W

$J = 1$

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W MASS

The *W*-mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass-dependent width. To obtain the world average, common systematics between experiments are properly taken into account. The LEP average *W* mass based on published results is 80.376 ± 0.030 GeV [CERN-PH-EP/2006-042]. The combined Tevatron data yields an average *W* mass of 80.430 ± 0.040 GeV.

OUR FIT uses these average LEP and Tevatron mass values.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
80.398± 0.025 OUR FIT					
80.336± 0.055±0.039	10.3k	[1] ABDALLAH	08A	DLPH	E^{ee}_{cm} = 161–209 GeV
80.413± 0.034±0.034	115k	[2] AALTONEN	07F	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.415± 0.042±0.031	11830	[3] ABBIENDI	06	OPAL	E^{ee}_{cm}= 170–209 GeV
80.270± 0.046±0.031	9909	[4] ACHARD	06	L3	E^{ee}_{cm}= 161–209 GeV
80.440± 0.043±0.027	8692	[5] SCHAEL	06	ALEP	E^{ee}_{cm}= 161–209 GeV
80.483± 0.084	49247	[6] ABAZOV	02D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
80.433± 0.079	53841	[7] AFFOLDER	01E	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
82.87 ± 1.82 $^{+0.30}_{-0.16}$	1500	[8] AKTAS	06	H1	$e^{\pm} p \rightarrow \overline{\nu}_e(\nu_e) X$, $\sqrt{s} \approx$ 300 GeV
80.3 ± 2.1 ± 1.2 ± 1.0	645	[9] CHEKANOV	02C	ZEUS	$e^- p \rightarrow \nu_e X$, $\sqrt{s}$= 318 GeV
$81.4^{+2.7}_{-2.6} \pm 2.0^{+3.3}_{-3.0}$	1086	[10] BREITWEG	00D	ZEUS	$e^+ p \rightarrow \overline{\nu}_e X$, $\sqrt{s} \approx$ 300 GeV
80.84 ± 0.22 ±0.83	2065	[11] ALITTI	92B	UA2	See *W*/*Z* ratio below
80.79 ± 0.31 ±0.84		[12] ALITTI	90B	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV
80.0 ± 3.3 ±2.4	22	[13] ABE	89I	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
82.7 ± 1.0 ±2.7	149	[14] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
81.8 $^{+6.0}_{-5.3}$ ±2.6	46	[15] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
89 ± 3 ±6	32	[16] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
81. ± 5.	6	ARNISON	83	UA1	E^{ee}_{cm}= 546 GeV
80. $^{+10.}_{-6.}$	4	BANNER	83B	UA2	Repl. by ALITTI 90B

[1] ABDALLAH 08A use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\overline{q}\ell\nu$ and $W^+W^- \rightarrow q\overline{q}q\overline{q}$ events for energies 172 GeV and above. The *W* mass was also extracted from the dependence of the *WW* cross section close to the production threshold and combined appropriately to obtain the final result. The systematic error includes ±0.025 GeV due to final state interactions and ±0.009 GeV due to LEP energy uncertainty.

[2] AALTONEN 07F obtain high purity $W \to e\nu_e$ and $W \to \mu\nu_\mu$ candidate samples totaling 63,964 and 51,128 events respectively. The W mass value quoted above is derived by simultaneously fitting the transverse mass and the lepton, and neutrino p_T distributions.

[3] ABBIENDI 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu_\ell$ and $W^+W^- \to q\overline{q}q\overline{q}$ events. The result quoted here is obtained combining this mass value with the results using $W^+W^- \to \ell\nu_\ell\ell'\nu_{\ell'}$ events in the energy range 183–207 GeV (ABBIENDI 03C) and the dependence of the WW production cross-section on m_W at threshold. The systematic error includes ± 0.009 GeV due to the uncertainty on the LEP beam energy.

[4] ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu_\ell$ and $W^+W^- \to q\overline{q}q\overline{q}$ events in the C.M. energy range 189–209 GeV. The result quoted here is obtained combining this mass value with the results obtained from a direct W mass reconstruction at 172 and 183 GeV and with those from the dependence of the WW production cross-section on m_W at 161 and 172 GeV (ACCIARRI 99).

[5] SCHAEL 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu_\ell$ and $W^+W^- \to q\overline{q}q\overline{q}$ events in the C.M. energy range 183–209 GeV. The result quoted here is obtained combining this mass value with those obtained from the dependence of the W pair production cross-section on m_W at 161 and 172 GeV (BARATE 97 and BARATE 97S respectively). The systematic error includes ± 0.009 GeV due to possible effects of final state interactions in the $q\overline{q}q\overline{q}$ channel and ± 0.009 GeV due to the uncertainty on the LEP beam energy.

[6] 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.

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

[8] AKTAS 06 fit the Q^2 dependence ($300 < Q^2 < 30{,}000$ GeV^2) of the charged-current differential cross section with a propagator mass. The first error is experimental and the second corresponds to uncertainties due to input parameters and model assumptions.

[9] 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.

[10] 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.

[11] 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.

[12] 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.

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

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

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

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

W/Z MASS RATIO

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.8819 ±0.0012 OUR AVERAGE					
0.8821 ±0.0011 ±0.0008	28323	[17] ABBOTT	98N	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
0.88114±0.00154±0.00252	5982	[18] ABBOTT	98P	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
0.8813 ±0.0036 ±0.0019	156	[19] ALITTI	92B	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV

[17] ABBOTT 98N obtain this from a study of 28323 $W \rightarrow e\nu_e$ and 3294 $Z \rightarrow e^+e^-$ decays. Of this latter sample, 2179 events are used to calibrate the electron energy scale.

[18] ABBOTT 98P obtain this from a study of 5982 $W \rightarrow e\nu_e$ events. The systematic error includes an uncertainty of ±0.00175 due to the electron energy scale.

[19] Scale error cancels in this ratio.

$m_Z - m_W$

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10.4±1.4±0.8	ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
11.3±1.3±0.9	ANSARI	87	UA2	$E^{p\overline{p}}_{cm}$= 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	$E^{p\overline{p}}_{cm}$= 1.8 TeV

W WIDTH

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, CERN-PH-EP/2006-042, and in the CDF paper, AALTONEN 08B. The respective average values are 2.196 ± 0.083 GeV from LEP and 2.056 ± 0.062 GeV from Tevatron.

The extracted W width determined by $p\overline{p}$ collider experiments agrees with the directly determined value.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2.141±0.041 OUR FIT					
2.032±0.045±0.057	6055	[20] AALTONEN	08B	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
2.404±0.140±0.101	10.3k	[21] ABDALLAH	08A	DLPH	E^{ee}_{cm}= 183–209 GeV
1.996±0.096±0.102	10729	[22] ABBIENDI	06	OPAL	E^{ee}_{cm}= 170–209 GeV
2.18 ±0.11 ±0.09	9795	[23] ACHARD	06	L3	E^{ee}_{cm}= 172–209 GeV
2.14 ±0.09 ±0.06	8717	[24] SCHAEL	06	ALEP	E^{ee}_{cm}= 183–209 GeV
2.23 $^{+0.15}_{-0.14}$ ±0.10	294	[25] ABAZOV	02E	D0	Direct meas.
2.05 ±0.10 ±0.08	662	[26] AFFOLDER	00M	CDF	Direct meas.

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

2.152 ± 0.066	79176	[27] ABBOTT	00B	D0	Extracted value
$2.064\pm0.060\pm0.059$		[28] ABE	95W	CDF	Extracted value
$2.10\ ^{+0.14}_{-0.13}\ \pm0.09$	3559	[29] ALITTI	92	UA2	Extracted value
$2.18\ ^{+0.26}_{-0.24}\ \pm0.04$		[30] ALBAJAR	91	UA1	Extracted value

[20] AALTONEN 08B obtain this result fitting the high-end tail (90–200 GeV) of the transverse mass spectrum in semileptonic $W \to e\nu_e$ and $W \to \mu\nu_\mu$ decays.

[21] ABDALLAH 08A use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu$ and $W^+W^- \to q\overline{q}q\overline{q}$ events. The systematic error includes ±0.065 GeV due to final state interactions.

[22] ABBIENDI 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu_\ell$ and $W^+W^- \to q\overline{q}q\overline{q}$ events. The systematic error includes ±0.003 GeV due to the uncertainty on the LEP beam energy.

[23] ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu_\ell$ and $W^+W^- \to q\overline{q}q\overline{q}$ events in the C.M. energy range 189–209 GeV. The result quoted here is obtained combining this value of the width with the result obtained from a direct W mass reconstruction at 172 and 183 GeV (ACCIARRI 99).

[24] SCHAEL 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\ell\nu_\ell$ and $W^+W^- \to q\overline{q}q\overline{q}$ events. The systematic error includes ±0.05 GeV due to possible effects of final state interactions in the $q\overline{q}q\overline{q}$ channel and ±0.01 GeV due to the uncertainty on the LEP beam energy.

[25] 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.

[26] AFFOLDER 00M fit the high transverse mass (100–200 GeV) $W \to e\nu_e$ and $W \to \mu\nu_\mu$ events to obtain $\Gamma(W)= 2.04 \pm 0.11(\text{stat})\pm0.09(\text{syst})$ GeV. This is combined with the earlier CDF measurement (ABE 95C) to obtain the quoted result.

[27] 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.

[28] 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.

[29] 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.

[30] 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.

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	$c X$		(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*
$\mathbf{30^{+52}_{-48} \pm 33}$	[31] BARATE	99I	ALEP	E^{ee}_{cm}= 161+172+183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[32] BARATE	99L	ALEP	E^{ee}_{cm}= 161+172+183 GeV

[31] 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.

[32] 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 $W \rightarrow e\nu_e$, $W \rightarrow \mu\nu_\mu$, and $W \rightarrow \tau\nu_\tau$, 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($W \rightarrow e\nu_e$), B($W \rightarrow \mu\nu_\mu$), and B($W \rightarrow \tau\nu_\tau$). This fit has a χ^2 = 4.7 for 10 degrees of freedom. A second fit assumes lepton universality and determines the leptonic branching ratio B($W \rightarrow \ell\nu_\ell$) and the hadronic branching ratio is derived as B($W \rightarrow$ hadrons) = 1–3 B($W \rightarrow \ell\nu$). This fit has a χ^2=11.3 for 12 degrees of freedom.

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

Note: The LEP combination including the new OPAL results, ABBIENDI 07A, could not be performed in time for this *Review*. Thus, the OUR FIT values quoted below use the previous OPAL results as in ABBIENDI,G 00.

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

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

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
10.80±0.09 OUR FIT					
10.86±0.12±0.08	16438	ABBIENDI	07A	OPAL	$E^{ee}_{\rm cm}$= 161–209 GeV
10.85±0.14±0.08	13600	ABDALLAH	04G	DLPH	$E^{ee}_{\rm cm}$= 161–209 GeV
10.83±0.14±0.10	11246	ACHARD	04J	L3	$E^{ee}_{\rm cm}$= 161–209 GeV
10.96±0.12±0.05	16116	SCHAEL	04A	ALEP	$E^{ee}_{\rm cm}$= 183–209 GeV
11.02±0.52	11858	[33] ABBOTT	99H	D0	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV
10.4 ±0.8	3642	[34] ABE	92I	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV

[33] ABBOTT 99H measure $R \equiv [\sigma_W\ {\rm B}(W \rightarrow \ell\nu_\ell)]/[\sigma_Z\ {\rm B}(Z \rightarrow \ell\ell)] = 10.90 \pm 0.52$ 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($Z \rightarrow \ell\ell$).

[34] $1216 \pm 38^{+27}_{-31}$ $W \rightarrow \mu\nu$ events from ABE 92I and 2426$W \rightarrow e\nu$ 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 (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
10.75±0.13 OUR FIT					
10.71±0.25±0.11	2374	ABBIENDI	07A	OPAL	$E^{ee}_{\rm cm}$= 161–209 GeV
10.55±0.31±0.14	1804	ABDALLAH	04G	DLPH	$E^{ee}_{\rm cm}$= 161–209 GeV
10.78±0.29±0.13	1576	ACHARD	04J	L3	$E^{ee}_{\rm cm}$= 161–209 GeV
10.78±0.27±0.10	2142	SCHAEL	04A	ALEP	$E^{ee}_{\rm cm}$= 183–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
10.61±0.28		[35] ABAZOV	04D	TEVA	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV

[35] 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 $[\sigma_W \cdot {\rm B}(W \rightarrow e\nu_e)]$ / $[\sigma_Z \cdot {\rm B}(Z \rightarrow ee)]$. The combination gives $R^{Tevatron}$ = 10.59 ± 0.23. σ_W / σ_Z is calculated at next–to–next–to–leading order (3.360 ± 0.051). The branching fraction B($Z \rightarrow ee$) is taken from this *Review* as (3.363 ± 0.004)%.

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
10.57±0.15 OUR FIT					
10.78±0.24±0.10	2397	ABBIENDI	07A	OPAL	E^{ee}_{cm}= 161–209 GeV
10.65±0.26±0.08	1998	ABDALLAH	04G	DLPH	E^{ee}_{cm} = 161–209 GeV
10.03±0.29±0.12	1423	ACHARD	04J	L3	E^{ee}_{cm} = 161–209 GeV
10.87±0.25±0.08	2216	SCHAEL	04A	ALEP	E^{ee}_{cm} = 183–209 GeV

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
11.25±0.20 OUR FIT					
11.14±0.31±0.17	2177	ABBIENDI	07A	OPAL	E^{ee}_{cm}= 161–209 GeV
11.46±0.39±0.19	2034	ABDALLAH	04G	DLPH	E^{ee}_{cm} = 161–209 GeV
11.89±0.40±0.20	1375	ACHARD	04J	L3	E^{ee}_{cm} = 161–209 GeV
11.25±0.32±0.20	2070	SCHAEL	04A	ALEP	E^{ee}_{cm} = 183–209 GeV

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

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
67.60±0.27 OUR FIT					
67.41±0.37±0.23	16438	ABBIENDI	07A	OPAL	E^{ee}_{cm}= 161–209 GeV
67.45±0.41±0.24	13600	ABDALLAH	04G	DLPH	E^{ee}_{cm} = 161–209 GeV
67.50±0.42±0.30	11246	ACHARD	04J	L3	E^{ee}_{cm} = 161–209 GeV
67.13±0.37±0.15	16116	SCHAEL	04A	ALEP	E^{ee}_{cm} = 183–209 GeV

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.983±0.018 OUR FIT					
0.89 ±0.10	13k	[36] ABACHI	95D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
1.02 ±0.08	1216	[37] ABE	92I	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
1.00 ±0.14 ±0.08	67	ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 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

[36] ABACHI 95D obtain this result from the measured $\sigma_W B(W \to \mu\nu)$= 2.09 ± 0.23 ± 0.11 nb and $\sigma_W B(W \to e\nu)$= 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.

[37] ABE 92I obtain $\sigma_W B(W \to \mu\nu)$= 2.21 ± 0.07 ± 0.21 and combine with ABE 91C σ_W 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	[38] ABBOTT	00D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
0.94 ±0.14	179	[39] ABE	92E	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[40] ALITTI	92F	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 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

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

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

[40] 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	$E^{p\overline{p}}_{cm}$= 1.8 TeV
< 4.9 × 10^{-3}	95	[41] ALITTI	92D	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV
<58 × 10^{-3}	95	[42] ALBAJAR	90	UA1	$E^{p\overline{p}}_{cm}$= 546, 630 GeV

[41] ALITTI 92D limit is 3.8 × 10^{-3} at 90%CL.
[42] 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	$E^{p\overline{p}}_{cm}$= 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	[43] ABBIENDI	00V	OPAL	E^{ee}_{cm}= 183 + 189 GeV
0.51 ±0.05 ±0.03	746	[44] BARATE	99M	ALEP	E^{ee}_{cm}= 172 + 183 GeV

[43] ABBIENDI 00V tag $W \rightarrow cX$ 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($W \rightarrow$ hadrons), $|V_{cs}|$ is determined to be 0.969 ± 0.045 ± 0.036.

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

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

VALUE	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.46^{+0.18}_{-0.14}\pm0.07}$	[45] ABREU	98N	DLPH	E^{ee}_{cm}= 161+172 GeV

[45] 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	[46] ABREU,P	00F	DLPH	E^{ee}_{cm}= 189 GeV

[46] 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	[47] ABREU,P	00F	DLPH	E^{ee}_{cm}= 189 GeV

[47] 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	[48] ABREU,P	00F	DLPH	E^{ee}_{cm}= 189 GeV

[48] 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
19.39±0.08 OUR AVERAGE				
19.38±0.05±0.08	[49] ABBIENDI	06A	OPAL	E^{ee}_{cm}= 189–209 GeV
19.44±0.17	[50] ABREU,P	00F	DLPH	E^{ee}_{cm}= 183+189 GeV
19.3 ±0.3 ±0.3	[51] ABBIENDI	99N	OPAL	E^{ee}_{cm}= 183 GeV
19.23±0.74	[52] ABREU	98C	DLPH	E^{ee}_{cm}= 172 GeV

[49] ABBIENDI 06A measure $\langle N_{\text{charged}}\rangle = 38.74 \pm 0.12 \pm 0.26$ when both W bosons decay hadronically and $\langle N_{\text{charged}}\rangle = 19.39 \pm 0.11 \pm 0.09$ when one W boson decays semileptonically. The value quoted here is obtained under the assumption that there is no color reconnection between W bosons; the value is a weighted average taking into account correlations in the systematic uncertainties.

[50] 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.

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

[52] 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)

A REVIEW GOES HERE – Check our WWW List of Reviews

g_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
$0.984^{+0.022}_{-0.019}$ OUR FIT					
$1.001 \pm 0.027 \pm 0.013$	9310	[53] SCHAEL	05A	ALEP	E^{ee}_{cm}= 183–209 GeV
$0.987^{+0.034}_{-0.033}$	9800	[54] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
$0.966^{+0.034}_{-0.032} \pm 0.015$	8325	[55] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	13	[56] ABAZOV	07Z	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[57] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$0.98 \pm 0.07 \pm 0.01$	2114	[58] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
	331	[59] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[53] 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.

[54] 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 $0.923 < g_1^Z < 1.054$.

[55] 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.

[56] ABAZOV 07Z set limits on anomalous TGCs using the measured cross section and $p_T(Z)$ distribution in WZ production with both the W and the Z decaying leptonically into electrons and muons. Setting other couplings to their standard model values, the 95% C.L. limits for a form factor scale $\Lambda = 1.5$ TeV are $-0.15 < \Delta g_1^Z < 0.35$, and for $\Lambda =$ 2 TeV are $-0.14 < \Delta g_1^Z < 0.34$.

[57] ABAZOV 05S study $\overline{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1.5$ TeV is $0.51 < g_1^Z <$ 1.66, fixing λ_Z and κ_Z to their Standard Model values.

[58] ABREU 01I combine results from $e^+ e^-$ interactions at 189 GeV leading to $W^+ W^-$ and $W e \nu_e$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.84 < g_1^Z < 1.13$.

[59] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.63 < g_1^Z < 1.57$, fixing λ_Z and κ_Z to their Standard Model values, and assuming Standard Model values for the $WW\gamma$ couplings.

κ_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
$0.973^{+0.044}_{-0.045}$ OUR FIT					
$0.971 \pm 0.055 \pm 0.030$	10689	[60] SCHAEL	05A	ALEP	$E^{ee}_{\rm cm}$= 183–209 GeV
$0.88\ ^{+0.09}_{-0.08}$	9800	[61] ABBIENDI	04D	OPAL	$E^{ee}_{\rm cm}$= 183–209 GeV
$1.013^{+0.067}_{-0.064} \pm 0.026$	10575	[62] ACHARD	04D	L3	$E^{ee}_{\rm cm}$= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	1617	[63] AALTONEN	07L	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.96 GeV
	17	[64] ABAZOV	06H	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
	141	[65] ABAZOV	05J	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
$1.25\ ^{+0.21}_{-0.20} \pm 0.06$	2298	[66] ABREU	01I	DLPH	$E^{ee}_{\rm cm}$= 183+189 GeV
		[67] BREITWEG	00	ZEUS	$e^+ p \rightarrow e^+ W^\pm X$, $\sqrt{s} \approx$ 300 GeV
0.92 ± 0.34	331	[68] ABBOTT	99I	D0	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV

[60] 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.

[61] 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 $0.73 < \kappa_\gamma < 1.07$.

[62] 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.

[63] AALTONEN 07L set limits on anomalous TGCs using the $p_T(W)$ distribution in WW and WZ production with the W decaying to an electron or muon and the Z to 2 jets. Setting other couplings to their standard model value, the 95% C.L. limits are $0.54 < \kappa_\gamma < 1.39$ for a form factor scale $\Lambda = 1.5$ TeV.

[64] ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+ \nu_e e^- \overline{\nu}_e$, $WW \rightarrow e^\pm \nu_e \mu^\mp \nu_\mu$ or $WW \rightarrow \mu^+ \nu_\mu \mu^- \overline{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 1$ TeV is $-0.05 < \kappa_\gamma < 2.29$, fixing λ_γ=0. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit (Λ = 2 TeV) is $0.68 < \kappa < 1.45$.

[65] ABAZOV 05J perform a likelihood fit to the photon E_T spectrum of $W\gamma$ + X events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda = 2.0$ TeV the 95% CL limits are $0.12 < \kappa_\gamma < 1.96$. In the fit λ_γ is kept fixed to its Standard Model value.

[66] ABREU 01I combine results from $e^+ e^-$ interactions at 189 GeV leading to $W^+ W^-$, $W e \nu_e$, and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.87 < \kappa_\gamma < 1.68$.

[67] 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 $-3.7 < \kappa_\gamma < 2.5$ (for λ_γ=0).

[68] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $W W \rightarrow$ dilepton, $W W/W Z \rightarrow e\nu jj$, $W W/W Z \rightarrow \mu\nu jj$, and $W Z \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.75 < \kappa_\gamma < 1.39$.

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*
$\mathbf{-0.028^{+0.020}_{-0.021}}$ **OUR FIT**					
$-0.012\pm0.027\pm0.011$	10689	[69] SCHAEL	05A	ALEP	E^{ee}_{cm}= 183–209 GeV
$-0.060^{+0.034}_{-0.033}$	9800	[70] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
$-0.021^{+0.035}_{-0.034}\pm0.017$	10575	[71] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	1617	[72] AALTONEN	07L	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 GeV
	17	[73] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	141	[74] ABAZOV	05J	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$0.05\ \pm0.09\ \pm0.01$	2298	[75] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
		[76] BREITWEG	00	ZEUS	$e^+ p \rightarrow e^+ W^\pm$X, $\sqrt{s} \approx$ 300 GeV
$0.00\ ^{+0.10}_{-0.09}$	331	[77] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[69] 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.

[70] 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 $-0.13 < \lambda_\gamma < 0.01$.

[71] 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.

[72] AALTONEN 07L set limits on anomalous TGCs using the $p_T(W)$ distribution in $W W$ and $W Z$ production with the W decaying to an electron or muon and the Z to 2 jets. Setting other couplings to their standard model value, the 95% C.L. limits are $-0.18 < \lambda_\gamma < 0.17$ for a form factor scale $\Lambda = 1.5$ TeV.

[73] ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+\nu_e e^-\overline{\nu}_e$, $WW \rightarrow e^\pm\nu_e\mu^\mp\nu_\mu$ or $WW \rightarrow \mu^+\nu_\mu\mu^-\overline{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 1$ TeV is $-0.97 < \lambda_\gamma < 1.04$, fixing κ_γ=1. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.

[74] ABAZOV 05J perform a likelihood fit to the photon E_T spectrum of $W\gamma$ + X events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda = 2.0$ TeV the 95% CL limits are $-0.20 < \lambda_\gamma < 0.20$. In the fit κ_γ is kept fixed to its Standard Model value.

[75] 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 $-0.11 < \lambda_\gamma < 0.23$.

[76] 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 κ_γ fixed to its Standard Model value.

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

κ_Z

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

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{0.924^{+0.059}_{-0.056} \pm 0.024}$	7171	[78] ACHARD	04D	L3	E^{ee}_{cm} = 189–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	17	[79] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[80] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV

[78] 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.

[79] ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+\nu_e e^-\overline{\nu}_e$, $WW \rightarrow e^\pm\nu_e\mu^\mp\nu_\mu$ or $WW \rightarrow \mu^+\nu_\mu\mu^-\overline{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $0.55 < \kappa_Z < 1.55$, fixing λ_Z=0. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $0.68 < \kappa < 1.45$.

[80] ABAZOV 05S study $\overline{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1$ TeV is $-1.0 < \kappa_Z < 3.4$, fixing λ_Z and g^Z_1 to their Standard Model values.

λ_Z

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

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{-0.088^{+0.060}_{-0.057} \pm 0.023}$	7171	[81] ACHARD	04D	L3	E^{ee}_{cm} = 189–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	13	[82] ABAZOV	07Z	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	17	[83] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[84] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV

[81] 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.

[82] ABAZOV 07Z set limits on anomalous TGCs using the measured cross section and $p_T(Z)$ distribution in WZ production with both the W and the Z decaying leptonically into electrons and muons. Setting other couplings to their standard model values, the 95% C.L. limits for a form factor scale $\Lambda = 1.5$ TeV are $-0.18 < \lambda_Z < 0.22$, and for $\Lambda = 2$ TeV are $-0.17 < \lambda_Z < 0.21$.

[83] ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+\nu_e e^-\overline{\nu}_e$, $WW \rightarrow e^\pm\nu_e\mu^\mp\nu_\mu$ or $WW \rightarrow \mu^+\nu_\mu\mu^-\overline{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $-0.39 < \lambda_Z < 0.39$, fixing κ_Z=1. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.

[84] ABAZOV 05S study $\overline{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1.5$ TeV is $-0.48 < \lambda_Z < 0.48$, fixing g_1^Z and κ_Z to their Standard Model values.

g_5^Z

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.93±0.09 OUR AVERAGE	Error includes scale factor of 1.1.				
$0.96^{+0.13}_{-0.12}$	9800	[85] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
$1.00\pm0.13\pm0.05$	7171	[86] ACHARD	04D	L3	E^{ee}_{cm}= 189–209 GeV
$0.56^{+0.23}_{-0.22}\pm0.12$	1154	[87] ACCIARRI	99Q	L3	E^{ee}_{cm}= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.84 ± 0.23		[88] EBOLI	00	THEO	LEP1, SLC+ Tevatron

[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 $0.72 < g_5^Z < 1.21$.

[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 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.

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

[88] EBOLI 00 extract this indirect value of the coupling studying the non-universal one-loop contributions to the experimental value of the $Z \rightarrow b\overline{b}$ 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
$\mathbf{-0.02^{+0.32}_{-0.33}}$	1065	[89] ABBIENDI	01H	OPAL	E^{ee}_{cm}= 189 GeV

[89] 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
$\mathbf{-0.20^{+0.10}_{-0.07}}$	1065	[90] ABBIENDI	01H	OPAL	E^{ee}_{cm}= 189 GeV

[90] 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
$\mathbf{-0.18^{+0.24}_{-0.16}}$	1065	[91] ABBIENDI	01H	OPAL	E^{ee}_{cm}= 189 GeV

[91] 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 $-e(\kappa-\lambda)/m^2_W$. 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
$\mathbf{2.22^{+0.20}_{-0.19}}$	2298	[92] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[93] ABE	95G	CDF	
		[94] ALITTI	92C	UA2	
		[95] SAMUEL	92	THEO	
		[96] SAMUEL	91	THEO	
		[97] GRIFOLS	88	THEO	
		[98] GROTCH	87	THEO	
		[99] VANDERBIJ	87	THEO	
		[100] GRAU	85	THEO	
		[101] SUZUKI	85	THEO	
		[102] HERZOG	84	THEO	

[92] 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^Z_1, $\Delta\kappa_\gamma$, and λ_γ. $\Delta\kappa_\gamma$ and λ_γ are simultaneously floated in the fit to determine μ_W.

[93] 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.

[94] 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 $-3.6 < \lambda < 3.5$.

[95] 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.

[96] 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 $\kappa = 1-\Delta\kappa$.

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

[98] 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.

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

[100] 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 $\lambda = 0$.

[101] 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 $|\Delta\kappa| \ll 1$.

[102] 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)

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

VALUE	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[103] ABBIENDI	04B	OPAL
	[104] ABBIENDI	04L	OPAL
	[105] HEISTER	04A	ALEP
	[106] ABDALLAH	03I	DLPH
	[107] ACHARD	02F	L3

[103] ABBIENDI 04B select 187 $e^+e^- \rightarrow W^+W^-\gamma$ 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}.

[104] ABBIENDI 04L select 20 $e^+ e^- \rightarrow \nu\overline{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+ e^- \rightarrow q\overline{q}\gamma\gamma$ 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}.

[105] In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+ e^- \rightarrow \nu\overline{\nu}\gamma\gamma$ 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}.

[106] ABDALLAH 03I select 122 $e^+ e^- \rightarrow W^+ W^- \gamma$ events in the C.M. energy range 189–209 GeV, where $E_\gamma > 5$ 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}.

[107] ACHARD 02F select 86 $e^+ e^- \rightarrow W^+ W^- \gamma$ events at 192–207 GeV, where $E_\gamma > 5$ GeV and the photon is well isolated. They also select 43 acoplanar $e^+ e^- \rightarrow \nu\overline{\nu}\gamma\gamma$ 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}, $a_c/\Lambda^2 = -0.013 \pm 0.023$ 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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