W

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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 systematic uncertainties between experiments are properly taken into account. The LEP-2 average W mass based on published results is 80.376 ± 0.033 GeV [SCHAEL 13A]. The combined Tevatron data yields an average W mass of 80.387 ± 0.016 GeV [AALTONEN 13N].

OUR FIT uses these average LEP and Tevatron mass values and combines them assuming no correlations.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
80.385± 0.015 OUR FIT					
80.375± 0.023	2177k	[1] ABAZOV	14N	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.387± 0.019	1095k	[2] AALTONEN	12E	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.336± 0.055±0.039	10.3k	[3] ABDALLAH	08A	DLPH	E^{ee}_{cm} = 161–209 GeV
80.415± 0.042±0.031	11830	[4] ABBIENDI	06	OPAL	E^{ee}_{cm}= 170–209 GeV
80.270± 0.046±0.031	9909	[5] ACHARD	06	L3	E^{ee}_{cm}= 161–209 GeV
80.440± 0.043±0.027	8692	[6] SCHAEL	06	ALEP	E^{ee}_{cm}= 161–209 GeV
80.483± 0.084	49247	[7] ABAZOV	02D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
80.433± 0.079	53841	[8] AFFOLDER	01E	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
80.367± 0.026	1677k	[9] ABAZOV	12F	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.401± 0.043	500k	[10] ABAZOV	09AB	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.413± 0.034±0.034	115k	[11] AALTONEN	07F	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
82.87 ± 1.82 $^{+0.30}_{-0.16}$	1500	[12] 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	[13] CHEKANOV	02C	ZEUS	$e^- p \rightarrow \nu_e X$, $\sqrt{s}$= 318 GeV
81.4$^{+2.7}_{-2.6}$ ± 2.0$^{+3.3}_{-3.0}$	1086	[14] BREITWEG	00D	ZEUS	$e^+ p \rightarrow \overline{\nu}_e X$, $\sqrt{s} \approx$ 300 GeV
80.84 ± 0.22 ±0.83	2065	[15] ALITTI	92B	UA2	See W/Z ratio below
80.79 ± 0.31 ±0.84		[16] ALITTI	90B	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV
80.0 ± 3.3 ±2.4	22	[17] ABE	89I	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
82.7 ± 1.0 ±2.7	149	[18] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
81.8 $^{+6.0}_{-5.3}$ ±2.6	46	[19] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
89 ± 3 ±6	32	[20] 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] ABAZOV 14N is a combination of ABAZOV 09AB and ABAZOV 12F, also giving more details on the analysis.

[2] AALTONEN 12E select 470k $W \rightarrow e\nu$ decays and 625k $W \rightarrow \mu\nu$ decays in 2.2 fb^{-1} of Run-II data. The mass is determined using the transverse mass, transverse lepton momentum and transverse missing energy distributions, accounting for correlations. This result supersedes AALTONEN 07F. AALTONEN 14D gives more details on the procedures followed by the authors.

[3] 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.

[4] ABBIENDI 06 use direct reconstruction of the kinematics of $W^+ W^- \rightarrow q\overline{q}\ell\nu_\ell$ and $W^+ W^- \rightarrow q\overline{q}q\overline{q}$ events. The result quoted here is obtained combining this mass value with the results using $W^+ W^- \rightarrow \ell\nu_\ell\ell'\nu_{\ell'}$ 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.

[5] ACHARD 06 use direct reconstruction of the kinematics of $W^+ W^- \rightarrow q\overline{q}\ell\nu_\ell$ and $W^+ W^- \rightarrow q\overline{q}q\overline{q}$ 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).

[6] SCHAEL 06 use direct reconstruction of the kinematics of $W^+ W^- \rightarrow q\overline{q}\ell\nu_\ell$ and $W^+ W^- \rightarrow q\overline{q}q\overline{q}$ 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.

[7] ABAZOV 02D improve the measurement of the W-boson mass including $W \rightarrow e\nu_e$ 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 $\pm$ 0.405 GeV. The value reported here is a combination of this measurement with all previous DØ W-boson mass measurements.

[8] AFFOLDER 01E fit the transverse mass spectrum of 30115 $W \rightarrow e\nu_e$ events ($M_W = 80.473 \pm 0.065 \pm 0.092$ GeV) and of 14740 $W \rightarrow \mu\nu_\mu$ 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.

[9] ABAZOV 12F select 1677k $W \rightarrow e\nu$ decays in 4.3 fb^{-1} of Run-II data. The mass is determined using the transverse mass and transverse lepton momentum distributions, accounting for correlations.

[10] ABAZOV 09AB study the transverse mass, transverse electron momentum, and transverse missing energy in a sample of 0.5 million $W \rightarrow e\nu$ decays selected in Run-II data. The quoted result combines all three methods, accounting for correlations.

[11] AALTONEN 07F obtain high purity $W \rightarrow e\nu_e$ and $W \rightarrow \mu\nu_\mu$ 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.

[12] 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.

[13] 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.
[14] 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.
[15] 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.
[16] 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.
[17] ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.
[18] ALBAJAR 89 result is from a total sample of 299 $W \rightarrow e\nu$ events.
[19] ALBAJAR 89 result is from a total sample of 67 $W \rightarrow \mu\nu$ events.
[20] ALBAJAR 89 result is from $W \rightarrow \tau\nu$ events.

W/Z MASS RATIO

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.88153±0.00017		[1] PDG	16		
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.8821 ±0.0011 ±0.0008	28323	[2] ABBOTT	98N	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
0.88114±0.00154±0.00252	5982	[3] ABBOTT	98P	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
0.8813 ±0.0036 ±0.0019	156	[4] ALITTI	92B	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV

[1] PDG 16 is the PDG average using the world average m_W and m_Z values as quoted in this edition of *Review of Particle Physics*. The directly measured values of m_W/m_Z are not used as their correlation with the Tevatron measured m_W is unknown.
[2] 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.
[3] 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.
[4] Scale error cancels in this ratio.

$m_Z - m_W$

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
10.803±0.015 OUR AVERAGE				
10.803±0.015	[1] PDG	16		
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

[1] PDG 16 value was obtained using the world average values of m_Z and m_W as listed in this publication.

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

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

The W width listed here corresponds to the width parameter in a Breit-Wigner distribution with mass-dependent width. To obtain the world average, common systematic uncertainties between experiments are properly taken into account. The LEP-2 average W width based on published results is 2.195 ± 0.083 GeV [SCHAEL 13A]. The combined Tevatron data yields an average W width of 2.046 ± 0.049 GeV [FERMILAB-TM-2460-E].

OUR FIT uses these average LEP and Tevatron width values and combines them assuming no correlations.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2.085±0.042 OUR FIT					
2.028±0.072	5272	[1] ABAZOV	09AK	D0	$E^{p\overline{p}}_{cm}$ = 1.96 GeV
2.032±0.045±0.057	6055	[2] AALTONEN	08B	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
2.404±0.140±0.101	10.3k	[3] ABDALLAH	08A	DLPH	E^{ee}_{cm}= 183–209 GeV
1.996±0.096±0.102	10729	[4] ABBIENDI	06	OPAL	E^{ee}_{cm}= 170–209 GeV
2.18 ±0.11 ±0.09	9795	[5] ACHARD	06	L3	E^{ee}_{cm}= 172–209 GeV
2.14 ±0.09 ±0.06	8717	[6] SCHAEL	06	ALEP	E^{ee}_{cm}= 183–209 GeV
2.23 $^{+0.15}_{-0.14}$ ±0.10	294	[7] ABAZOV	02E	D0	$E^{p\overline{p}}_{cm}$ = 1.8 TeV
2.05 ±0.10 ±0.08	662	[8] AFFOLDER	00M	CDF	$E^{p\overline{p}}_{cm}$ = 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.152±0.066	79176	[9] ABBOTT	00B	D0	Extracted value
2.064±0.060±0.059		[10] ABE	95W	CDF	Extracted value
2.10 $^{+0.14}_{-0.13}$ ±0.09	3559	[11] ALITTI	92	UA2	Extracted value
2.18 $^{+0.26}_{-0.24}$ ±0.04		[12] ALBAJAR	91	UA1	Extracted value

[1] ABAZOV 09AK obtain this result fitting the high-end tail (100-200 GeV) of the transverse mass spectrum in $W \rightarrow e\nu$ decays.

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

[3] 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. The systematic error includes ±0.065 GeV due to final state interactions.

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

[5] ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\overline{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\overline{q}q\overline{q}$ 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).

[6] SCHAEL 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\overline{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\overline{q}q\overline{q}$ 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.

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

[8] 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 ± 0.11(stat)±0.09(syst) GeV. This is combined with the earlier CDF measurement (ABE 95C) to obtain the quoted result.

[9] 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.

[10] ABE 95W measured $R = 10.90 \pm 0.32 \pm 0.29$. They use m_W=80.23 ± 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.

[11] 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.

[12] 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]	(10.86 ± 0.09) %	
Γ_2	$e^+\nu$		(10.71 ± 0.16) %	
Γ_3	$\mu^+\nu$		(10.63 ± 0.15) %	
Γ_4	$\tau^+\nu$		(11.38 ± 0.21) %	
Γ_5	hadrons		(67.41 ± 0.27) %	
Γ_6	$\pi^+\gamma$		$< 7 \times 10^{-6}$	95%
Γ_7	$D_s^+\gamma$		$< 1.3 \times 10^{-3}$	95%
Γ_8	cX		(33.3 ± 2.6) %	
Γ_9	$c\bar{s}$		$(31 ^{+13}_{-11})$ %	
Γ_{10}	invisible	[b]	(1.4 ± 2.9) %	

[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
$30^{+52}_{-48} \pm 33$	[1] BARATE	99I	ALEP	E^{ee}_{cm}= 161+172+183 GeV

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

	[2] BARATE	99L	ALEP	E^{ee}_{cm}= 161+172+183 GeV

[1] 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.

[2] 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 boson. Averages on $W \rightarrow e\nu$, $W \rightarrow \mu\nu$, and $W \rightarrow \tau\nu$, and their correlations are obtained by combining results from the four LEP experiments properly taking into account the common systematic uncertainties and their correlations [SCHAEL 13A]. A first fit determines the three individual leptonic braching ratios B($W \rightarrow e\nu$), B($W \rightarrow \mu\nu$), and B($W \rightarrow \tau\nu$). This fit has a χ^2 = 6.3 for 9 degrees of freedom. The correlation coefficients between the branching fractions are 0.14 ($e-\mu$), -0.20 ($e-\tau$), -0.12 ($\mu-\tau$). A second fit assumes lepton universality and determines the leptonic branching ratio br$W \rightarrow \ell\nu$ and the hadronic branching ratio is derived as B($W \rightarrow$ hadrons) = 1–3 br$W \rightarrow \ell$. This fit has a χ^2 = 15.4 for 11 degrees of freedom.

$\Gamma(\ell^+\nu)/\Gamma_{total}$ — 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*
10.86±0.09 OUR FIT					
10.86±0.12±0.08	16438	ABBIENDI	07A	OPAL	E^{ee}_{cm}= 161–209 GeV
10.85±0.14±0.08	13600	ABDALLAH	04G	DLPH	E^{ee}_{cm}= 161–209 GeV
10.83±0.14±0.10	11246	ACHARD	04J	L3	E^{ee}_{cm}= 161–209 GeV
10.96±0.12±0.05	16116	SCHAEL	04A	ALEP	E^{ee}_{cm}= 183–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
11.02±0.52	11858	[1] ABBOTT	99H	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
10.4 ±0.8	3642	[2] ABE	92I	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[1] ABBOTT 99H measure $R \equiv [\sigma_W \text{B}(W \rightarrow \ell\nu_\ell)]/[\sigma_Z \text{B}(Z \rightarrow \ell\ell)] = 10.90 \pm 0.52$ combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and B($Z \rightarrow \ell\ell$).

[2] $1216 \pm 38^{+27}_{-31}$ $W \rightarrow \mu\nu$ 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.

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

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
10.71±0.16 OUR FIT					
10.71±0.25±0.11	2374	ABBIENDI	07A	OPAL	E^{ee}_{cm}= 161–209 GeV
10.55±0.31±0.14	1804	ABDALLAH	04G	DLPH	E^{ee}_{cm}= 161–209 GeV
10.78±0.29±0.13	1576	ACHARD	04J	L3	E^{ee}_{cm}= 161–209 GeV
10.78±0.27±0.10	2142	SCHAEL	04A	ALEP	E^{ee}_{cm}= 183–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
10.61±0.28		[1] ABAZOV	04D	TEVA	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[1] 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)%.

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
10.63±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
11.38±0.21 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
67.41±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
0.991±0.018 OUR AVERAGE					
0.993±0.019		SCHAEL	13A	LEP	E^{ee}_{cm}= 130–209 GeV
0.89 ±0.10	13k	[1] ABACHI	95D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
1.02 ±0.08	1216	[2] 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

[1] 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.

[2] 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
1.043±0.024 OUR AVERAGE					
1.063±0.027		SCHAEL	13A	LEP	E^{ee}_{cm}= 130–209 GeV
0.961±0.061	980	[1] ABBOTT	00D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
0.94 ±0.14	179	[2] ABE	92E	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[3] 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

[1] 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.

[2] 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.

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

$\Gamma(\tau^+\nu)/\Gamma(\mu^+\nu)$ — Γ_4/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
1.070±0.026	SCHAEL	13A	LEP	E^{ee}_{cm}= 130–209 GeV

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$< 6.4 \times 10^{-5}$	95	AALTONEN	12W	CDF	$E^{p\overline{p}}_{cm}$= 1.96 Tev
$< 7 \times 10^{-4}$	95	ABE	98H	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
$< 4.9 \times 10^{-3}$	95	[1] ALITTI	92D	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV
$<58 \times 10^{-3}$	95	[2] ALBAJAR	90	UA1	$E^{p\overline{p}}_{cm}$= 546, 630 GeV

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

[2] 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
$<1.2 \times 10^{-2}$	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	[1] ABBIENDI	00V	OPAL	E^{ee}_{cm}= 183 + 189 GeV
0.51 ±0.05 ±0.03	746	[2] BARATE	99M	ALEP	E^{ee}_{cm}= 172 + 183 GeV

[1] 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 Γ(W) and B($W \rightarrow$ hadrons), $|V_{cs}|$ is determined to be 0.969 ± 0.045 ± 0.036.

[2] 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
$\mathbf{0.46^{+0.18}_{-0.14}\pm0.07}$	[1] ABREU	98N	DLPH	E^{ee}_{cm}= 161+172 GeV

[1] 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	[1] ABREU,P	00F	DLPH	E^{ee}_{cm}= 189 GeV

[1] 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	[1] ABREU,P	00F	DLPH	E^{ee}_{cm}= 189 GeV

[1] 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	[1] ABREU,P	00F	DLPH	E^{ee}_{cm}= 189 GeV

[1] 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	[1] ABBIENDI	06A	OPAL	E^{ee}_{cm}= 189–209 GeV
19.44±0.17	[2] ABREU,P	00F	DLPH	E^{ee}_{cm}= 183+189 GeV
19.3 ±0.3 ±0.3	[3] ABBIENDI	99N	OPAL	E^{ee}_{cm}= 183 GeV
19.23±0.74	[4] ABREU	98C	DLPH	E^{ee}_{cm}= 172 GeV

[1] 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.

[2] 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 ± 0.31 ± 0.27 and 19.78 ± 0.49 ± 0.43 in the semileptonic final states. The value quoted is a weighted average without assuming any correlations.

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

[4] ABREU 98C combine results from both the fully hadronic as well semileptonic $W W$ 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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g_1^Z

OUR FIT below is taken from [SCHAEL 13A].

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.984^{+0.018}_{-0.020}$ OUR FIT					
$0.975^{+0.033}_{-0.030}$	7872	[1] ABDALLAH	10	DLPH	E^{ee}_{cm}= 189–209 GeV
1.001±0.027±0.013	9310	[2] SCHAEL	05A	ALEP	E^{ee}_{cm}= 183–209 GeV
$0.987^{+0.034}_{-0.033}$	9800	[3] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
$0.966^{+0.034}_{-0.032}$±0.015	8325	[4] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[5] AAD	14Y	ATLS	E^{pp}_{cm} = 8 TeV
		[6] AAD	13AL	ATLS	E^{pp}_{cm} = 7 TeV
		[7] CHATRCHYAN	13BF	CMS	E^{pp}_{cm} = 7 TeV
		[8] AAD	12CD	ATLS	E^{pp}_{cm} = 7 TeV
		[9] AALTONEN	12AC	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[10] ABAZOV	12AG	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	34	[11] ABAZOV	11	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	334	[12] AALTONEN	10K	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
1.04 ±0.09		[13] ABAZOV	09AD	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[14] ABAZOV	09AJ	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$1.07\ ^{+0.08}_{-0.12}$	1880	[15] ABDALLAH	08C	DLPH	Superseded by ABDALLAH 10
	13	[16] ABAZOV	07Z	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[17] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
0.98 ±0.07 ±0.01	2114	[18] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
	331	[19] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[1] ABDALLAH 10 use data on the final states $e^+ e^- \rightarrow jj\ell\nu$, $jjjj$, jjX, ℓX, at center-of-mass energies between 189–209 GeV at LEP2, where j = jet, ℓ = lepton, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

[2] 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.

[3] 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 $0.923 < g_1^Z < 1.054$.

[4] 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.

[5] AAD 14Y determine the electroweak Z-dijet cross section in 8 TeV pp collisions. $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ decays are selected with the di-lepton $p_T > 20$ GeV and mass in the 81–101 GeV range. Minimum two jets are required with $p_T > 55$ and 45 GeV and no additional jets with $p_T > 25$ GeV in the rapidity interval between them. The normalized p_T balance between the Z and the two jets is required to be < 0.15. This leads to a selection of 900 events with dijet mass > 1 TeV. The number of signal and background events expected is 261 and 592 respectively. A Poisson likelihood method is used on an event by event basis to obtain the 95% CL limit $0.5 < g_1^Z < 1.26$ for a form factor value $\Lambda = \infty$.

[6] AAD 13AL study WW production in pp collisions and select 1325 WW candidates in decay modes with electrons or muons with an expected background of 369 ± 61 events. Assuming the LEP formulation and setting the form-factor Λ = infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $0.961 < g_1^Z < 1.052$. Supersedes AAD 12AC.

[7] CHATRCHYAN 13BF determine the $W^+ W^-$ production cross section using unlike sign di-lepton (e or μ) events with high $\not{p}_T$. The leptons have $p_T > 20$ GeV/c and are isolated. 1134 candidate events are observed with an expected SM background of 247 ± 34. The p_T distribution of the leading lepton is fitted to obtain 95% C.L. limits of $0.905 \leq g_1^Z \leq 1.095$.

[8] AAD 12CD study WZ production in pp collisions and select 317 WZ candidates in three $\ell\nu$ decay modes with an expected background of 68.0 ± 10.0 events. The resulting 95% C.L. range is: $0.943 < g_1^Z < 1.093$. Supersedes AAD 12V.

[9] AALTONEN 12AC study WZ production in $p\overline{p}$ collisions and select 63 WZ candidates in three $\ell\nu$ decay modes with an expected background of 7.9 ± 1.0 events. Based on the cross section and shape of the Z transverse momentum spectrum, the following 95% C.L. range is reported: $0.92 < g_1^Z < 1.20$ for a form factor of $\Lambda = 2$ TeV.

[10] ABAZOV 12AG combine new results with already published results on $W\gamma$, WW and WZ production in order to determine the couplings with increased precision, superseding ABAZOV 08R, ABAZOV 11AC, ABAZOV 09AJ, ABAZOV 09AD. The 68% C.L. result for a formfactor cutoff of $\Lambda = 2$ TeV is $g_1^Z = 1.022^{+0.032}_{-0.030}$.

[11] ABAZOV 11 study the $p\overline{p} \rightarrow 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $0.944 < g_1^Z < 1.154$, for a form factor $\Lambda = 2$ TeV.

[12] AALTONEN 10K study $p\overline{p} \rightarrow W^+ W^-$ with $W \rightarrow e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $0.76 < g_1^Z < 1.34$ for $\Lambda = 1.5$ TeV and $0.78 < g_1^Z < 1.30$ for $\Lambda = 2$ TeV.

[13] ABAZOV 09AD study the $p\overline{p} \rightarrow \ell\nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and

for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is 0.88 < g_1^Z < 1.20.

[14] ABAZOV 09AJ study the $p\overline{p} \rightarrow 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of 0.86 < g_1^Z < 1.3, for a form factor Λ = 2 TeV.

[15] ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+ e^- \rightarrow W^+ W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ. Values of all other couplings are fixed to their standard model values.

[16] 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 the other couplings to their standard model values, the 95% C.L. limit for a form factor scale Λ = 2 TeV is $0.86 < g_1^Z < 1.35$.

[17] 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 Λ = 1.5 TeV is $0.51 < g_1^Z < 1.66$, fixing λ_Z and κ_Z to their Standard Model values.

[18] 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 $0.84 < g_1^Z < 1.13$.

[19] 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 Λ = 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 taken from [SCHAEL 13A].

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.982±0.042 OUR FIT					
$1.024^{+0.077}_{-0.081}$	7872	[1] ABDALLAH	10	DLPH	E^{ee}_{cm}= 189–209 GeV
0.971±0.055±0.030	10689	[2] SCHAEL	05A	ALEP	E^{ee}_{cm}= 183–209 GeV
$0.88^{+0.09}_{-0.08}$	9800	[3] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
$1.013^{+0.067}_{-0.064}$±0.026	10575	[4] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[5] CHATRCHYAN	14AB	CMS	E^{pp}_{cm} = 7 TeV
		[6] AAD	13AN	ATLS	E^{pp}_{cm} = 7 TeV
		[7] CHATRCHYAN	13BF	CMS	E^{pp}_{cm} = 7 TeV
		[8] ABAZOV	12AG	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[9] ABAZOV	11AC	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[10] CHATRCHYAN	11M	CMS	E^{pp}_{cm} = 7 TeV
	334	[11] AALTONEN	10K	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	53	[12] AARON	09B	H1	E^{ep}_{cm} = 0.3 TeV
$1.07^{+0.26}_{-0.29}$		[13] ABAZOV	09AD	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV

		[14] ABAZOV	09AJ	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
		[15] ABAZOV	08R	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
$0.68\ ^{+0.17}_{-0.15}$	1880	[16] ABDALLAH	08C	DLPH	Superseded by ABDALLAH 10
	1617	[17] AALTONEN	07L	CDF	$E^{p\overline{p}}_{\rm cm} = 1.96$ GeV
	17	[18] ABAZOV	06H	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
	141	[19] ABAZOV	05J	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
$1.25\ ^{+0.21}_{-0.20} \pm 0.06$	2298	[20] ABREU	01I	DLPH	$E^{ee}_{\rm cm}$= 183+189 GeV
		[21] BREITWEG	00	ZEUS	$e^+ p \rightarrow e^+ W^{\pm} X$, $\sqrt{s} \approx$ 300 GeV
0.92 ± 0.34	331	[22] ABBOTT	99I	D0	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV

[1] ABDALLAH 10 use data on the final states $e^+ e^- \rightarrow jj\ell\nu, jjjj, jjX, \ell X$, at center-of-mass energies between 189–209 GeV at LEP2, where j = jet, ℓ = lepton, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

[2] 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.

[3] 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 $0.73 < \kappa_\gamma < 1.07$.

[4] 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.

[5] CHATRCHYAN 14AB measure $W\gamma$ production cross section for $p_T^\gamma > 15$ GeV and R($\ell\gamma$) > 0.7, which is the separation between the γ and the final state charged lepton (e or μ) in the azimuthal angle-pseudorapidity ($\phi - \eta$) plane. After background subtraction the number of $e\nu\gamma$ and $\mu\nu\gamma$ events is determined to be 3200 $\pm$ 325 and 4970 $\pm$ 543 respectively, compatible with expectations from the SM. This leads to a 95% CL limit of $0.62 < \kappa_\gamma < 1.29$, assuming other parameters have SM values.

[6] AAD 13AN study $W\gamma$ production in pp collisions. In events with no additional jet, 4449 (6578) W decays to electron (muon) are selected, with an expected background of 1662 $\pm$ 262 (2538 $\pm$ 362) events. Analysing the photon p_T spectrum above 100 GeV yields a 95% C.L. limit of $0.59 < \kappa_\gamma < 1.46$. Supersedes AAD 12BX.

[7] CHATRCHYAN 13BF determine the $W^+ W^-$ production cross section using unlike sign di-lepton (e or μ) events with high $\not{p}_T$. The leptons have $p_T > 20$ GeV/c and are isolated. 1134 candidate events are observed with an expected SM background of 247 $\pm$ 34. The p_T distribution of the leading lepton is fitted to obtain 95% C.L. limits of $0.79 \leq k_\gamma \leq 1.22$.

[8] ABAZOV 12AG combine new results with already published results on $W\gamma$, WW and WZ production in order to determine the couplings with increased precision, superseding ABAZOV 08R, ABAZOV 11AC, ABAZOV 09AJ, ABAZOV 09AD. The 68% C.L. result for a formfactor cutoff of $\Lambda = 2$ TeV is $\kappa_\gamma = 1.048^{+0.106}_{-0.105}$.

[9] ABAZOV 11AC study $W\gamma$ production in $p\overline{p}$ collisions at 1.96 TeV, with the W decay products containing an electron or a muon. They select 196 (363) events in the electron (muon) mode, with a SM expectation of 190 (372) events. A likelihood fit to the photon E_T spectrum above 15 GeV yields at 95% C.L. the result: $0.6 < \kappa_\gamma < 1.4$ for a formfactor $\Lambda = 2$ TeV.

[10] CHATRCHYAN 11M study $W\gamma$ production in pp collisions at $\sqrt{s} = 7$ TeV using 36 pb^{-1} pp data with the W decaying to electron and muon. The total cross section is measured for photon transverse energy $E_T^{\gamma} > 10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell,\gamma) > 0.7$. The number of candidate (background) events is 452 (228 ± 21) for the electron channel and 520 (277 ± 25) for the muon channel. Setting other couplings to their standard model value, they derive a 95% CL limit of $-0.11 < \kappa_\gamma < 2.04$.

[11] AALTONEN 10K study $p\overline{p} \rightarrow W^+ W^-$ with $W \rightarrow e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $0.37 < \kappa_\gamma < 1.72$ for $\Lambda = 1.5$ TeV and $0.43 < \kappa_\gamma < 1.65$ for $\Lambda = 2$ TeV.

[12] AARON 09B study single-W production in ep collisions at 0.3 TeV C.M. energy. They select 53 $W \rightarrow e/\mu$ events with a standard model expectation of 54.1 ± 7.4 events. Fitting the transverse momentum spectrum of the hadronic recoil system they obtain a 95% C.L. limit of $-3.7 < \kappa_\gamma < -1.5$ or $0.3 < \kappa_\gamma < 1.5$, where the ambiguity is due to the quadratic dependence of the cross section to the coupling parameter.

[13] ABAZOV 09AD study the $p\overline{p} \rightarrow \ell\nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $0.56 < \kappa_\gamma < 1.55$.

[14] ABAZOV 09AJ study the $p\overline{p} \rightarrow 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of $0.46 < \kappa_\gamma < 1.83$, for a form factor $\Lambda = 2$ TeV.

[15] ABAZOV 08R use 0.7 fb^{-1} $p\overline{p}$ data at $\sqrt{s} = 1.96$ TeV to select 263 $W\gamma + X$ events, of which 187 constitute signal, with the W decaying into an electron or a muon, which is required to be well separated from a photon with $E_T > 9$ GeV. A likelihood fit to the photon E_T spectrum yields a 95% CL limit $0.49 < \kappa_\gamma < 1.51$ with other couplings fixed to their Standard Model values.

[16] ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+ e^- \rightarrow W^+ W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ. Values of all other couplings are fixed to their standard model values.

[17] 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.

[18] 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 $\lambda_\gamma = 0$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $0.68 < \kappa < 1.45$.

[19] 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.

[20] 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 $0.87 < \kappa_\gamma < 1.68$.

[21] 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 $\lambda_\gamma = 0$).

[22] 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 $0.75 < \kappa_\gamma < 1.39$.

λ_γ

OUR FIT below is taken from [SCHAEL 13A].

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.022±0.019 OUR FIT					
0.002±0.035	7872	[1] ABDALLAH	10	DLPH	E^{ee}_{cm}= 189–209 GeV
−0.012±0.027±0.011	10689	[2] SCHAEL	05A	ALEP	E^{ee}_{cm}= 183–209 GeV
$-0.060^{+0.034}_{-0.033}$	9800	[3] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
$-0.021^{+0.035}_{-0.034}\pm0.017$	10575	[4] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[5] CHATRCHYAN	14AB	CMS	E^{pp}_{cm} = 7 TeV
		[6] AAD	13AN	ATLS	E^{pp}_{cm} = 7 TeV
		[7] ABAZOV	12AG	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[8] ABAZOV	11AC	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[9] CHATRCHYAN	11M	CMS	E^{pp}_{cm} = 7 TeV
	53	[10] AARON	09B	H1	E^{ep}_{cm} = 0.3 TeV
0.00 ±0.06		[11] ABAZOV	09AD	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[12] ABAZOV	09AJ	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[13] ABAZOV	08R	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$0.16\ ^{+0.12}_{-0.13}$	1880	[14] ABDALLAH	08C	DLPH	Superseded by ABDALLAH 10
	1617	[15] AALTONEN	07L	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 GeV
	17	[16] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	141	[17] ABAZOV	05J	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
0.05 ±0.09 ±0.01	2298	[18] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
		[19] BREITWEG	00	ZEUS	$e^+ p \rightarrow e^+ W^\pm X$, $\sqrt{s} \approx$ 300 GeV
$0.00\ ^{+0.10}_{-0.09}$	331	[20] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[1] ABDALLAH 10 use data on the final states $e^+ e^- \rightarrow jj\ell\nu$, $jjjj$, jjX, ℓX, at center-of-mass energies between 189–209 GeV at LEP2, where j = jet, ℓ = lepton, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

[2] 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.

[3] 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 $-0.13 < \lambda_\gamma < 0.01$.

[4] 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.

[5] CHATRCHYAN 14AB measure $W\gamma$ production cross section for $p_T^{\gamma} > 15$ GeV and R($\ell\gamma$) > 0.7, which is the separation between the γ and the final state charged lepton (e or μ) in the azimuthal angle-pseudorapidity ($\phi - \eta$) plane. After background subtraction the number of $e\nu\gamma$ and $\mu\nu\gamma$ events is determined to be 3200 $\pm$ 325 and 4970 $\pm$ 543 respectively, compatible with expectations from the SM. This leads to a 95% CL limit of $-0.050 < \lambda_\gamma < 0.037$, assuming all other parameters have SM values.

[6] AAD 13AN study $W\gamma$ production in pp collisions. In events with no additional jet, 4449 (6578) W decays to electron (muon) are selected, with an expected background of 1662 $\pm$ 262 (2538 $\pm$ 362) events. Analysing the photon p_T spectrum above 100 GeV yields a 95% C.L. limit of $-0.065 < \lambda_\gamma < 0.061$. Supersedes AAD 12BX.

[7] ABAZOV 12AG combine new results with already published results on $W\gamma$, WW and WZ production in order to determine the couplings with increased precision, superseding ABAZOV 08R, ABAZOV 11AC, ABAZOV 09AJ, ABAZOV 09AD. The 68% C.L. result for a formfactor cutoff of $\Lambda = 2$ TeV is $\lambda_\gamma = 0.007^{+0.021}_{-0.022}$.

[8] ABAZOV 11AC study $W\gamma$ production in $p\overline{p}$ collisions at 1.96 TeV, with the W decay products containing an electron or a muon. They select 196 (363) events in the electron (muon) mode, with a SM expectation of 190 (372) events. A likelihood fit to the photon E_T spectrum above 15 GeV yields at 95% C.L. the result: $-0.08 < \lambda_\gamma < 0.07$ for a formfactor $\Lambda = 2$ TeV.

[9] CHATRCHYAN 11M study $W\gamma$ production in pp collisions at $\sqrt{s} = 7$ TeV using 36 pb^{-1} pp data with the W decaying to electron and muon. The total cross section is measured for photon transverse energy $E_T^{\gamma} > 10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell,\gamma) > 0.7$. The number of candidate (background) events is 452 (228 $\pm$ 21) for the electron channel and 520 (277 $\pm$ 25) for the muon channel. Setting other couplings to their standard model value, they derive a 95% CL limit of $-0.18 < \lambda_\gamma < 0.17$.

[10] AARON 09B study single-W production in ep collisions at 0.3 TeV C.M. energy. They select 53 $W \rightarrow e/\mu$ events with a standard model expectation of 54.1 $\pm$ 7.4 events. Fitting the transverse momentum spectrum of the hadronic recoil system they obtain a 95% C.L. limit of $-2.5 < \lambda_\gamma < 2.5$.

[11] ABAZOV 09AD study the $p\overline{p} \rightarrow \ell\nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $-0.10 < \lambda_\gamma < 0.11$.

[12] ABAZOV 09AJ study the $p\overline{p} \rightarrow 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of $-0.14 < \lambda_\gamma < 0.18$, for a form factor $\Lambda = 2$ TeV.

[13] ABAZOV 08R use 0.7 fb^{-1} $p\overline{p}$ data at $\sqrt{s} = 1.96$ TeV to select 263 $W\gamma + X$ events, of which 187 constitute signal, with the W decaying into an electron or a muon, which is required to be well separated from a photon with $E_T > 9$ GeV. A likelihood fit to the photon E_T spectrum yields a 95% CL limit $-0.12 < \lambda_\gamma < 0.13$ with other couplings fixed to their Standard Model values.

[14] ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+ e^- \rightarrow W^+ W^- \rightarrow (qq)(\ell\nu)$, where $\ell = e$ or μ. Values of all other couplings are fixed to their standard model values.

[15] 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 $-0.18 < \lambda_\gamma < 0.17$ for a form factor scale $\Lambda = 1.5$ TeV.

[16] 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 (Λ = 2 TeV) is $-0.29 < \lambda < 0.30$.

[17] 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.

[18] 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 $-0.11 < \lambda_\gamma < 0.23$.

[19] 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.

[20] 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	[1] ACHARD	04D	L3	E^{ee}_{cm} = 189–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] AAD	13AL	ATLS	E^{pp}_{cm} = 7 TeV
		[3] AAD	12CD	ATLS	E^{pp}_{cm} = 7 TeV
		[4] AALTONEN	12AC	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	34	[5] ABAZOV	11	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	17	[6] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[7] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV

[1] 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.

[2] AAD 13AL study WW production in pp collisions and select 1325 WW candidates in decay modes with electrons or muons with an expected background of 369 ± 61 events. Assuming the LEP formulation and setting the form-factor Λ = infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $0.957 < \kappa_Z < 1.043$. Supersedes AAD 12AC.

[3] AAD 12CD study WZ production in pp collisions and select 317 WZ candidates in three $\ell\nu$ decay modes with an expected background of 68.0 ± 10.0 events. The resulting 95% C.L. range is: $0.63 < \kappa_Z < 1.57$. Supersedes AAD 12V.

[4] AALTONEN 12AC study WZ production in $p\overline{p}$ collisions and select 63 WZ candidates in three $\ell\nu$ decay modes with an expected background of 7.9 ± 1.0 events. Based on the cross section and shape of the Z transverse momentum spectrum, the following 95% C.L. range is reported: $0.61 < \kappa_Z < 1.90$ for a form factor of $\Lambda = 2$ TeV.

[5] ABAZOV 11 study the $p\overline{p} \rightarrow 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $0.600 < \kappa_Z < 1.675$, for a form factor $\Lambda = 2$ TeV.

[6] 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 $0.68 < \kappa < 1.45$.

[7] ABAZOV 05S study $\overline{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ (ℓ and ℓ' = 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_1^Z 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	[1] ACHARD	04D	L3	E^{ee}_{cm} = 189–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] AAD	14Y	ATLS	E^{pp}_{cm} = 8 TeV
		[3] AAD	13AL	ATLS	E^{pp}_{cm} = 7 TeV
		[4] CHATRCHYAN	13BF	CMS	E^{pp}_{cm} = 7 TeV
		[5] AAD	12CD	ATLS	E^{pp}_{cm} = 7 TeV
		[6] AALTONEN	12AC	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	34	[7] ABAZOV	11	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	334	[8] AALTONEN	10K	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	13	[9] ABAZOV	07Z	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	17	[10] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[11] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV

[1] 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.

[2] AAD 14Y determine the electroweak Z-dijet cross section in 8 TeV pp collisions. $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ decays are selected with the di-lepton $p_T > 20$ GeV and mass in the 81–101 GeV range. Minimum two jets are required with $p_T > 55$ and 45 GeV and no additional jets with $p_T > 25$ GeV in the rapidity interval between them. The normalized p_T balance between the Z and the two jets is required to be < 0.15. This leads to a selection of 900 events with dijet mass > 1 TeV. The number of signal and background events expected is 261 and 592 respectively. A Poisson likelihood method is used on an event by event basis to obtain the 95% CL limit $-0.15 < \lambda_Z < 0.13$ for a form factor value $\Lambda = \infty$.

[3] AAD 13AL study WW production in pp collisions and select 1325 WW candidates in decay modes with electrons or muons with an expected background of 369 ± 61 events. Assuming the LEP formulation and setting the form-factor Λ = infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $-0.062 < \lambda_Z < 0.059$. Supersedes AAD 12AC.

[4] CHATRCHYAN 13BF determine the W^+W^- production cross section using unlike sign di-lepton (e or μ) events with high $\not{p}_T$. The leptons have $p_T > 20$ GeV/c and are isolated. 1134 candidate events are observed with an expected SM background of 247 ± 34. The p_T distribution of the leading lepton is fitted to obtain 95% C.L. limits of $-0.048 \leq \lambda_Z \leq 0.048$.

[5] AAD 12CD study WZ production in pp collisions and select 317 WZ candidates in three $\ell\nu$ decay modes with an expected background of 68.0 ± 10.0 events. The resulting 95% C.L. range is: $-0.046 < \lambda_Z < 0.047$. Supersedes AAD 12V.

[6] AALTONEN 12AC study WZ production in $p\overline{p}$ collisions and select 63 WZ candidates in three $\ell\nu$ decay modes with an expected background of 7.9 ± 1.0 events. Based on the cross section and shape of the Z transverse momentum spectrum, the following 95% C.L. range is reported: $-0.08 < \lambda_Z < 0.10$ for a form factor of $\Lambda = 2$ TeV.

[7] ABAZOV 11 study the $p\overline{p} \rightarrow 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $-0.077 < \lambda_Z < 0.093$, for a form factor $\Lambda = 2$ TeV.

[8] AALTONEN 10K study $p\overline{p} \rightarrow W^+W^-$ with $W \rightarrow e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $-0.16 < \lambda_Z < 0.16$ for $\Lambda = 1.5$ TeV and $-0.14 < \lambda_Z < 0.15$ for $\Lambda = 2$ TeV.

[9] 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 the other couplings to their standard model values, the 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $-0.17 < \lambda_Z < 0.21$.

[10] 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 (Λ = 2 TeV) is $-0.29 < \lambda < 0.30$.

[11] ABAZOV 05S study $\overline{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ (ℓ and ℓ' = 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
−0.07±0.09 OUR AVERAGE		Error includes scale factor of 1.1.			
$-0.04^{+0.13}_{-0.12}$	9800	[1] ABBIENDI	04D	OPAL	E^{ee}_{cm}= 183–209 GeV
0.00±0.13±0.05	7171	[2] ACHARD	04D	L3	E^{ee}_{cm}= 189–209 GeV
$-0.44^{+0.23}_{-0.22}$±0.12	1154	[3] ACCIARRI	99Q	L3	E^{ee}_{cm}= 161+172+ 183 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−0.31±0.23		[4] EBOLI	00	THEO	LEP1, SLC+ Tevatron

[1] 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 $-0.28 < g_5^Z < +0.21$.

[2] 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.

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

[4] 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
-0.30 ± 0.17 OUR AVERAGE					
$-0.39^{+0.19}_{-0.20}$	1880	[1] ABDALLAH	08C	DLPH	E^{ee}_{cm}= 189–209 GeV
$-0.02^{+0.32}_{-0.33}$	1065	[2] ABBIENDI	01H	OPAL	E^{ee}_{cm}= 189 GeV

[1] ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (q q)(\ell\nu)$, where $\ell = e$ or μ. Values of all other couplings are fixed to their standard model values.

[2] 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
$-0.12^{+0.06}_{-0.04}$ OUR AVERAGE					
$-0.09^{+0.08}_{-0.05}$	1880	[1] ABDALLAH	08C	DLPH	E^{ee}_{cm}= 189–209 GeV
$-0.20^{+0.10}_{-0.07}$	1065	[2] ABBIENDI	01H	OPAL	E^{ee}_{cm}= 189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[3] BLINOV	11	LEP	E^{ee}_{cm}= 183–207 GeV

[1] ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (q q)(\ell\nu)$, where $\ell = e$ or μ. Values of all other couplings are fixed to their standard model values.

[2] 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.

[3] BLINOV 11 use the LEP-average $e^+e^- \rightarrow W^+W^-$ cross section data for $\sqrt{s}$ = 183–207 GeV to determine an upper limit on the TGC $\widetilde{\kappa}_Z$. The average values of the cross sections as well as their correlation matrix, and standard model expectations of the cross sections are taken from the LEPEWWG note hep-ex/0612034. At 95% confidence level $|\widetilde{\kappa}_Z| < 0.13$.

$\widetilde{\lambda}_Z$

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
-0.09 ± 0.07 OUR AVERAGE					
-0.08 ± 0.07	1880	[1] ABDALLAH	08C	DLPH	E^{ee}_{cm}= 189–209 GeV
$-0.18^{+0.24}_{-0.16}$	1065	[2] ABBIENDI	01H	OPAL	E^{ee}_{cm}= 189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[3] BLINOV	11	LEP	E^{ee}_{cm}= 183–207 GeV

[1] ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (q q)(\ell\nu)$, where $\ell = e$ or μ. Values of all other couplings are fixed to their standard model values.

[2] 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.

[3] BLINOV 11 use the LEP-average $e^+e^- \rightarrow W^+W^-$ cross section data for $\sqrt{s}$ = 183–207 GeV to determine an upper limit on the TGC $\widetilde{\lambda}_Z$. The average values of the cross sections as well as their correlation matrix, and standard model expectations of the cross sections are taken from the LEPEWWG note hep-ex/0612034. At 95% confidence level $|\widetilde{\lambda}_Z| < 0.31$.

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*
$\mathbf{2.22^{+0.20}_{-0.19}}$	2298	[1] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] ABE	95G	CDF	
		[3] ALITTI	92C	UA2	
		[4] SAMUEL	92	THEO	
		[5] SAMUEL	91	THEO	
		[6] GRIFOLS	88	THEO	
		[7] GROTCH	87	THEO	
		[8] VANDERBIJ	87	THEO	
		[9] GRAU	85	THEO	
		[10] SUZUKI	85	THEO	
		[11] HERZOG	84	THEO	

[1] 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 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.

[2] 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.

[3] 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 $-3.6 < \lambda < 3.5$.

[4] 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.

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

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

[7] 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.

[8] 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 $\Delta\kappa$.

[9] 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 $\lambda = 0$.

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

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

ANOMALOUS W/Z QUARTIC COUPLINGS

A REVIEW GOES HERE – Check our WWW List of Reviews

a_0/Λ^2, a_c/Λ^2, a_n/Λ^2, κ_0^W/Λ^2, κ_c^W/Λ^2, $f_{T,0}/\Lambda^4$, $f_{M,i}/\Lambda^4$, α_4, α_5, $F_{S,i}/\Lambda^4$, $F_{M,i}/\Lambda^4$, $F_{T,i}/\Lambda^4$

Anomalous W quartic couplings are measured by the experiments at LEP, the Tevatron, and the LHC. Some of the recent results from the Tevatron and LHC experiments individually surpass the combined LEP-2 results in precision (see below). As discussed in the review on the "Anomalous W/Z quartic couplings (QGCS)," the measurements are typically done using different operator expansions which then do not allow the results to be compared and averaged. At least one common framework should be agreed upon for the use in the future publications by the experiments.

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[1] AAD	15N	ATLS
	[2] KHACHATRY...	15D	CMS
	[3] AAD	14AM	ATLS
	[4] CHATRCHYAN	14Q	CMS
	[5] ABAZOV	13D	D0
	[6] CHATRCHYAN	13AA	CMS
	[7] ABBIENDI	04B	OPAL
	[8] ABBIENDI	04L	OPAL
	[9] HEISTER	04A	ALEP
	[10] ABDALLAH	03I	DLPH
	[11] ACHARD	02F	L3

[1] AAD 15N study $W\gamma\gamma$ events in 8 TeV pp interactions, where the W decays into an electron or a muon. The events are characterized by an isolated lepton, a missing transverse energy due to the decay neutrino, and two isolated photons, with the p_T of the lepton and the photons being > 20 GeV. The number of candidate events observed in the electron channel for N(jet) $\geq$ 0 and N(jet) = 0 is 47 and 15, the corresponding numbers for the muon channel being 110 and 53. The backgrounds expected are 30.2 ± 7.4, 8.7 ± 3.0, 52.1 ± 12.2, and 24.4 ± 8.3 respectively. The 95% C.L. limits on the values of the parameters $f_{T,0}/\Lambda^4$, $f_{M,2}/\Lambda^4$ and $f_{M,3}/\Lambda^4$ are -0.9–0.9×10^2, -0.8–0.8×10^4, and -1.5–1.4×10^4 respectively, without application of a form factor Λ_{FF}.

[2] KHACHATRYAN 15D study vector-boson-scattering tagged by two jets, requiring two same-sign charged leptons arising from $W^{\pm} W^{\pm}$ production and decay. The two jets must have a transverse momentum larger than 30 GeV, while the leptons, electrons or muons, must have a transverse momentum $>$ 20 GeV. The dijet mass is required to be $>$ 500 GeV, the dilepton mass $>$ 50 GeV, with additional requirement of differing from the Z mass by $>$ 15 GeV. In the two categories $W^+ W^+$ and $W^- W^-$, 10 and 2 data events are observed in a data sample corresponding to an integrated luminosity of 19.4 fb^{-1}, with an expected background of 3.1 ± 0.6 and 2.6 ± 0.5 events. Analysing the distribution of the dilepton invariant mass, the following limits at 95% C.L. are obtained, in units of TeV^{-4}: $-38 < F_{S,0}/\Lambda^4 < 40$, $-118 < F_{S,1}/\Lambda^4 < 120$, $-33 < F_{M,0}/\Lambda^4 < 32$, $-44 < F_{M,1}/\Lambda^4 < 47$, $-65 < F_{M,6}/\Lambda^4 < 63$, $-70 < F_{M,7}/\Lambda^4 < 66$, $-4.2 < F_{T,0}/\Lambda^4 < 4.6$, $-1.9 < F_{T,1}/\Lambda^4 < 2.2$, $-6.2 < F_{T,2}/\Lambda^4 < 6.4$.

[3] AAD 14AM analyze electroweak production of WW jet jet same-charge diboson plus two jets production, with the W bosons decaying to electron or muon, to study the quartic $WWWW$ coupling. In a kinematic region enhancing the electroweak production over the strong production, 34 events are observed in the data while 29.8 ± 2.4 events are expected with a backgound of 15.9 ± 1.9 events. Assuming the other QGC coupling to have the SM value of zero, the observed event yield is used to determine 95% CL limits on the quartic gauge couplings: $-0.14 < \alpha_4 < 0.16$ and $-0.23 < \alpha_5 < 0.24$.

[4] CHATRCHYAN 14Q study $WV\gamma$ production in 8 TeV pp collisions, in the single lepton final state, with $W \rightarrow \ell\nu$, $Z \rightarrow$ dijet or $W \rightarrow \ell\nu$, $W \rightarrow$ dijet, the dijet mass resolution precluding differentiation between the W and Z. p_T and pseudo-rapidity cuts are put on the lepton, the photon and the two jets to minimize backgrounds. The dijet mass is required to be between 7–100 GeV and $|\Delta\eta_{jj}| < 1.4$. The selected number of muon (electron) events are 183 (139), with SM expectation being 194.2 ± 11.5 (147.9 ± 10.7) including signal and background. The photon E_T distribution is used to set limits on the anomalous quartic couplings. The following 95% CL limits are deduced (all in units of TeV^{-2} or TeV^{-4}): $-21 < a_0^W/\Lambda^2 < 20$, $-34 < a_c^W/\Lambda^2 < 32$, $-12 < \kappa_0^W/\Lambda^2 < 10$ and $-18 < \kappa_c^W/\Lambda^2 < 17$; and $-25 < f_{T,0}/\Lambda^4 < 24$ TeV^{-4}.

[5] ABAZOV 13D searches for anomalous $WW\gamma\gamma$ quartic gauge couplings in the two-photon-mediated process $pp \rightarrow ppWW$, assuming the $WW\gamma$ triple gauge boson couplings to be at their Standard Model values. 946 events containing an e^+e^- pair with missing energy are selected in a total luminosity of 9.7 fb^{-1}, with an expectation of 983 ± 108 events from Standard-Model processes. The following 1-parameter limits at 95% CL are otained: $|a_0^W/\Lambda^2| < 4.3 \times 10^{-4}$ GeV^{-2} ($a_c^W = 0$), $|a_c^W/\Lambda^2| < 1.5 \times 10^{-3}$ GeV^{-2} ($a_0^W = 0$).

[6] CHATRCHYAN 13AA searches for anomalous $WW\gamma\gamma$ quartic gauge couplings in the two-photon-mediated process $pp \rightarrow ppWW$, assuming the $WW\gamma$ triple gauge boson couplings to be at their Standard Model values. 2 events containing an $e^{\pm}\mu^{\mp}$ pair with $p_T(e,\mu) > 30$ GeV are selected in a total luminosity of 5.05 fb^{-1}, with an expected $ppWW$ signal of 2.2 ± 0.4 events and an expected background of 0.84 ± 0.15 events. The following 1-parameter limits at 95% CL are otained from the $p_T(e,\mu)$ spectrum: $|a_0^W/\Lambda^2| < 4.0 \times 10^{-6}$ GeV^{-2} ($a_c^W = 0$), $|a_c^W/\Lambda^2| < 1.5 \times 10^{-5}$ GeV^{-2} ($a_0^W = 0$).

[7] ABBIENDI 04B select 187 $e^+e^- \rightarrow W^+W^-\gamma$ events in the C.M. energy range 180–209 GeV, where $E_\gamma > 2.5$ 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}.

[8] 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}.

[9] 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 $> 0.2\sqrt{s}$), $p_{T_\gamma}/E_{\text{beam}} > 0.05$ 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}.

[10] ABDALLAH 03I select 122 $e^+e^- \to W^+W^-\gamma$ 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}.

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

W REFERENCES

PDG	16	Chin. Phys. C	C. Patrignani *et al.*	(PDG Collab.)
AAD	15N	PRL 115 031802	G. Aad *et al.*	(ATLAS Collab.)
KHACHATRY...	15D	PRL 114 051801	V. Khachatryan *et al.*	(CMS Collab.)
AAD	14AM	PRL 113 141803	G. Aad *et al.*	(ATLAS Collab.)
AAD	14Y	JHEP 1404 031	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	14D	PR D89 072003	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	14N	PR D89 012005	V.M. Abazov *et al.*	(D0 Collab.)
CHATRCHYAN	14AB	PR D89 092005	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	14Q	PR D90 032008	S. Chatrchyan *et al.*	(CMS Collab.)
AAD	13AL	PR D87 112001	G. Aad *et al.*	(ATLAS Collab.)
Also		PR D88 079906 (errat.)	G. Aad *et al.*	(ATLAS Collab.)
AAD	13AN	PR D87 112003	G. Aad *et al.*	(ATLAS Collab.)
Also		PR D91 119901 (errat.)	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	13N	PR D88 052018	T. Aaltonen *et al.*	(CDF and D0 Collabs.)

ABAZOV	13D	PR D88 012005	V.M. Abazov *et al.*	(D0 Collab.)
CHATRCHYAN	13AA	JHEP 1307 116	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13BF	EPJ C73 2610	S. Chatrchyan *et al.*	(CMS Collab.)
SCHAEL	13A	PRPL 532 119	S. Schael *et al.*	(ALEPH Collab., DELPHI, L3+)
AAD	12AC	PL B712 289	G. Aad *et al.*	(ATLAS Collab.)
AAD	12BX	PL B717 49	G. Aad *et al.*	(ATLAS Collab.)
AAD	12CD	EPJ C72 2173	G. Aad *et al.*	(ATLAS Collab.)
AAD	12V	PL B709 341	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	12AC	PR D86 031104	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	12E	PRL 108 151803	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	12W	PR D85 032001	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	12AG	PL B718 451	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	12F	PRL 108 151804	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	11	PL B695 67	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	11AC	PRL 107 241803	V.M. Abazov *et al.*	(D0 Collab.)
BLINOV	11	PL B699 287	A.E. Blinov, A.S. Rudenko	(NOVO)
CHATRCHYAN	11M	PL B701 535	S. Chatrchyan *et al.*	(CMS Collab.)
AALTONEN	10K	PRL 104 201801	T. Aaltonen *et al.*	(CDF Collab.)
Also		PRL 105 019905(errat.)	T. Aaltonen *et al.*	(CDF Collab.)
ABDALLAH	10	EPJ C66 35	J. Abdallah *et al.*	(DELPHI Collab.)
AARON	09B	EPJ C64 251	F.D. Aaron *et al.*	(H1 Collab.)
ABAZOV	09AB	PRL 103 141801	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	09AD	PR D80 053012	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	09AJ	PRL 103 191801	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	09AK	PRL 103 231802	V.M. Abazov *et al.*	(D0 Collab.)
AALTONEN	08B	PRL 100 071801	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	08R	PRL 100 241805	V.M. Abazov *et al.*	(D0 Collab.)
ABDALLAH	08A	EPJ C55 1	J. Abdallah *et al.*	(DELPHI Collab.)
ABDALLAH	08C	EPJ C54 345	J. Abdallah *et al.*	(DELPHI Collab.)
AALTONEN	07F	PRL 99 151801	T. Aaltonen *et al.*	(CDF Collab.)
Also		PR D77 112001	T. Aaltonen *et al.*	(CDF Collab.)
AALTONEN	07L	PR D76 111103	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	07Z	PR D76 111104	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	07A	EPJ C52 767	G. Abbiendi *et al.*	(OPAL Collab.)
ABAZOV	06H	PR D74 057101	V.M. Abazov *et al.*	(D0 Collab.)
Also		PR D74 059904(errat.)	V.M. Abazov *et al.*	(D0 Collab.)
ABBIENDI	06	EPJ C45 307	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	06A	EPJ C45 291	G. Abbiendi *et al.*	(OPAL Collab.)
ACHARD	06	EPJ C45 569	P. Achard *et al.*	(L3 Collab.)
AKTAS	06	PL B632 35	A. Aktas *et al.*	(H1 Collab.)
SCHAEL	06	EPJ C47 309	S. Schael *et al.*	(ALEPH Collab.)
ABAZOV	05J	PR D71 091108	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	05S	PRL 95 141802	V.M. Abazov *et al.*	(D0 Collab.)
SCHAEL	05A	PL B614 7	S. Schael *et al.*	(ALEPH Collab.)
ABAZOV	04D	PR D70 092008	V.M. Abazov *et al.*	(CDF Collab., D0 Collab.)
ABBIENDI	04B	PL B580 17	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04D	EPJ C33 463	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04L	PR D70 032005	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	04G	EPJ C34 127	J. Abdallah *et al.*	(DELPHI Collab.)
ACHARD	04D	PL B586 151	P. Achard *et al.*	(L3 Collab.)
ACHARD	04J	PL B600 22	P. Achard *et al.*	(L3 Collab.)
HEISTER	04A	PL B602 31	A. Heister *et al.*	(ALEPH Collab.)
SCHAEL	04A	EPJ C38 147	S. Schael *et al.*	(ALEPH Collab.)
ABBIENDI	03C	EPJ C26 321	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	03I	EPJ C31 139	J. Abdallah *et al.*	(DELPHI Collab.)
ABAZOV	02D	PR D66 012001	V.M. Abazov *et al.*	(D0 Collab.)
ABAZOV	02E	PR D66 032008	V.M. Abazov *et al.*	(D0 Collab.)
ACHARD	02F	PL B527 29	P. Achard *et al.*	(L3 Collab.)
CHEKANOV	02C	PL B539 197	S. Chekanov *et al.*	(ZEUS Collab.)
ABBIENDI	01H	EPJ C19 229	G. Abbiendi *et al.*	(OPAL Collab.)
ABREU	01I	PL B502 9	P. Abreu *et al.*	(DELPHI Collab.)
AFFOLDER	01E	PR D64 052001	T. Affolder *et al.*	(CDF Collab.)
ABBIENDI	00V	PL B490 71	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	00B	PR D61 072001	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	00D	PRL 84 5710	B. Abbott *et al.*	(D0 Collab.)
ABREU,P	00F	EPJ C18 203	P. Abreu *et al.*	(DELPHI Collab.)
Also		EPJ C25 493 (errat.)	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	00T	PL B490 187	M. Acciarri *et al.*	(L3 Collab.)
AFFOLDER	00M	PRL 85 3347	T. Affolder *et al.*	(CDF Collab.)
BREITWEG	00	PL B471 411	J. Breitweg *et al.*	(ZEUS Collab.)
BREITWEG	00D	EPJ C12 411	J. Breitweg *et al.*	(ZEUS Collab.)

EBOLI	00	MPL A15 1	O. Eboli, M. Gonzalez-Garcia, S. Novaes	
ABBIENDI	99N	PL B453 153	G. Abbiendi *et al.*	(OPAL Collab.)
ABBOTT	99H	PR D60 052003	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	99I	PR D60 072002	B. Abbott *et al.*	(D0 Collab.)
ABREU	99L	PL B459 382	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	99	PL B454 386	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99Q	PL B467 171	M. Acciarri *et al.*	(L3 Collab.)
BARATE	99I	PL B453 107	R. Barate *et al.*	(ALEPH Collab.)
BARATE	99L	PL B462 389	R. Barate *et al.*	(ALEPH Collab.)
BARATE	99M	PL B465 349	R. Barate *et al.*	(ALEPH Collab.)
ABBOTT	98N	PR D58 092003	B. Abbott *et al.*	(D0 Collab.)
ABBOTT	98P	PR D58 012002	B. Abbott *et al.*	(D0 Collab.)
ABE	98H	PR D58 031101	F. Abe *et al.*	(CDF Collab.)
ABE	98P	PR D58 091101	F. Abe *et al.*	(CDF Collab.)
ABREU	98C	PL B416 233	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	98N	PL B439 209	P. Abreu *et al.*	(DELPHI Collab.)
BARATE	97	PL B401 347	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97S	PL B415 435	R. Barate *et al.*	(ALEPH Collab.)
ABACHI	95D	PRL 75 1456	S. Abachi *et al.*	(D0 Collab.)
ABE	95C	PRL 74 341	F. Abe *et al.*	(CDF Collab.)
ABE	95G	PRL 74 1936	F. Abe *et al.*	(CDF Collab.)
ABE	95P	PRL 75 11	F. Abe *et al.*	(CDF Collab.)
Also		PR D52 4784	F. Abe *et al.*	(CDF Collab.)
ABE	95W	PR D52 2624	F. Abe *et al.*	(CDF Collab.)
Also		PRL 73 220	F. Abe *et al.*	(CDF Collab.)
ABE	92E	PRL 68 3398	F. Abe *et al.*	(CDF Collab.)
ABE	92I	PRL 69 28	F. Abe *et al.*	(CDF Collab.)
ALITTI	92	PL B276 365	J. Alitti *et al.*	(UA2 Collab.)
ALITTI	92B	PL B276 354	J. Alitti *et al.*	(UA2 Collab.)
ALITTI	92C	PL B277 194	J. Alitti *et al.*	(UA2 Collab.)
ALITTI	92D	PL B277 203	J. Alitti *et al.*	(UA2 Collab.)
ALITTI	92F	PL B280 137	J. Alitti *et al.*	(UA2 Collab.)
SAMUEL	92	PL B280 124	M.A. Samuel *et al.*	(OKSU, CARL)
ABE	91C	PR D44 29	F. Abe *et al.*	(CDF Collab.)
ALBAJAR	91	PL B253 503	C. Albajar *et al.*	(UA1 Collab.)
ALITTI	91C	ZPHY C52 209	J. Alitti *et al.*	(UA2 Collab.)
SAMUEL	91	PRL 67 9	M.A. Samuel *et al.*	(OKSU, CARL)
Also		PRL 67 2920 (erratum)	M.A. Samuel *et al.*	
ABE	90G	PRL 65 2243	F. Abe *et al.*	(CDF Collab.)
Also		PR D43 2070	F. Abe *et al.*	(CDF Collab.)
ALBAJAR	90	PL B241 283	C. Albajar *et al.*	(UA1 Collab.)
ALITTI	90B	PL B241 150	J. Alitti *et al.*	(UA2 Collab.)
ABE	89I	PRL 62 1005	F. Abe *et al.*	(CDF Collab.)
ALBAJAR	89	ZPHY C44 15	C. Albajar *et al.*	(UA1 Collab.)
BAUR	88	NP B308 127	U. Baur, D. Zeppenfeld	(FSU, WISC)
GRIFOLS	88	IJMP A3 225	J.A. Grifols, S. Peris, J. Sola	(BARC, DESY)
Also		PL B197 437	J.A. Grifols, S. Peris, J. Sola	(BARC, DESY)
ALBAJAR	87	PL B185 233	C. Albajar *et al.*	(UA1 Collab.)
ANSARI	87	PL B186 440	R. Ansari *et al.*	(UA2 Collab.)
GROTCH	87	PR D36 2153	H. Grotch, R.W. Robinett	(PSU)
HAGIWARA	87	NP B282 253	K. Hagiwara *et al.*	(KEK, UCLA, FSU)
VANDERBIJ	87	PR D35 1088	J.J. van der Bij	(FNAL)
GRAU	85	PL 154B 283	A. Grau, J.A. Grifols	(BARC)
SUZUKI	85	PL 153B 289	M. Suzuki	(LBL)
ARNISON	84D	PL 134B 469	G.T.J. Arnison *et al.*	(UA1 Collab.)
HERZOG	84	PL 148B 355	F. Herzog	(WISC)
Also		PL 155B 468 (erratum)	F. Herzog	(WISC)
ARNISON	83	PL 122B 103	G.T.J. Arnison *et al.*	(UA1 Collab.)
BANNER	83B	PL 122B 476	M. Banner *et al.*	(UA2 Collab.)