sqrt{s}$), $p_{T_\gamma}/E_{beam} > 0.05$ and $|\cos\theta_\gamma| < 0.94$. A likelihood fit to the photon energy and recoil missing mass yields the following one–parameter 95% CL limits: -0.012 $< a_0^Z/\Lambda^2 <$ 0.019 GeV^{-2}, -0.041 $< a_c^Z/\Lambda^2 <$ 0.044 GeV^{-2}, -0.060 $< a_0^W/\Lambda^2 <$ 0.055 GeV^{-2}, -0.099 $< a_c^W/\Lambda^2 <$ 0.093 GeV^{-2}.

[113] ABDALLAH 03I select 122 $e^+e^- \to W^+W^-\gamma$ events in the C.M. energy range 189–209 GeV, where E_γ >5 GeV, the photon has a polar angle $|\cos\theta_\gamma| < 0.95$ and is well isolated from the nearest charged fermion. A fit to the photon energy spectra yields $a_c/\Lambda^2 = 0.000^{+0.019}_{-0.040}$ GeV^{-2}, $a_0/\Lambda^2 = -0.004^{+0.018}_{-0.010}$ GeV^{-2}, $\tilde{a}_0/\Lambda^2 = -0.007^{+0.019}_{-0.008}$ GeV^{-2}, $a_n/\Lambda^2 = -0.09^{+0.16}_{-0.05}$ GeV^{-2}, and $\tilde{a}_n/\Lambda^2 = +0.05^{+0.07}_{-0.15}$ GeV^{-2}, keeping the other parameters fixed to their Standard Model values (0). The 95% CL limits are: -0.063 GeV^{-2} $< a_c/\Lambda^2 < +0.032$ GeV^{-2}, -0.020 GeV^{-2} $< a_0/\Lambda^2 < +0.020$ GeV^{-2}, -0.020 GeV^{-2} $< \tilde{a}_0/\Lambda^2 < +0.020$ GeV^{-2}, -0.18 GeV^{-2} $< a_n/\Lambda^2 < +0.14$ GeV^{-2}, -0.16 GeV^{-2} $< \tilde{a}_n/\Lambda^2 < +0.17$ GeV^{-2}.

[114] ACHARD 02F select 86 $e^+e^- \to W^+W^-\gamma$ events at 192–207 GeV, where E_γ >5 GeV and the photon is well isolated. They also select 43 acoplanar $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ events in this energy range, where the photon energies are >5 GeV and >1 GeV and the photon polar angles are between 14° and 166°. All these 43 events are in the recoil mass region corresponding to the Z (75–110 GeV). Using the shape and normalization of the photon spectra in the $W^+W^-\gamma$ events, and combining with the 42 event sample from 189 GeV data (ACCIARRI 00T), they obtain: $a_0/\Lambda^2 = 0.000 \pm 0.010$ GeV^{-2}, $a_c/\Lambda^2 =$

-0.013 ± 0.023 GeV^{-2}, and $a_n/\Lambda^2 = -0.002 \pm 0.076$ GeV^{-2}. Further combining the analyses of $W^+W^-\gamma$ events with the low recoil mass region of $\nu\overline{\nu}\gamma\gamma$ events (including samples collected at $183 + 189$ GeV), they obtain the following one-parameter 95% CL limits: -0.015 GeV$^{-2} < a_0/\Lambda^2 < 0.015$ GeV^{-2}, -0.048 GeV$^{-2} < a_c/\Lambda^2 < 0.026$ GeV^{-2}, and -0.14 GeV$^{-2} < a_n/\Lambda^2 < 0.13$ GeV^{-2}.

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ABBIENDI	04B	PL B580 17	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04D	EPJ C33 463	G. Abbiendi *et al.*	(OPAL Collab.)
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ABDALLAH	04G	EPJ C34 127	J. Abdallah *et al.*	(DELPHI Collab.)
ACHARD	04D	PL B586 151	P. Achard *et al.*	(L3 Collab.)
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HEISTER	04A	PL B602 31	A. Heister *et al.*	(ALEPH Collab.)
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ACHARD	02F	PL B527 29	P. Achard *et al.*	(L3 Collab.)
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ACCIARRI	00T	PL B490 187	M. Acciarri *et al.*	(L3 Collab.)
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