W

$J = 1$

See the related review(s):

Mass and Width of the W Boson

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 averages of various measurements, common systematic uncertainties between experiments are evaluated and accounted for in combinations [SCHAEL 13A, AMOROSO 24].

Until 2022, the measurements of the W-boson mass at lepton and hadron colliders, LEP-2 (ALEPH, DELPHI, L3, and OPAL), Tevatron (CDF and D0), and LHC (ALEPH and LHCb), were in good agreement with each other [PDG 22]. However, with the new CDF result [AALTONEN 22] based on their complete Run-II data set, this is no longer the case.

The LHC-TeV MW Working Group, including W-mass experts from CDF, D0, ATLAS, CMS and LHCb [AMOROSO 24], has examined this issue in depth. They report that a combination of all W-mass measurements corrected to a common theory description and PDF set, has a probability of compatibility of 0.5% only, and is therefore disfavoured. A 91% probability of compatibility is obtained when the CDF-II measurement is removed. The corresponding value of the W boson mass is 80369.2 ± 13.3 MeV, which we quote as the World Average.

More information is given in [M. Grunewald and A. Gurtu, Mass and Width of the W Boson review, PDG 24] and in [AMOROSO 24].

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
80.3692± 0.0133 OUR EVALUATION		(AMOROSO 24)			
80.4335± 0.0094		(AALTONEN 22 CDF)			
80.354 ± 0.023 ±0.022	2.4M	[1] AAIJ	22C	LHCB	$E^{pp}_{\rm cm}$ = 13 TeV
80.4335± 0.0064±0.0069	4.2M	[2] AALTONEN	22	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
80.370 ± 0.007 ±0.017	13.7M	[3] AABOUD	18J	ATLS	$E^{pp}_{\rm cm}$ = 7 TeV
80.375 ± 0.011 ±0.020	2177k	[4] ABAZOV	12F	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
80.336 ± 0.055 ±0.039	10.3k	[5] ABDALLAH	08A	DLPH	$E^{ee}_{\rm cm}$ = 161–209 GeV
80.415 ± 0.042 ±0.031	11830	[6] ABBIENDI	06	OPAL	$E^{ee}_{\rm cm}$= 170–209 GeV
80.270 ± 0.046 ±0.031	9909	[7] ACHARD	06	L3	$E^{ee}_{\rm cm}$= 161–209 GeV
80.440 ± 0.043 ±0.027	8692	[8] SCHAEL	06	ALEP	$E^{ee}_{\rm cm}$= 161–209 GeV
80.483 ± 0.084	49247	[9] ABAZOV	02D	D0	$E^{p\overline{p}}_{\rm cm}$= 1.8 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
80.520 ± 0.070 ±0.092		[10] ANDREEV	18A	H1	$e^{\pm} p$
80.387 ± 0.012 ±0.015	1095k	[11] AALTONEN	12E	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV

80.367 ± 0.013 ±0.022	1677k	[12] ABAZOV	12F	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.401 ± 0.021 ±0.038	500k	[13] ABAZOV	09AB	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
80.413 ± 0.034 ±0.034	115k	[14] AALTONEN	07F	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
82.87 ± 1.82 $^{+0.30}_{-0.16}$	1500	[15] 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	[16] CHEKANOV	02C	ZEUS	$e^- p \rightarrow \nu_e X$, $\sqrt{s}$= 318 GeV
80.433 ± 0.079	53841	[17] AFFOLDER	01E	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
$81.4^{+2.7}_{-2.6} \pm 2.0^{+3.3}_{-3.0}$	1086	[18] BREITWEG	00D	ZEUS	$e^+ p \rightarrow \overline{\nu}_e X$, $\sqrt{s} \approx$ 300 GeV
80.84 ± 0.22 ±0.83	2065	[19] ALITTI	92B	UA2	See W/Z ratio below
80.79 ± 0.31 ±0.84		[20] ALITTI	90B	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV
80.0 ± 3.3 ±2.4	22	[21] ABE	89I	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
82.7 ± 1.0 ±2.7	149	[22] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
81.8 $^{+6.0}_{-5.3}$ ±2.6	46	[23] ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
89 ± 3 ±6	32	[24] 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] AAIJ 22C analyse W production in the muon decay channel, with the transverse momentum of the muon required to be between 28 and 52 GeV. Analysing the distribution of the muon charge divided by the muon transverse momentum of approximately 2.4 million selected W candidates, a value of M_W = 80354 ± 23(stat.)±10(exp.)±17(theo.)±9(PDF) MeV is obtained; we combine the three systematic uncertainties in quadrature.

[2] AALTONEN 22 select a data sample of about 4 million W boson candidates in 8.8 fb^{-1} of Run-II data. The mass is determined using the transverse mass, transverse lepton momentum and transverse missing momentum distributions of W decays into electrons or muons, accounting for correlations. This measurement supersedes AALTONEN 12E, but is not used in OUR EVALUATION.

[3] AABOUD 18J select 4.61M $W^+ \rightarrow \mu^+\nu_\mu$, 3.40M $W^+ \rightarrow e^+\nu_e$, 3.23M $W^- \rightarrow \mu^-\overline{\nu}_\mu$ and 2.49M $W^- \rightarrow e^-\overline{\nu}_e$ events in 4.6 fb^{-1} pp data at 7 TeV. The W mass is determined using the transverse mass and transverse lepton momentum distributions, accounting for correlations. The systematic error includes 0.011 GeV experimental and 0.014 GeV modelling uncertainties.

[4] Combination of results from ABAZOV 12F and ABAZOV 09AB as quoted in ABAZOV 12F.

[5] 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.

[6] 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.

[7] 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).

[8] 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.

[9] 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 ± 0.405 GeV. The value reported here is a combination of this measurement with all previous DØ W-boson mass measurements.

[10] ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic $e^+ p$ and $e^- p$ neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

[11] 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. This measurement is superseded by AALTONEN 22.

[12] 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.

[13] 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.

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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.

[19] 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.

[20] There are two contributions to the systematic error ($\pm$0.84): one ($\pm$0.81) which cancels in m_W/m_Z and one ($\pm$0.21) which is non-cancelling. These were added in quadrature.
[21] ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.
[22] ALBAJAR 89 result is from a total sample of 299 $W \rightarrow e\nu$ events.
[23] ALBAJAR 89 result is from a total sample of 67 $W \rightarrow \mu\nu$ events.
[24] ALBAJAR 89 result is from $W \rightarrow \tau\nu$ events.

W/Z MASS RATIO

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.88136±0.00015		[1] PDG	24		
• • • 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] This value was obtained using the world average values of m_Z and m_W as presented in these listings.
[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 $\pm$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
10.818±0.013	[1] PDG	24		
• • • We do not use the following data for averages, fits, limits, etc. • • •				
10.4 ±1.4 ±0.8	ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV
11.3 ±1.3 ±0.9	ANSARI	87	UA2	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[1] This value was obtained using the world average values of m_Z and m_W as presented in these listings.

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

Test of *CPT* invariance.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
−0.029±0.028 OUR AVERAGE					
−0.029±0.013±0.025	13.7M	[1] AABOUD	18J	ATLS	E^{pp}_{cm} = 7 TeV
−0.19 ±0.58	1722	ABE	90G	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[1] AABOUD 18J select 4.61M $W^+ \rightarrow \mu^+\nu_\mu$, 3.40M $W^+ \rightarrow e^+\nu_e$, 3.23M $W^- \rightarrow \mu^-\overline{\nu}_\mu$ and 2.49M $W^- \rightarrow e^-\overline{\nu}_e$ events in 4.6 fb^{-1} pp data at 7 TeV. The W mass is determined using the transverse mass and transverse lepton momentum distributions, accounting for correlations. The systematic error includes 0.007 GeV experimental and 0.024 GeV modelling uncertainties.

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 $W \to e\nu$ decays.

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

[3] 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.

[4] 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.

[5] 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).

[6] 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.

[7] 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.

[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 ± 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 ± 0.32 ± 0.29. They use m_W=80.23 ± 0.18 GeV, $\sigma(W)/\sigma(Z)$ = 3.35 ± 0.03, $\Gamma(W \to e\nu)$ = 225.9 ± 0.9 MeV, $\Gamma(Z \to e^+e^-)$ = 83.98 ± 0.18 MeV, and $\Gamma(Z)$ = 2.4969 ± 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 ± 0.27 GeV, and m_Z = 91.175 ± 0.021 GeV along with the corresponding value of $\sin^2\theta_W$ = 0.2274. They use $\sigma(W)/\sigma(Z)$ = 3.26 ± 0.07 ± 0.05 and $\Gamma(Z)$ = 2.487 ± 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 ± 0.28 GeV and m_Z = 91.172 ± 0.031 GeV along with $\sin^2\theta_W$ = 0.2322 ± 0.0014. They use $\sigma(W)/\sigma(Z)$ = 3.23 ± 0.05 and $\Gamma(Z)$ = 2.498 ± 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 × 10^{-6}	95%
Γ_7	$D_s^+\gamma$		< 6 × 10^{-4}	95%
Γ_8	cX		(33.3 ± 2.6) %	
Γ_9	$c\bar{s}$		$(31 \; ^{+13}_{-11})$ %	
Γ_{10}	invisible	[b]	(1.4 ± 2.9) %	
Γ_{11}	$\pi^+\pi^+\pi^-$		< 1.01 × 10^{-6}	95%

[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
$30^{+52}_{-48}\pm33$	[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 $W \to e\nu$, $W \to \mu\nu$, and $W \to \tau\nu$, 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($W \to e\nu$), B($W \to \mu\nu$), and B($W \to \tau\nu$). 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 B($W \to \ell\nu$) and the hadronic branching ratio is derived as B($W \to$ hadrons) = 1 −3 B($W \to \ell\nu$). This fit has a χ^2 = 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					
10.89±0.01±0.08		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
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 $R \equiv [\sigma_W \text{B}(W \to \ell\nu_\ell)]/[\sigma_Z \text{B}(Z \to \ell\ell)] = 10.90 \pm 0.52$ 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($Z \to \ell\ell$).

[2] $1216 \pm 38^{+27}_{-31}$ $W \to \mu\nu$ events from ABE 92I and 2426$W \to e\nu$ events of ABE 91C. ABE 92I give the inverse quantity as 9.6 ± 0.7 and we have inverted.

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
10.71±0.16 OUR FIT					
10.83±0.01±0.10		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
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					
10.94±0.01±0.08		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
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

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.002±0.006 OUR AVERAGE					
1.009±0.009		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
1.003±0.010		[1] AABOUD	17Q	ATLS	E^{pp}_{cm}= 7 TeV
0.980±0.018		[2] AAIJ	16AJ	LHCB	E^{pp}_{cm}= 8 TeV
0.993±0.019		SCHAEL	13A	LEP	E^{ee}_{cm}= 130–209 GeV
0.89 ±0.10	13k	[3] ABACHI	95D	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV
1.02 ±0.08	1216	[4] 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] AABOUD 17Q make a precise determination of $W \to e\nu$ and $W \to \mu\nu$ production in the follwoing fiducial phase space: lepton pseudo-rapidity range $|\eta| < 2.5$, lepton and neutrino transverse momenta larger than 25 GeV each, and W transverse mass larger than 25 GeV. They determine the ratio of the W branching fractions $B(W \to e\nu)/B(W \to \mu\nu) = 0.9967 \pm 0.0004 \pm 0.0101 = 0.997 \pm 0.010$.

[2] AAIJ 16AJ make precise measurements of forward $W \to e\nu$ and $W \to \mu\nu$ production in proton-proton collisions at 8 TeV and determine the ratio of the W branching fractions $B(W \to e\nu)/B(W \to \mu\nu) = 1.020 \pm 0.002 \pm 0.019$.

[3] ABACHI 95D obtain this result from the measured σ_WB($W \rightarrow \mu\nu$)= 2.09 ± 0.23 ± 0.11 nb and σ_WB($W \rightarrow e\nu$)= 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.

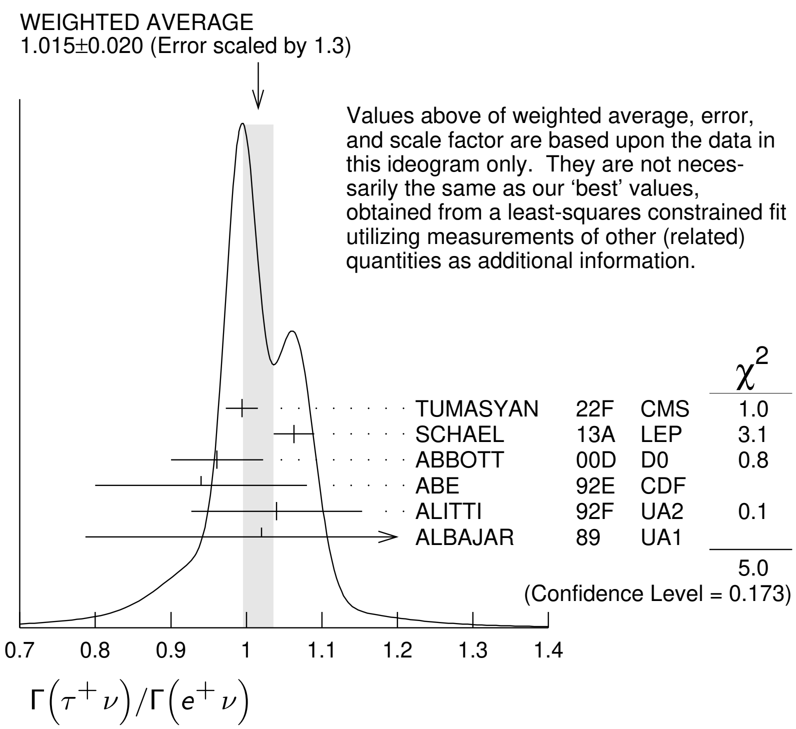
[4] ABE 92I obtain σ_WB($W \rightarrow \mu\nu$)= 2.21 ± 0.07 ± 0.21 and combine with ABE 91C σ_W B(($W \rightarrow e\nu$)) to give a ratio of the couplings from which we derive this measurement.

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
11.38±0.21 OUR FIT					
10.77±0.05±0.21		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
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

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.015±0.020 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.				
0.994±0.021		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
1.063±0.027		SCHAEL	13A	LEP	E^{ee}_{cm}= 130–209 GeV
0.961±0.061	980	[1] ABBOTT	00D	D0	$E^{p\overline{p}}_{\text{cm}}$= 1.8 TeV
0.94 ±0.14	179	[2] ABE	92E	CDF	$E^{p\overline{p}}_{\text{cm}}$= 1.8 TeV
1.04 ±0.08 ±0.08	754	[3] ALITTI	92F	UA2	$E^{p\overline{p}}_{\text{cm}}$= 630 GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89	UA1	$E^{p\overline{p}}_{\text{cm}}$= 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($W \to \tau \nu_\tau$) = 2.22 ± 0.09 ± 0.10 ± 0.10 nb. Using the ABBOTT 00B result $\sigma_W \times$B($W \to e \nu_e$) = 2.31 ± 0.01 ± 0.05 ± 0.10 nb, they quote the ratio of the couplings from which we derive this measurement.

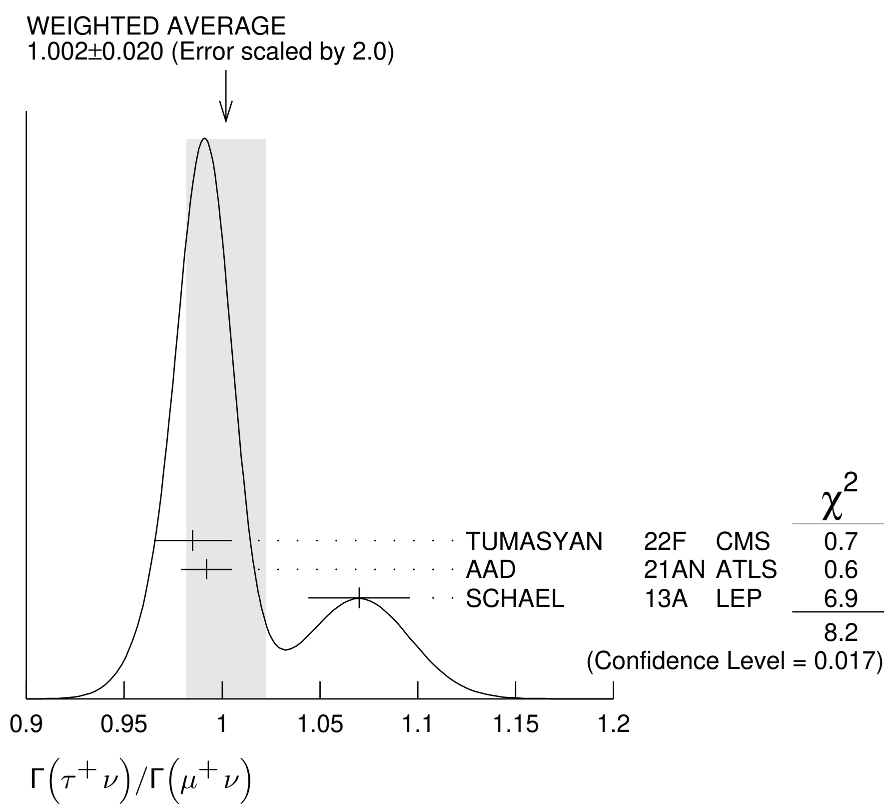
[2] ABE 92E use two procedures for selecting $W \to \tau \nu_\tau$ events. The missing E_T trigger leads to 132 ± 14 ± 8 events and the τ trigger to 47 ± 9 ± 4 events. Proper statistical and systematic correlations are taken into account to arrive at σB($W \to \tau \nu$) = 2.05 ± 0.27 nb. Combined with ABE 91C result on σB($W \to e \nu$), 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
1.002±0.020 OUR AVERAGE	Error includes scale factor of 2.0. See the ideogram below.			
0.985±0.020	TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
0.992±0.007±0.011	[1] AAD	21AN	ATLS	E^{pp}_{cm} = 13 TeV
1.070±0.026	SCHAEL	13A	LEP	E^{ee}_{cm}= 130–209 GeV

[1] AAD 21AN study $t\bar{t}$ production, with the W bosons in top-quark decay decaying to electrons or taus, with the tau decaying further into a muon. Analyzing the muon impact parameter and its transverse momentum, the contributions from prompt muons (arising from W decay) and non-prompt muons (arising from tau decay) are separated, allowing a measurement of the ratio of the W branching fractions into taus and muons, R(τ/μ) = 0.992 ± 0.007 ± 0.011 where the first error is statistical and the second systematic.



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

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

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
67.41±0.27 OUR FIT					
67.32±0.02±0.23		TUMASYAN	22F	CMS	E^{pp}_{cm} = 13 TeV
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

$\Gamma(\pi^+\gamma)/\Gamma_{total}$ — Γ_6/Γ

A stronger limit of $<7 \times 10^{-6}$ is obtained from $\Gamma(W^+ \rightarrow \pi^+\gamma)/\Gamma(W^+ \rightarrow e^+\nu)$ measurements.

VALUE	CL%	DOCUMENT ID		COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<1.50 \times 10^{-5}$	95	[1] SIRUNYAN	21I	E^{pp}_{cm} = 13 TeV

[1] SIRUNYAN 21I search for the rare decay of a W boson into a charged pion accompanied by a photon. A signal is not observed, and an upper limit on the branching fraction $B(W \rightarrow \pi\gamma) < 1.50 \times 10^{-5}$ is obtained at 95% C.L.

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

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<$ 6.4 × 10^{-5}	95	AALTONEN	12W	CDF	$E^{p\overline{p}}_{cm}$= 1.96 Tev
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 7 \times 10^{-4}$	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
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.2 \times 10^{-2}$	95	ABE	98P	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV

$\Gamma(D_s^+\gamma)/\Gamma(\mu^+\nu)$ — Γ_7/Γ_3

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<6.1 \times 10^{-3}$	95	[1] AAIJ	23AM	LHCB	E^{pp}_{cm} = 13 TeV

[1] AAIJ 23AM also quotes the branching fraction limit $B(W^+ \rightarrow D_s^+\gamma) < 6.5 \times 10^{-4}$, using the known $W \rightarrow \mu\nu$ branching fraction.

$\Gamma(cX)/\Gamma(\text{hadrons})$ — 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 $\Gamma(W)$ and B($W \rightarrow$ hadrons), $|V_{cs}|$ is determined to be $0.969 \pm 0.045 \pm 0.036$.
[2] BARATE 99M tag c jets using a neural network algorithm. From this measurement $|V_{cs}|$ is determined to be $1.00 \pm 0.11 \pm 0.07$.

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

VALUE	DOCUMENT ID		TECN	COMMENT
$0.46^{+0.18}_{-0.14} \pm 0.07$	[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 $0.94^{+0.32}_{-0.26} \pm 0.13$.

$\Gamma(\pi^+\pi^+\pi^-)/\Gamma_{\text{total}}$ — Γ_{11}/Γ

VALUE (units 10^{-6})	CL%	DOCUMENT ID		TECN	COMMENT
<1.01	95	[1] SIRUNYAN	19BG	CMS	E^{pp}_{cm} = 13 TeV

[1] SIRUNYAN 19BG search for the rare decay of a W boson into three charged pions. Three pion candidates are required in each event, with transverse momentum larger than 35 GeV, 35 GeV, 18 GeV, respectively, while the transverse momentum of the three-pion system is required to be larger than 40 GeV. Analyzing the three-pion invariant mass, no excess is observed in the W mass region, leading to the 95% C.L. upper limit on the branching fraction.

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 ± 0.12 ± 0.26 when both W bosons decay hadronically and $\langle N_{\text{charged}} \rangle$ = 19.39 ± 0.11 ± 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 ± 0.33 ± 0.36 and 38.11 ± 0.57 ± 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)

Revised April 2017 by M.W. Grünewald (U. College Dublin) and A. Gurtu (Formerly Tata Inst.).

Fourteen independent couplings, seven each for ZWW and γWW, completely describe the VWW vertices within the most general framework of the electroweak Standard Model (SM) consistent with Lorentz invariance and U(1) gauge invariance. Of each of the seven TGCs, three conserve C and P individually, three violate CP, and one violates C and P individually while conserving CP. Assumption of C and P conservation and electromagnetic gauge invariance reduces the number of independent VWW couplings to five: one common set [1,2] is $(\kappa_\gamma, \kappa_Z, \lambda_\gamma, \lambda_Z, g_1^Z)$, where $\kappa_\gamma = \kappa_Z = g_1^Z = 1$ and $\lambda_\gamma = \lambda_Z = 0$ in the Standard Model at tree level. The parameters κ_Z and λ_Z are related to the other three due to constraints of gauge invariance as follows: $\kappa_Z = g_1^Z - (\kappa_\gamma - 1)\tan^2\theta_W$ and $\lambda_Z = \lambda_\gamma$, where θ_W is the weak mixing angle. The W magnetic dipole moment, μ_W, and the W electric quadrupole moment, q_W, are expressed as $\mu_W = e\ (1 + \kappa_\gamma + \lambda_\gamma)/2M_W$ and $q_W = -e\ (\kappa_\gamma - \lambda_\gamma)/M_W^2$.

Precision measurements of suitable observables at LEP1 has already led to an exploration of much of the TGC parameter space. At LEP2, the VWW coupling arises in W-pair production via s-channel exchange, or in single W production via the radiation of a virtual photon off the incident e^+ or e^-. At the Tevatron and the LHC, hard-photon bremsstrahlung off a produced W or Z signals the presence of a triple-gauge vertex. In order to extract the value of one TGC, the others are generally kept fixed to their SM values. While most analyses use the above gauge constraints in the extraction of TGCs, one analysis of W-pair events also determines the real and imaginary parts of all 14 couplings using unconstrained single-parameter fits [3]. The results are consistent. Some experiments have determined limits on the couplings under various non-LEP scenarios and assuming different values of the form factor Λ, where the coupling parameters are scaled by $1/(1 + s/\Lambda^2)^2$. For practical reasons it is not possible to quote all such determinations in the listings. For that the individual papers may be consulted. Recently, EFT-inspired sets of couplings [4,5], such as $c_{WWW}/\Lambda^2, c_W/\Lambda^2, c_B/\Lambda^2$ which are linearly related to the couplings discussed above, are also determined by the LHC experiments.

References

1. K. Hagiwara *et al.*, Nucl. Phys. **B282**, 253 (1987).
2. G. Gounaris *et al.*, CERN 96-01 p. 525.
3. S. Schael *et al.* (ALEPH Collab.), Phys. Lett. **B614**, 7 (2005).
4. K. Hagiwara *et al.*, Phys. Rev. **D48**, 2182 (1993).
5. C. Degrande *et al.*, Annals Phys. 335 (2013) 21-32.

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
$1.001\pm0.027\pm0.013$	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
$0.966^{+0.034}_{-0.032}\pm0.015$	8325	[4] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[5] SIRUNYAN	20BA	CMS	E^{pp}_{cm} = 13 TeV
		[6] SIRUNYAN	19CL	CMS	E^{pp}_{cm} = 13 TeV
		[7] SIRUNYAN	18BZ	CMS	E^{pp}_{cm} = 13 TeV
		[8] AABOUD	17S	ATLS	E^{pp}_{cm} = 7+8 TeV
		[9] AABOUD	17U	ATLS	E^{pp}_{cm} = 8 TeV
		[10] KHACHATRY...	17O	CMS	E^{pp}_{cm} = 8 TeV
		[11] SIRUNYAN	17X	CMS	E^{pp}_{cm} = 8 TeV
		[12] AAD	16AR	ATLS	E^{pp}_{cm} = 8 TeV
		[13] AAD	16P	ATLS	E^{pp}_{cm} = 8 TeV
		[14] AAD	14Y	ATLS	E^{pp}_{cm} = 8 TeV
		[15] AAD	13AL	ATLS	E^{pp}_{cm} = 7 TeV
		[16] CHATRCHYAN	13BF	CMS	E^{pp}_{cm} = 7 TeV
		[17] AAD	12CD	ATLS	E^{pp}_{cm} = 7 TeV
		[18] AALTONEN	12AC	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[19] ABAZOV	12AG	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	34	[20] ABAZOV	11	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	334	[21] AALTONEN	10K	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$1.04\ \pm0.09$		[22] ABAZOV	09AD	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[23] ABAZOV	09AJ	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$1.07\ ^{+0.08}_{-0.12}$	1880	[24] ABDALLAH	08C	DLPH	Superseded by ABDALLAH 10
	13	[25] ABAZOV	07Z	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[26] ABAZOV	05S	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
$0.98\ \pm0.07\ \pm0.01$	2114	[27] ABREU	01I	DLPH	E^{ee}_{cm}= 183+189 GeV
	331	[28] ABBOTT	99I	D0	$E^{p\overline{p}}_{cm}$= 1.8 TeV

[1] ABDALLAH 10 use data on the final states $e^+e^- \to jj\ell\nu$, $jjjj$, 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] SIRUNYAN 20BA study electroweak production of a W boson in association with two jets, using W decays in the electron or muon channel. The isolated muons (electrons) are required to have a transverse momentum larger than 25 (30) GeV, while the transverse momentum of the two jets has to be larger than 50 and 30 GeV. A total of 2.382 (1.051) million events are selected in the muon (electron) channel, with a Standard Model expectation of 2.39 ± 0.17 (1.054 ± 0.058) million events. Analyzing the transverse momentum distribution of the charged leptons from W decay, the following 95% C.L. limit is obtained: $0.971 < g_1^Z < 1.044$. Combining this result with that from the closely-related electroweak Z-jet-jet production SIRUNYAN 18BZ, the limit becomes: $0.979 < g_1^Z < 1.034$.

[6] SIRUNYAN 19CL study WW and WZ production in lepton + jet events, with one W boson decaying leptonically (electron or muon), and another W or Z boson decaying hadronically, reconstructed as a single massive large-radius jet. In the electron channel 2,456 (2,235) events are selected in the $WW(WZ)$ category, while in the muon channel 3,996 (3572) events are selected in the $WW(WZ)$ category. Analysing the di-boson invariant mass distribution, the following 95% C.L. limit is obtained: $0.9939 < g_1^Z < 1.0074$.

[7] SIRUNYAN 18BZ study $pp \to$ *Z jet jet* events at 13 TeV where $Z \to e^+ e^- / \mu^+ \mu^-$. Isolated electrons and muons are selected with p_T of the leading/sub-leading lepton > 30/20 GeV and $|\eta| < 2.4$, with the di-lepton invariant mass within 15 GeV of the Z mass. The two highest p_T jets are selected with p_T of the leading/sub-leading jet > 50/30 GeV respectively and dijet invariant mass > 200 GeV. Templates in the transverse momentum of the Z are utilized to set limits on the triple gauge couplings in the EFT and the LEP parametrizations. The following 95% C.L. limit is obtained: $0.965 < g_1^Z < 1.042$.

[8] AABOUD 17S analyze electroweak production of a W boson in association with two jets at high dijet invariant mass, with the W boson decaying to electron or muon plus neutrino. In the signal region of dijet mass larger than 1 TeV and leading-jet transverse momentum larger than 600 GeV, 30 events are observed in the data with 39 ± 4 events expected in the Standard Model, yielding the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $0.87 < g_1^Z < 1.12$.

[9] AABOUD 17U analyze production of WW or WZ boson pairs with one W boson decaying to electron or muon plus neutrino, and the other W or Z boson decaying hadronically. The hadronic decay system is reconstructed as either a resolved two-jet system or as a single large jet. Analysing the transverse momentum distribution of the hadronic system above 100 GeV yields the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $0.979 < g_1^Z < 1.024$.

[10] KHACHATRYAN 17O analyse WZ production where each boson decays into electrons or muons. Events are required to have a tri-lepton invariant mass larger than 100 GeV, with one of the lepton pairs having an invariant mass within 20 GeV of the Z boson mass. The Z transverse momentum spectrum is analyzed to set a 95% C.L. limit of: $0.982 < g_1^Z < 1.035$.

[11] SIRUNYAN 17X study $pp \to WW/WZ \to \ell \nu q \overline{q}$ production at 8 TeV where ℓ is an electron or muon with $p_T > 30$ or 25 GeV respectively. Suitable cuts are put on the

p_T of the dijet system and the missing E_T of the event yielding a total of 285 and 204 WV events observed in the electron and muon channels. The following 95% C.L. limit is obtained: $0.9913 < g_1^Z < 1.024$.

[12] AAD 16AR study WW production in pp collisions and select 6636 WW candidates in decay modes with electrons or muons with an expected background of 1546 ± 157 events. Assuming the LEP formulation and setting the form-factor Λ to infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $0.984 < g_1^Z < 1.027$.

[13] AAD 16P study WZ production in pp collisions and select 2091 WZ candidates in 4 decay modes with electrons and muons, with an expected background of 1825 ± 7 events. Analyzing the WZ transverse momentum distribution, the resulting 95% C.L. limit is: $0.981 < g_1^Z < 1.029$.

[14] 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 $\Lambda = \infty$.

[15] 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.

[16] 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 $0.905 \leq g_1^Z \leq 1.095$.

[17] 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.

[18] 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.

[19] 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 $g_1^Z = 1.022^{+0.032}_{-0.030}$.

[20] 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.

[21] 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.

[22] ABAZOV 09AD study the $p\overline{p} \rightarrow \ell\nu\,2$jet 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 $0.88 < g_1^Z < 1.20$.

[23] ABAZOV 09AJ study the $p\overline{p} \to 2\ell 2\nu$ 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 $\Lambda = 2$ TeV.

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

[25] 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 $0.86 < g_1^Z < 1.35$.

[26] ABAZOV 05S study $\overline{p}p \to WZ$ 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.

[27] 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 $0.84 < g_1^Z < 1.13$.

[28] ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \to$ dilepton, $WW/WZ \to e\nu jj$, $WW/WZ \to \mu\nu jj$, and $WZ \to$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.63 < g_1^Z < 1.57$, 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
$0.971 \pm 0.055 \pm 0.030$	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
$1.013^{+0.067}_{-0.064} \pm 0.026$	10575	[4] ACHARD	04D	L3	E^{ee}_{cm}= 161–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[5] AABOUD	17U	ATLS	E^{pp}_{cm} = 8 TeV
		[6] SIRUNYAN	17X	CMS	E^{pp}_{cm} = 8 TeV
		[7] CHATRCHYAN	14AB	CMS	E^{pp}_{cm} = 7 TeV
		[8] AAD	13AN	ATLS	E^{pp}_{cm} = 7 TeV
		[9] CHATRCHYAN	13BF	CMS	E^{pp}_{cm} = 7 TeV
		[10] ABAZOV	12AG	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[11] ABAZOV	11AC	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
		[12] CHATRCHYAN	11M	CMS	E^{pp}_{cm} = 7 TeV
	334	[13] AALTONEN	10K	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	53	[14] AARON	09B	H1	E^{ep}_{cm} = 0.3 TeV

$1.07\ {}^{+0.26}_{-0.29}$			[15] ABAZOV	09AD	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
			[16] ABAZOV	09AJ	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
			[17] ABAZOV	08R	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
$0.68\ {}^{+0.17}_{-0.15}$		1880	[18] ABDALLAH	08C	DLPH	Superseded by ABDALLAH 10
		1617	[19] AALTONEN	07L	CDF	$E^{p\overline{p}}_{\rm cm} = 1.96$ GeV
		17	[20] ABAZOV	06H	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
		141	[21] ABAZOV	05J	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
$1.25\ {}^{+0.21}_{-0.20}$	± 0.06	2298	[22] ABREU	01I	DLPH	$E^{ee}_{\rm cm}$= 183+189 GeV
			[23] BREITWEG	00	ZEUS	$e^+ p \rightarrow e^+ W^{\pm} X$, $\sqrt{s} \approx$ 300 GeV
$0.92\ \pm 0.34$		331	[24] 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, 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 $0.73 < \kappa_\gamma < 1.07$.

[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] AABOUD 17U analyze production of WW or WZ boson pairs with one W boson decaying to electron or muon plus neutrino, and the other W or Z boson decaying hadronically. The hadronic decay system is reconstructed as either a resolved two-jet system or as a single large jet. Analysing the transverse momentum distribution of the hadronic system above 100 GeV yields the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \rightarrow \infty$: $0.939 < \kappa_\gamma < 1.064$.

[6] SIRUNYAN 17X study $pp \rightarrow WW/WZ \rightarrow \ell\nu q\overline{q}$ production at 8 TeV where ℓ is an electron or muon with $p_T > 30$ or 25 GeV respectively. Suitable cuts are put on the p_T of the dijet system and the missing E_T of the event yielding a total of 285 and 204 WV events observed in the electron and muon channels. The following 95% C.L. limit is obtained: $0.956 < \kappa_\gamma < 1.063$.

[7] CHATRCHYAN 14AB measure $W\gamma$ production cross section for $p^{\gamma}_T > 15$ 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.

[8] 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.

[9] 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.

[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 $\kappa_\gamma = 1.048^{+0.106}_{-0.105}$.

[11] 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.

[12] 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 $-0.11 < \kappa_\gamma < 2.04$.

[13] 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 $\pm$ 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.

[14] 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 $-3.7 < \kappa_\gamma < -1.5$ or $0.3 < \kappa_\gamma < 1.5$, where the ambiguity is due to the quadratic dependence of the cross section to the coupling parameter.

[15] ABAZOV 09AD study the $p\overline{p} \rightarrow \ell\nu\,2$jet 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 $0.56 < \kappa_\gamma < 1.55$.

[16] 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.

[17] 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.

[18] 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.

[19] 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.

[20] 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 $0.68 < \kappa < 1.45$.

[21] 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.

[22] 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 $0.87 < \kappa_\gamma < 1.68$.

[23] 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).

[24] 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
$-0.012 \pm 0.027 \pm 0.011$	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
$-0.021^{+0.035}_{-0.034} \pm 0.017$	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
$0.05 \pm 0.09 \pm 0.01$	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 Λ = 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 Λ = 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 Λ = 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 Λ = 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
$0.924^{+0.059}_{-0.056}\pm0.024$	7171	[1] ACHARD	04D	L3	E^{ee}_{cm} = 189–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] SIRUNYAN	20BA	CMS	E^{pp}_{cm} = 13 TeV
		[3] SIRUNYAN	19CL	CMS	E^{pp}_{cm} = 13 TeV
		[4] AABOUD	17S	ATLS	E^{pp}_{cm} = 7+8 TeV
		[5] KHACHATRY...	17O	CMS	E^{pp}_{cm} = 8 TeV
		[6] AAD	16AR	ATLS	E^{pp}_{cm} = 8 TeV
		[7] AAD	16P	ATLS	E^{pp}_{cm} = 8 TeV
		[8] AAD	13AL	ATLS	E^{pp}_{cm} = 7 TeV
		[9] AAD	12CD	ATLS	E^{pp}_{cm} = 7 TeV
		[10] AALTONEN	12AC	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	34	[11] ABAZOV	11	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	17	[12] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[13] 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] SIRUNYAN 20BA study electroweak production of a W boson in association with two jets, using W decays in the electron or muon channel. The isolated muons (electrons) are required to have a transverse momentum larger than 25 (30) GeV, while the transverse momentum of the two jets has to be larger than 50 and 30 GeV. A total of 2.382 (1.051) million events are selected in the muon (electron) channel, with a Standard Model expectation of 2.39 ± 0.17 (1.054 ± 0.058) million events. Analysing the transverse momentum distribution of the charged leptons from W decay, the following 95% C.L. limit is obtained: $0.956 < \kappa_Z < 1.044$. Combining this result with that from the closely-related electroweak Z-jet-jet production SIRUNYAN 18BZ, the limit becomes: $0.957 < \kappa_Z < 1.042$.

[3] SIRUNYAN 19CL study WW and WZ production in lepton + jet events, with one W boson decaying leptonically (electron or muon), and another W or Z boson decaying hadronically, reconstructed as a single massive large-radius jet. In the electron channel 2,456 (2,235) events are selected in the $WW(WZ)$ category, while in the muon channel 3,996 (3572) events are selected in the $WW(WZ)$ category. Analysing the di-boson invariant mass distribution, the following 95% C.L. limit is obtained: $0.9921 < \kappa_Z < 1.0082$.

[4] AABOUD 17S analyze electroweak production of a W boson in association with two jets at high dijet invariant mass, with the W boson decaying to electron or muon plus neutrino. In the signal region of dijet mass larger than 1 TeV and leading-jet transverse momentum larger than 600 GeV, 30 events are observed in the data with 39 ± 4 events expected in the Standard Model, yielding the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $0.85 < \kappa_Z < 1.16$.

[5] KHACHATRYAN 17O analyse WZ production where each boson decays into electrons or muons. Events are required to have a tri-lepton invariant mass larger than 100 GeV, with one of the lepton pairs having an invariant mass within 20 GeV of the Z boson mass. The Z transverse momentum spectrum is analyzed to set a 95% C.L. limit of: $0.79 < \kappa_Z < 1.25$.

[6] AAD 16AR study WW production in pp collisions and select 6636 WW candidates in decay modes with electrons or muons with an expected background of 1546 ± 157 events. Assuming the LEP formulation and setting the form-factor Λ to infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $0.975 < \kappa_Z < 1.020$.

[7] AAD 16P study WZ production in pp collisions and select 2091 WZ candidates in 4 decay modes with electrons and muons, with an expected background of 1825 ± 7 events. Analyzing the WZ transverse momentum distribution, the resulting 95% C.L. limit is: $0.81 < \kappa_Z < 1.30$.

[8] 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.

[9] 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.

[10] 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.

[11] ABAZOV 11 study the $p\overline{p} \to 3\ell\nu$ 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.

[12] 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 $0.68 < \kappa < 1.45$.

[13] 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_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
$\mathbf{-0.088^{+0.060}_{-0.057}\pm0.023}$	7171	[1] ACHARD	04D	L3	E^{ee}_{cm} = 189–209 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[2] SIRUNYAN	20BA	CMS	E^{pp}_{cm} = 13 TeV
		[3] SIRUNYAN	19CL	CMS	E^{pp}_{cm} = 13 TeV
		[4] SIRUNYAN	18BZ	CMS	E^{pp}_{cm} = 13 TeV
		[5] AABOUD	17S	ATLS	E^{pp}_{cm} = 7+8 TeV
		[6] AABOUD	17U	ATLS	E^{pp}_{cm} = 8 TeV
		[7] KHACHATRY...	17O	CMS	E^{pp}_{cm} = 8 TeV
		[8] SIRUNYAN	17X	CMS	E^{pp}_{cm} = 8 TeV
		[9] AAD	16AR	ATLS	E^{pp}_{cm} = 8 TeV
		[10] AAD	16P	ATLS	E^{pp}_{cm} = 8 TeV
		[11] AAD	14Y	ATLS	E^{pp}_{cm} = 8 TeV
		[12] AAD	13AL	ATLS	E^{pp}_{cm} = 7 TeV
		[13] CHATRCHYAN	13BF	CMS	E^{pp}_{cm} = 7 TeV
		[14] AAD	12CD	ATLS	E^{pp}_{cm} = 7 TeV
		[15] AALTONEN	12AC	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	34	[16] ABAZOV	11	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	334	[17] AALTONEN	10K	CDF	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	13	[18] ABAZOV	07Z	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	17	[19] ABAZOV	06H	D0	$E^{p\overline{p}}_{cm}$ = 1.96 TeV
	2.3	[20] 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] SIRUNYAN 20BA study electroweak production of a W boson in association with two jets, using W decays in the electron or muon channel. The isolated muons (electrons) are required to have a transverse momentum larger than 25 (30) GeV, while the transverse momentum of the two jets has to be larger than 50 and 30 GeV. A total of 2.382 (1.051) million events are selected in the muon (electron) channel, with a Standard Model expectation of 2.39 ± 0.17 (1.054 ± 0.058) million events. Analysing the transverse momentum distribution of the charged leptons from W decay, the following 95% C.L.

limit is obtained: -0.0088 < λ_Z < 0.0095. Combining this result with that from the closely-related electroweak Z-jet-jet production SIRUNYAN 18BZ, the limit becomes: $-0.0071 < \lambda_Z < 0.0076$.

[3] SIRUNYAN 19CL study WW and WZ production in lepton + jet events, with one W boson decaying leptonically (electron or muon), and another W or Z boson decaying hadronically, reconstructed as a single massive large-radius jet. In the electron channel 2,456 (2,235) events are selected in the $WW(WZ)$ category, while in the muon channel 3,996 (3572) events are selected in the $WW(WZ)$ category. Analysing the di-boson invariant mass distribution, the following 95% C.L. limit is obtained: $-0.0065 < \lambda_Z < 0.0066$.

[4] SIRUNYAN 18BZ study $pp \rightarrow$ *Z jet jet* events at 13 TeV where $Z \rightarrow e^+e^-/\mu^+\mu^-$. Isolated electrons and muons are selected with p_T of the leading/sub-leading lepton > 30/20 GeV and $|\eta| < 2.4$, with the di-lepton invariant mass within 15 GeV of the Z mass. The two highest p_T jets are selected with p_T of the leading/sub-leading jet > 50/30 GeV respectively and dijet invariant mass > 200 GeV. Templates in the transverse momentum of the Z are utilized to set limits on the triple gauge couplings in the EFT and the LEP parametrizations. The following 95% C.L. limit is obtained $-0.010 < \lambda_Z < 0.010$.

[5] AABOUD 17S analyze electroweak production of a W boson in association with two jets at high dijet invariant mass, with the W boson decaying to electron or muon plus neutrino. In the signal region of dijet mass larger than 1 TeV and leading-jet transverse momentum larger than 600 GeV, 30 events are observed in the data with 39 ± 4 events expected in the Standard Model, yielding the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \rightarrow \infty$: $-0.053 < \lambda_Z < 0.042$.

[6] AABOUD 17U analyze production of WW or WZ boson pairs with one W boson decaying to electron or muon plus neutrino, and the other W or Z boson decaying hadronically. The hadronic decay system is reconstructed as either a resolved two-jet system or as a single large jet. Analysing the transverse momentum distribution of the hadronic system above 100 GeV yields the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \rightarrow \infty$: $-0.013 < \lambda_Z < 0.013$.

[7] KHACHATRYAN 17O analyse WZ production where each boson decays into electrons or muons. Events are required to have a tri-lepton invariant mass larger than 100 GeV, with one of the lepton pairs having an invariant mass within 20 GeV of the Z boson mass. The Z transverse momentum spectrum is analyzed to set a 95% C.L. limit of: $-0.018 < \lambda_Z < 0.016$.

[8] SIRUNYAN 17X study $pp \rightarrow WW/WZ \rightarrow \ell\nu q\overline{q}$ production at 8 TeV where ℓ is an electron or muon with $p_T > 30$ or 25 GeV respectively. Suitable cuts are put on the p_T of the dijet system and the missing E_T of the event yielding a total of 285 and 204 WV events observed in the electron and muon channels. The following 95% C.L. limit is obtained: $-0.011 < \lambda_Z < 0.011$.

[9] AAD 16AR study WW production in pp collisions and select 6636 WW candidates in decay modes with electrons or muons with an expected background of 1546 ± 157 events. Assuming the LEP formulation and setting the form-factor Λ to infinity, a fit to the transverse momentum distribution of the leading charged lepton, leads to a 95% C.L. range of $-0.019 < \lambda_Z < 0.019$.

[10] AAD 16P study WZ production in pp collisions and select 2091 WZ candidates in 4 decay modes with electrons and muons, with an expected background of 1825 ± 7 events. Analyzing the WZ transverse momentum distribution, the resulting 95% C.L. limit is: $-0.016 < \lambda_Z < 0.016$.

[11] 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 $\Lambda = \infty$.

[12] 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 $\pm$ 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.

[13] 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 $-0.048 \leq \lambda_Z \leq 0.048$.

[14] 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 $\pm$ 10.0 events. The resulting 95% C.L. range is: $-0.046 < \lambda_Z < 0.047$. Supersedes AAD 12V.

[15] 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 $\pm$ 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.

[16] 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.

[17] 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 $\pm$ 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.

[18] 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 $-0.17 < \lambda_Z < 0.21$.

[19] 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 $-0.29 < \lambda < 0.30$.

[20] 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 $\pm$ 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
$0.00\pm0.13\pm0.05$	7171	[2] ACHARD	04D	L3	E^{ee}_{cm}= 189–209 GeV
$-0.44^{+0.23}_{-0.22}\pm0.12$	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 $Z \to b\overline{b}$ width (Λ=1 TeV is assumed).

g_4^Z

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

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
-0.30 ± 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 $e^+ e^- \to W^+ W^- \to (q q)(\ell \nu)$, 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] AABOUD	17S	ATLS	E^{pp}_{cm} = 7+8 TeV
		[4] 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 $e^+ e^- \to W^+ W^- \to (q q)(\ell \nu)$, 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] AABOUD 17S analyze electroweak production of a W boson in association with two jets at high dijet invariant mass, with the W boson decaying to electron or muon plus neutrino. In the signal region of dijet mass larger than 1 TeV and leading-jet transverse momentum larger than 600 GeV, 30 events are observed in the data with 39 $\pm$ 4 events expected in the Standard Model, yielding the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $-0.56 < \widetilde{\kappa}_Z < 0.56$.

[4] BLINOV 11 use the LEP-average $e^+ e^- \to W^+ W^-$ 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] AABOUD	17S	ATLS	E^{pp}_{cm} = 7+8 TeV
		[4] 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 $e^+ e^- \to W^+ W^- \to (q q)(\ell \nu)$, 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] AABOUD 17S analyze electroweak production of a W boson in association with two jets at high dijet invariant mass, with the W boson decaying to electron or muon plus neutrino. In the signal region of dijet mass larger than 1 TeV and leading-jet transverse momentum larger than 600 GeV, 30 events are observed in the data with 39 ± 4 events expected in the Standard Model, yielding the following limit at 95% CL for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $-0.047 < \widetilde{\lambda}_Z < 0.046$.

[4] BLINOV 11 use the LEP-average $e^+ e^- \to W^+ W^-$ 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 $-e(\kappa - \lambda)/m^2_W$. 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	[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^-, $We\nu_e$, and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV to determine Δg_1^Z, $\Delta\kappa_\gamma$, and λ_γ. $\Delta\kappa_\gamma$ and λ_γ are simultaneously floated in the fit to determine μ_W.

[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/Λ^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 $WW\gamma$. Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV.

c_{WWW}/Λ^2, c_W/Λ^2, c_B/Λ^2

These couplings are used in EFT-based approaches to anomalous couplings. They are linearly related to the couplings discussed above.

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] TUMASYAN	22AB	CMS	$E^{pp}_{cm} = 13$ TeV
	[2] TUMASYAN	22E	CMS	$E^{pp}_{cm} = 13$ TeV
	[3] AAD	21AC	ATLS	$E^{pp}_{cm} = 13$ TeV
	[4] AAD	21W	ATLS	$E^{pp}_{cm} = 13$ TeV
	[5] SIRUNYAN	21G	CMS	$E^{pp}_{cm} = 13$ TeV
	[6] SIRUNYAN	20BA	CMS	$E^{pp}_{cm} = 13$ TeV
	[7] SIRUNYAN	20BF	CMS	$E^{pp}_{cm} = 13$ TeV
	[8] AABOUD	19BA	ATLS	$E^{pp}_{cm} = 13$ TeV
	[9] SIRUNYAN	19AD	CMS	$E^{pp}_{cm} = 13$ TeV
	[10] SIRUNYAN	19CL	CMS	$E^{pp}_{cm} = 13$ TeV
	[11] AABOUD	18Q	ATLS	$E^{pp}_{cm} = 13$ TeV
	[12] SIRUNYAN	18BZ	CMS	$E^{pp}_{cm} = 13$ TeV

[13] AABOUD	17S	ATLS	$E^{pp}_{\rm cm}$ = 7+8 TeV
[14] AABOUD	17U	ATLS	$E^{pp}_{\rm cm}$ = 8 TeV
[15] KHACHATRY...	17O	CMS	$E^{pp}_{\rm cm}$ = 8 TeV
[16] SIRUNYAN	17X	CMS	$E^{pp}_{\rm cm}$ = 8 TeV
[17] AAD	16AR	ATLS	$E^{pp}_{\rm cm}$ = 8 TeV
[18] AAD	16P	ATLS	$E^{pp}_{\rm cm}$ = 8 TeV
[19] KHACHATRY...	16BI	CMS	$E^{pp}_{\rm cm}$ = 8 TeV

[1] TUMASYAN 22AB study WZ production, measuring cross sections and various distributions. Analysing the WZ invariant mass distribution, the following 95% C.L. limits are derived in units of TeV^{-2}: $-2.5 < c_W/\Lambda^2 < 0.3$, $-1.0 < c_{WWW}/\Lambda^2 < 1.2$, $-43 < c_b/\Lambda^2 < 113$, $-0.62 < \widetilde{c}_{WWW}/\Lambda^2 < 0.53$, $-32 < \widetilde{c}_W/\Lambda^2 < 32$.

[2] TUMASYAN 22E measure $W\gamma$ production where the W boson decays to electrons or muons. Analysing the photon transverse momentum distribution in bins of lepton azimuth, the following 95% C.L. limit is derived in units of TeV^{-2}: $-0.062 < c_{3W}/\Lambda^2 < 0.052$. This limit is derived including the non-SM, SM and their interference effects.

[3] AAD 21AC study the differential cross-section for the electroweak production of dijets in association with a Z boson, where the Z boson decays to electrons or muons. The number of events selected in the data is 10,870 (12,125) in the electron (muon) channel. Analyzing the distribution of the azimuthal separation of the two jets, the following 95% C.L. limits are derived in units of TeV^{-2}: $-2.7 < c_{WWW}/\Lambda^2 < 5.8$, $-1.6 < \widetilde{c}_{WWW}/\Lambda^2 < 2.0$, $-0.19 < c_W/\Lambda^2 < 0.41$, $-0.11 < \widetilde{c}_W/\Lambda^2 < 0.14$, $-6.31 < c_{HWB}/\Lambda^2 < 1.01$, $0.23 < \widetilde{c}_{HWB}/\Lambda^2 < 2.35$.

[4] AAD 21W analyze W^+W^- production in association with at least one jet. Events with exactly one oppositely-charged electron-muon pair and at least one hadronic jet of transverse momentum larger than 30 GeV (120 GeV) are selected. In the data, 89,239 (5,825) events are found, with a total Standard-Model expectation of 91600 ± 2500 (5980 ± 150). Analyzing the electron-muon invariant mass distribution, the following limit at 95% C.L. is obtained: $-0.33 < c_W/\Lambda^2 < 0.33$ ($-0.60 < c_W/\Lambda^2 < 0.58$), for a fixed choice of $\Lambda = 1$ TeV.

[5] SIRUNYAN 21G measure $W\gamma$ production where the W decays into electrons or muons. In the data, 385,224 (395,818) events are selected in the electron (muon) channel, with a total Standard-Model expectation of 396913±54686 (396257±22837) events. Analysing the photon transverse momentum distribution, the following 95% C.L. limits are derived in units of TeV^{-2}: $-0.90 < c_{WWW}/\Lambda^2 < 0.91$, $-40 < c_B/\Lambda^2 < 41$, $-0.45 < c_{\overline{W}WW}/\Lambda^2 < 0.45$, $-20 < c_{\overline{W}}/\Lambda^2 < 20$.

[6] SIRUNYAN 20BA study electroweak production of a W boson in association with two jets, using W decays in the electron or muon channel. The isolated muons (electrons) are required to have a transverse momentum larger than 25 (30) GeV, while the transverse momentum of the two jets has to be larger than 50 and 30 GeV. A total of 2.382 (1.051) million events are selected in the muon (electron) channel, with a Standard Model expectation of 2.39±0.17 (1.054±0.058) million events. Analysing the transverse momentum distribution of the charged leptons from W decay, the following 95% C.L. limits are obtained in units of TeV^{-2}: $-2.3 < c_{WWW}/\Lambda^2 < 2.5$, $-8.8 < c_W/\Lambda^2 < 16$, $-45 < c_B/\Lambda^2 < 46$. Combining these results with those from the closely-related electroweak Z-jet-jet production SIRUNYAN 18BZ, the limits become: $-1.8 < c_{WWW}/\Lambda^2 < 2.0$, $-5.8 < c_W/\Lambda^2 < 10$, $-43 < c_B/\Lambda^2 < 45$.

[7] SIRUNYAN 20BF study W^+W^- production with the W bosons decaying to electrons or muons. The leading (subleading) lepton is required to have a transverse momentum larger than 25 (20) GeV. Events with a same-flavor di-lepton invariant mass within 15 GeV of the Z mass are rejected, as are event with a third lepton of transverse momentum larger than 10 GeV. In the same- (different-) flavor category a total of 9,604 (20,270) events are

selected while the number of expected events is 9640 ± 490 (20280 ± 430). Analyzing the different-flavor di-lepton invariant mass distribution, the following 95% C.L. limits are obtained in units of TeV^{-2}: $-1.8 < c_{WWW}/\Lambda^2 < 1.8$, $-3.6 < c_W/\Lambda^2 < 2.8$, $-9.4 < c_B/\Lambda^2 < 8.5$.

[8] AABOUD 19BA study WW production in decay modes with an electron and a muon. The charged leptons are each required to have a transverse momentum larger than 27 GeV and rapidity less than 2.5. The electron-muon system is required to have a mass larger than 55 GeV and a transverse momentum larger than 30 GeV. The missing transverse energy must be larger than 20 GeV. Events containing a jet with transverse momentum exceeding 35 GeV and rapidity smaller than 4.5 are rejected. A total of 12,659 events are selected in the data, with an expected background of 4240 ± 477 events. Analysing the transverse momentum spectrum of the leading charged lepton, the following 95% C.L. limits are derived in units of TeV^{-2}: $-3.4 < c_{WWW}/\Lambda^2 < 3.3$, $-7.4 < c_W/\Lambda^2 < 4.1$, $-21 < c_B/\Lambda^2 < 18$, $-1.6 < c_{\overline{W}WW}/\Lambda^2 < 1.6$, $-76 < c_{\overline{W}}/\Lambda^2 < 76$.

[9] SIRUNYAN 19AD study inclusive WZ production, with W and Z decaying to electrons or muons. The leading (subleading) charged lepton candidate from the Z boson decay is required to have a transverse momentum larger than 25 GeV (10 GeV). The charged lepton candidate from the W boson decay is required to have a transverse momentum larger than 25 GeV. The invariant mass of the two leptons from Z decay is required to be within 15 GeV of the Z mass, while the invariant mass of the tri-lepton system is required to exceed 100 GeV. A total of 3,831 tri-lepton events are observed, with a fitted SM WZ signal of 3166 ± 62 events and a fitted background of 666 ± 45 events. The approximated WZ invariant mass distribution is analyzed to set 95% C.L. limits as follows: $-4.1 < c_W/\Lambda^2 < 1.1$, $-2.0 < c_{WWW}/\Lambda^2 < 2.1$, $-100 < c_B/\Lambda^2 < 160$, in units of TeV^{-2}.

[10] SIRUNYAN 19CL study WW and WZ production in lepton + jet events, with one W boson decaying leptonically (electron or muon), and another W or Z boson decaying hadronically, reconstructed as a single massive large-radius jet. In the electron channel 2,456 (2,235) events are selected in the $WW(WZ)$ category, while in the muon channel 3,996 (3572) events are selected in the $WW(WZ)$ category. Analysing the di-boson invariant mass distribution, the following 95% C.L. limits are obtained in units of TeV^{-2}: $-1.58 < c_{WWW}/\Lambda^2 < 1.59$, $-2.00 < c_W/\Lambda^2 < 2.65$, $-8.78 < c_B/\Lambda^2 < 8.54$.

[11] AABOUD 18Q study $pp \rightarrow ZZ$ events at $\sqrt{s} = 13$ TeV with $Z \rightarrow e^+e^-$ or $Z \rightarrow \mu^+\mu^-$. The number of events observed in the 4e, 2e 2μ, and 4μ channels is 249, 465, and 303 respectively. Analysing the p_T spectrum of the leading Z boson, the following the following 95% C.L. limits are derived in units of TeV^{-4}: $-5.9 < c_{\widetilde{B}W}/\Lambda^4 < 5.9$, $-3.0 < c_{WW}/\Lambda^4 < 3.0$, $-3.3 < c_{BW}/\Lambda^4 < 3.3$, $-2.7 < c_{BB}/\Lambda^4 < 2.8$.

[12] SIRUNYAN 18BZ study $pp \rightarrow Z\,jet\,jet$ events at 13 TeV where $Z \rightarrow e^+e^-/\mu^+\mu^-$. Isolated electrons and muons are selected with p_T of the leading/sub-leading lepton > 30/20 GeV and $|\eta| < 2.4$, with the di-lepton invariant mass within 15 GeV of the Z mass. The two highest p_T jets are selected with p_T of the leading/sub-leading jet > 50/30 GeV respectively and dijet invariant mass > 200 GeV. Templates in the transverse momentum of the Z are utilized to set limits on the triple gauge couplings in the EFT and the LEP parametrizations. The following 95% C.L. limits are obtained in units of TeV^{-2}: $-2.6 < c_{WWW}/\Lambda^2 < 2.6$ and $-8.4 < c_W/\Lambda^2 < 10.1$.

[13] AABOUD 17S analyze electroweak production of a W boson in association with two jets at high dijet invariant mass, with the W boson decaying to electron or muon plus neutrino. In the signal region of dijet mass larger than 1 TeV and leading-jet transverse momentum larger than 600 GeV, 30 events are observed in the data with 39 ± 4 events expected in the Standard Model, yielding the following limits at 95% CL for the form factor cut-off scale $\Lambda_{FF} \rightarrow \infty$: $-33 < c_W/\Lambda^2 < 30$, $-170 < c_B/\Lambda^2 < 160$,

$-13 < c_{WWW}/\Lambda^2 < 9$, $-580 < c_{\widetilde{W}}/\Lambda^2 < 580$, $-11 < c_{\widetilde{W}WW}/\Lambda^2 < 11$, in units of TeV^{-2}.

[14] AABOUD 17U analyze production of WW or WZ boson pairs with one W boson decaying to electron or muon plus neutrino, and the other W or Z boson decaying hadronically. The hadronic decay system is reconstructed as either a resolved two-jet system or as a single large jet. Analysing the transverse momentum distribution of the hadronic system above 100 GeV yields the following limits at 95% CL for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $-3.1 < c_{WWW}/\Lambda^2 < 3.1$, $-19 < c_B/\Lambda^2 < 20$, $-5.1 < c_W/\Lambda^2 < 5.8$, in units of TeV^{-2}.

[15] KHACHATRYAN 17O analyse WZ production where each boson decays into electrons or muons. Events are required to have a tri-lepton invariant mass larger than 100 GeV, with one of the lepton pairs having an invariant mass within 20 GeV of the Z boson mass. The Z transverse momentum spectrum is analyzed to set 95% C.L. limits of: $-260 < c_B/\Lambda^2 < 210$, $-4.2 < c_W/\Lambda^2 < 8.0$, $-4.6 < c_{WWW}/\Lambda^2 < 4.2$, in units of TeV^{-2}.

[16] SIRUNYAN 17X study $pp \to WW/WZ \to \ell\nu q\overline{q}$ production at 8 TeV where ℓ is an electron or muon with $p_T > 30$ or 25 GeV respectively. Suitable cuts are put on the p_T of the dijet system and the missing E_T of the event yielding a total of 285 and 204 WV events observed in the electron and muon channels. The following 95% C.L. limits in units of TeV^{-2} are obtained: $-2.7 < c_{WWW}/\Lambda^2 < 2.7$, $-14 < c_B/\Lambda^2 < 17$, $-2.0 < c_W/\Lambda^2 < 5.7$.

[17] AAD 16AR study WW production in pp collisions and select 6636 WW candidates in decay modes with electrons or muons with an expected background of 1546 $\pm$ 157 events. Assuming an EFT formulation, a fit to the transverse momentum distribution of the leading charged lepton, leads to 95% C.L. ranges of: $-4.61 < c_{WWW}/\Lambda^2 < 4.60$, $-5.87 < c_W/\Lambda^2 < 10.54$ and $-20.9 < c_B/\Lambda^2 < 26.3$,in units of TeV^{-2}.

[18] AAD 16P study WZ production in pp collisions and select 2091 WZ candidates in 4 decay modes with electrons and muons, with an expected background of 1825 ± 7 events. Analyzing the WZ transverse momentum distribution, the resulting 95% C.L. limits are: $-3.9 < c_{WWW}/\Lambda^2 < 4.0$, $-4.3 < c_W/\Lambda^2 < 6.8$, and $-320 < c_B/\Lambda^2 < 210$, in units of TeV^{-2}.

[19] KHACHATRYAN 16BI determine the W^+W^- production cross section using unlike sign di-lepton (e or μ) events with high p_T. The leptons have $p_T > 20$ GeV/c and are isolated. Events are required to have no jets above p_T of 30 GeV/c. 4847 (2233) events are selected with different (same) flavor leptons, with an expected total background of 1179 $\pm$ 123 (643 $\pm$ 73) events. Analysing the di-lepton invariant mass spectrum, the following values are obtained: $c_{WWW}/\Lambda^2 = 0.1 \pm 3.2$, $c_W/\Lambda^2 = -3.6^{+5.0}_{-4.5}$ and $c_B/\Lambda^2 = -3.2^{+15.0}_{-14.5}$, in units of TeV^{-2}. The limits at 95% C.L. are: $-5.7 < c_{WWW}/\Lambda^2 < 5.9$, $-11.4 < c_W/\Lambda^2 < 5.4$ and $-29.2 < c_B/\Lambda^2 < 23.9$, in units of TeV^{-2}.

ANOMALOUS W/Z QUARTIC COUPLINGS

Revised March 2024 by M.W. Grünewald (U. College Dublin) and A. Gurtu (CERN; TIFR Mumbay).

Quartic couplings, $WWZZ$, $WWZ\gamma$, $WW\gamma\gamma$, and $ZZ\gamma\gamma$, were studied at LEP and Tevatron at energies at which the Standard Model predicts negligible contributions to multiboson production. Thus, to parametrize limits on these couplings, an effective theory approach is adopted which supplements the Standard Model Lagrangian with higher dimensional operators which include quartic couplings. The LEP collaborations chose the lowest dimensional representation of operators (dimension 6) which presumes the SU(2)×U(1) gauge symmetry is broken by means other than the conventional Higgs scalar doublet [1–3]. In this representation possible quartic couplings, a_0, a_c, a_n, are expressed in terms of the following dimension-6 operators [1,2];

$$L_6^0 = -\frac{e^2}{16\Lambda^2}\, a_0\, F^{\mu\nu}\, F_{\mu\nu}\vec{W}^{\alpha}\cdot\vec{W}_{\alpha}$$
$$L_6^c = -\frac{e^2}{16\Lambda^2}\, a_c\, F^{\mu\alpha}\, F_{\mu\beta}\vec{W}^{\beta}\cdot\vec{W}_{\alpha}$$
$$L_6^n = -i\frac{e^2}{16\Lambda^2}\, a_n\epsilon_{ijk}\, W^{(i)}_{\mu\alpha}\, W^{(j)}_{\nu}\, W^{(k)\alpha}F^{\mu\nu}$$
$$\widetilde{L}_6^0 = -\frac{e^2}{16\Lambda^2}\, \widetilde{a}_0\, F^{\mu\nu}\, \widetilde{F}_{\mu\nu}\vec{W}^{\alpha}\cdot\vec{W}_{\alpha}$$
$$\widetilde{L}_6^n = -i\frac{e^2}{16\Lambda^2}\, \widetilde{a}_n\epsilon_{ijk}\, W^{(i)}_{\mu\alpha}\, W^{(j)}_{\nu}\, W^{(k)\alpha}\widetilde{F}^{\mu\nu}$$

where F, W are photon and W fields, L_6^0 and L_6^c conserve C, P separately ($\widetilde{L}_6^0$ conserves only C) and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, L_6^n violates CP ($\widetilde{L}_6^n$ violates both C and P) and generates an anomalous $W^+W^-Z\gamma$ coupling, and Λ is an energy scale for new physics. For the $ZZ\gamma\gamma$ coupling the CP-violating term represented by L_6^n does not contribute. These couplings are assumed to be real and to vanish at tree level in the Standard Model.

Within the same framework as above, a more recent description of the quartic couplings [3] treats the anomalous parts of the $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings separately, leading to two sets parametrized as a_0^V/Λ^2 and a_c^V/Λ^2, where $V = W$ or Z.

With the discovery of a Higgs at the LHC in 2012, it is then useful to go to the next higher dimensional representation (dimension 8 operators) in which the gauge symmetry is broken by the conventional Higgs scalar doublet [3,4]. There are 14 operators which can contribute to the anomalous quartic coupling signal. Some of the operators have analogues in the dimension 6 scheme. The CMS collaboration, [5], have used this parametrization, in which the connections between the two schemes are also summarized:

$$\begin{aligned}\mathcal{L}_{AQGC} = &- \frac{e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+a}W_a^- \\ &- \frac{e^2}{16}\frac{a_c^W}{\Lambda^2}F_{\mu\nu}F^{\mu a}(W^{+\nu}W_a^- + W^{-\nu}W_a^+) \\ &- e^2g^2\frac{\kappa_0^W}{\Lambda^2}F_{\mu\nu}Z^{\mu\nu}W^{+a}W_a^- \\ &- \frac{e^2g^2}{2}\frac{\kappa_c^W}{\Lambda^2}F_{\mu\nu}Z^{\mu a}(W^{+\nu}W_a^- + W^{-\nu}W_a^+) \\ &+ \frac{f_{T,0}}{\Lambda^4}Tr[\widehat{W}_{\mu\nu}\widehat{W}^{\mu\nu}] \times Tr[\widehat{W}_{\alpha\beta}\widehat{W}^{\alpha\beta}]\end{aligned}$$

The energy scale of possible new physics is Λ, and $g = e/sin(\theta_W)$, e being the unit electric charge and θ_W the Weinberg angle. The field tensors are described in [3,4].

The two dimension 6 operators a_0^W/Λ^2 and a_c^W/Λ^2 are associated with the $WW\gamma\gamma$ vertex. Among dimension 8 operators, κ_0^W/Λ^2 and κ_c^W/Λ^2 are associated with the $WWZ\gamma$ vertex, whereas the parameter $f_{T,0}/\Lambda^4$ contributes to both vertices. There is a relationship between these two dimension 6 parameters and the dimension 8 parameters $f_{M,i}/\Lambda^4$ as follows [3]:

$$\frac{a_0^W}{\Lambda^2} = -\frac{4M_W^2}{g^2}\frac{f_{M,0}}{\Lambda^4} - \frac{8M_W^2}{g'^2}\frac{f_{M,2}}{\Lambda^4}$$

$$\frac{a_c^W}{\Lambda^2} = -\frac{4M_W^2}{g^2}\frac{f_{M,1}}{\Lambda^4} - \frac{8M_W^2}{g'^2}\frac{f_{M,3}}{\Lambda^4}$$

where $g' = e/cos(\theta_W)$ and M_W is the invariant mass of the W boson. This relation provides a translation between limits on dimension 6 operators $a_{0,c}^W$ and $f_{M,j}/\Lambda^4$. It is further required [4] that $f_{M,0} = 2f_{M,2}$ and $f_{M,1} = 2f_{M,3}$ which suppresses contributions to the $WWZ\gamma$ vertex. The complete set of Lagrangian contributions as presented in [4] corresponds to 19 anomalous couplings in total – $f_{S,i},\ \ i = 1, 2,\ f_{M,i},\ \ i = 0, \ldots, 8$ and $f_{T,i}, i = 0, \ldots, 9$ – each scaled by $1/\Lambda^4$.

Another approach to couplings is the so called K-matrix framework [7], in which the anomalous couplings can be expressed in terms of two parameters α_4 and α_5, which account for all BSM effects.

The LHC collaborations have published couplings results based on various theoretical frameworks. It is hoped that the collaborations will agree to use at least one common set of parameters to express these limits to enable the reader to make a comparison, and to allow for a possible LHC combination.

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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.

Some publications from LHC experiments derive limits for various assumed values of the form-factor cutoff Λ_{FF}. The values quoted below are for $\Lambda_{FF} \to \infty$.

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] AAD	24C	ATLS	$E^{pp}_{cm} = 13$ TeV
	[2] AAD	23BH	ATLS	$E^{pp}_{cm} = 13$ TeV
	[3] AAD	23K	ATLS	$E^{pp}_{cm} = 13$ TeV
	[4] TUMASYAN	23AK	CMS	$E^{pp}_{cm} = 13$ TeV
	[5] TUMASYAN	23AM	CMS	$E^{pp}_{cm} = 13$ TeV
	[6] SIRUNYAN	21	CMS	$E^{pp}_{cm} = 13$ TeV
	[7] TUMASYAN	21A	CMS	$E^{pp}_{cm} = 13$ TeV
	[8] TUMASYAN	21B	CMS	$E^{pp}_{cm} = 13$ TeV
	[9] SIRUNAYN	20	CMS	$E^{pp}_{cm} = 13$ TeV
	[10] SIRUNYAN	20AL	CMS	$E^{pp}_{cm} = 13$ TeV
	[11] SIRUNYAN	20BD	CMS	$E^{pp}_{cm} = 13$ TeV
	[12] SIRUNYAN	19BM	CMS	$E^{pp}_{cm} = 13$ TeV
	[13] SIRUNYAN	19BP	CMS	$E^{pp}_{cm} = 13$ TeV
	[14] SIRUNYAN	19CQ	CMS	$E^{pp}_{cm} = 13$ TeV
	[15] SIRUNYAN	18CC	CMS	$E^{pp}_{cm} = 13$ TeV
	[16] AABOUD	17AA	ATLS	$E^{pp}_{cm} = 8$ TeV
	[17] AABOUD	17AG	ATLS	$E^{pp}_{cm} = 8$ TeV
	[18] AABOUD	17D	ATLS	$E^{pp}_{cm} = 8$ TeV
	[19] AABOUD	17J	ATLS	$E^{pp}_{cm} = 8$ TeV
	[20] AABOUD	17M	ATLS	$E^{pp}_{cm} = 8$ TeV
	[21] KHACHATRY...	17AA	CMS	$E^{pp}_{cm} = 8$ TeV
	[22] KHACHATRY...	17M	CMS	$E^{pp}_{cm} = 8$ TeV
	[23] SIRUNYAN	17AD	CMS	$E^{pp}_{cm} = 13$ TeV
	[24] SIRUNYAN	17AR	CMS	$E^{pp}_{cm} = 8$ TeV
	[25] AABOUD	16E	ATLS	$E^{pp}_{cm} = 8$ TeV
	[26] AAD	16Q	ATLS	$E^{pp}_{cm} = 8$ TeV
	[27] KHACHATRY...	16AX	CMS	$E^{pp}_{cm} = 8$ TeV

[28] AAD	15N	ATLS	$E^{pp}_{\rm cm} = 8$ TeV
[29] KHACHATRY...	15D	CMS	$E^{pp}_{\rm cm} = 8$ TeV
[30] AAD	14AM	ATLS	
[31] CHATRCHYAN	14Q	CMS	
[32] ABAZOV	13D	D0	
[33] CHATRCHYAN	13AA	CMS	
[34] ABBIENDI	04B	OPAL	
[35] ABBIENDI	04L	OPAL	
[36] HEISTER	04A	ALEP	
[37] ABDALLAH	03I	DLPH	
[38] ACHARD	02F	L3	

[1] AAD 24C study the production of four charged leptons (electrons or muons) in association with two jets. Analysing the 4-lepton invariant mass distribution and the di-jet invarinat mass distribution leads to the following 95% C.L. limits: $-0.98 < f_{T,0}/\Lambda^4 < 0.93$, $-1.2 < f_{T,1}/\Lambda^4 < 1.2$, $-2.5 < f_{T,2}/\Lambda^4 < 2.4$, $-2.5 < f_{T,5}/\Lambda^4 < 2.4$, $-3.9 < f_{T,6}/\Lambda^4 < 3.9$, $-8.5 < f_{T,7}/\Lambda^4 < 8.1$, $-2.1 < f_{T,8}/\Lambda^4 < 2.1$, $-4.5 < f_{T,9}/\Lambda^4 < 4.5$, in units of TeV^{-4}. The article also reports limits on these couplings by cutting the EFT expansion at various values of the cut-off scale.

[2] AAD 23BH study $pp \to Z\gamma\gamma$ events with the Z boson decaying to electron or muon pairs. The number of observed data events is 148 for the electron mode and 171 for the muon mode. The respective number of (data-background) events is 105.5 ± 12.2(stat)± 8.1(syst) and 120.4 ± 13.1(stat)± 9.4(syst). The corresponding number of predicted signal events is 91.5 ± 0.9 and 119.5 ± 1.0 using SHERPA (NLO), and 91.0 ± 1.0 and 118.1 ± 1.2 using MADGRAPH 5 AMC (NLO), where the error is statistical only. Analysing the transverse momentum distribution of the dilepton system, the following 95% C.L. limits are derived: $-9.87 < f_{T,0}/\Lambda^4 < 9.33$, $-9.88 < f_{T,1}/\Lambda^4 < 9.34$, $-20.31 < f_{T,2}/\Lambda^4 < 18.68$, $-4.64 < f_{T,5}/\Lambda^4 < 4.54$, $-7.04 < f_{T,6}/\Lambda^4 < 6.94$, $-15.55 < f_{T,7}/\Lambda^4 < 15.04$, $-1.64 < f_{T,8}/\Lambda^4 < 1.61$, $-3.26 < f_{T,9}/\Lambda^4 < 3.26$, in units of TeV^{-4}.

[3] AAD 23K measure Z production in association with a photon and two jets in proton-proton collisions at 13 TeV CM energy, where the Z boson decays into neutrinos. Within a sensitive fiducial phase-space region, 356 signal events are selected, with an expectation of 357 ± 30. Analysing the photon transverse energy distribution, the following 95% C.L. limits are derived in units of TeV^{-4}: $-0.094 < f_{T,0}/\Lambda^4 < 0.084$, $-0.088 < f_{T,5}/\Lambda^4 < 0.099$, $-0.059 < f_{T,8}/\Lambda^4 < 0.059$, $-0.13 < f_{T,9}/\Lambda^4 < 0.13$, $-4.6 < f_{M,0}/\Lambda^4 < 4.6$, $-7.7 < f_{M,1}/\Lambda^4 < 7.7$, $-1.9 < f_{M,2}/\Lambda^4 < 1.9$.

[4] TUMASYAN 23AK study electroweak $W\gamma$ production in association with 2 jets. The events selected for the couplings analysis are required to have a dijet invariant mass in excess of 800 GeV, jet-jet separation of at least 2.5 in rapidity, invariant mass of the $W\gamma$ system larger than 150 GeV and transverse photon momentum larger than 100 GeV. Analysing the $W\gamma$ invariant mass distribution, varying one coupling at a time while fixing the others to their Standard Model value, leads to the following 95% C.L. limits: $-5.6 < f_{M,0}/\Lambda^4 < 5.5$, $-7.8 < f_{M,1}/\Lambda^4 < 8.1$, $-1.9 < f_{M,2}/\Lambda^4 < 1.9$, $-2.7 < f_{M,3}/\Lambda^4 < 2.7$, $-3.7 < f_{M,4}/\Lambda^4 < 3.6$, $-3.9 < f_{M,5}/\Lambda^4 < 3.9$, $-14 < f_{M,7}/\Lambda^4 < 14$, $-0.47 < f_{T,0}/\Lambda^4 < 0.51$, $-0.31 < f_{T,1}/\Lambda^4 < 0.34$, $-0.85 < f_{T,2}/\Lambda^4 < 1.0$, $-0.31 < f_{T,5}/\Lambda^4 < 0.33$, $-0.25 < f_{T,6}/\Lambda^4 < 0.27$, $-0.67 < f_{T,7}/\Lambda^4 < 0.73$, in units of TeV^{-4}.

[5] TUMASYAN 23AM use the combined CMS-TOTEM detector system to study exclusive $\gamma\gamma \to WW$ and $\gamma\gamma \to ZZ$ production in pp collisions at 13 TeV. The W and Z are identified through their hadronic decays with the added requirements of the invariant mass of the di-boson pair to be larger than 1 TeV, and the relative beam proton momentum loss between 0.04 and 0.20. The following limits are obtained at 95% C.L.: (i) on the dimension-6 (LEP like) couplings, in units of GeV^{-2}: $|a_0^W/\Lambda^2| < 4.3 \times 10^{-6}$, $|a_C^W/\Lambda^2| < 1.6 \times 10^{-5}$, $|a_0^Z/\Lambda^2| < 0.9 \times 10^{-5}$, $|a_C^Z/\Lambda^2| < 4.0 \times 10^{-5}$. (ii) on the dimension-8 operators, in units of TeV^{-4}: $|f_{M,0}/\Lambda^4| < 66.0$, $|f_{M,1}/\Lambda^4| < 245.5$, $|f_{M,2}/\Lambda^4| < 9.8$, $|f_{M,3}/\Lambda^4| < 73.0$, $|f_{M,4}/\Lambda^4| < 36.0$, $|f_{M,5}/\Lambda^4| < 67.0$, $|f_{M,7}/\Lambda^4| < 490.9$.

[6] SIRUNYAN 21 study electroweak Z-pair production in association with two jets, with the Z bosons decaying to oppositely-charged electron or muon pairs. Leptons with high transverse momentum are selected, with the di-lepton invariant mass of the two Z boson candidates between 60 GeV and 120 GeV, and the four-lepton invariant mass larger than 180 GeV. A total of 365 events are selected in the data, while the number of expected events is 370 ± 48. Analyzing the four-lepton invariant mass distribution, the following 95% C.L. limits are derived: $-0.24 < f_{T,0}/\Lambda^4 < 0.22$, $-0.31 < f_{T,1}/\Lambda^4 < 0.31$, $-0.63 < f_{T,2}/\Lambda^4 < 0.59$, $-0.43 < f_{T,8}/\Lambda^4 < 0.43$, $-0.92 < f_{T,9}/\Lambda^4 < 0.92$, in units of TeV^{-4}.

[7] TUMASYAN 21A study electroweak $Z\gamma$ production in association with two jets, where the Z boson decays to electron or muon pairs and the pair of two jets has high invariant mass, superseeding SIRUNYAN 20AL. The number of observed (expected) electron events in the barrel and endcap regions are 375 (349 ± 9) and 174 (166 ± 6) events, respectively, while for muon events the respective numbers are 584 (612 ± 13) and 320 (303 ± 8). Analysing the $Z\gamma$ invariant mass distribution, the following 95% C.L. limits are derived: $-15.8 < f_{M,0}/\Lambda^4 < 16.0$, $-35.0 < f_{M,1}/\Lambda^4 < 34.7$, $-6.55 < f_{M,2}/\Lambda^4 < 6.49$, $-13.0 < f_{M,3}/\Lambda^4 < 13.0$, $-13.0 < f_{M,4}/\Lambda^4 < 12.7$, $-22.2 < f_{M,5}/\Lambda^4 < 21.3$, $-56.6 < f_{M,7}/\Lambda^4 < 55.9$, $-0.64 < f_{T,0}/\Lambda^4 < 0.57$, $-0.81 < f_{T,1}/\Lambda^4 < 0.90$, $-1.68 < f_{T,2}/\Lambda^4 < 1.54$, $-0.58 < f_{T,5}/\Lambda^4 < 0.64$, $-1.30 < f_{T,6}/\Lambda^4 < 1.33$, $-2.15 < f_{T,7}/\Lambda^4 < 2.43$, $-0.47 < f_{T,8}/\Lambda^4 < 0.47$, $-0.91 < f_{T,9}/\Lambda^4 < 0.91$, in units of TeV^{-4}.

[8] TUMASYAN 21B measure W or Z boson production in association with two photons, using the leptonic decays modes of W and Z with electrons or muons. The number of selected $W \to e(\mu)\nu$ events is 1987 (2384) and the number of selected $Z \to ee(\mu\mu)$ events is 110 (272) respectively. Analyzing the transverse momentum of the di-photon system, the following 95 % C.L. limits are derived in units of TeV^{-4}: In the W production channel, the observed limits are: $-39.9 < f_{M,2}/\Lambda^4 < 39.5$, $-63.8 < f_{M,3}/\Lambda^4 < 65.0$, $-1.30 < f_{T,0}/\Lambda^4 < 1.30$, $-1.70 < f_{T,1}/\Lambda^4 < 1.66$, $-3.64 < f_{T,2}/\Lambda^4 < 3.64$, $-0.52 < f_{T,5}/\Lambda^4 < 0.60$, $-0.60 < f_{T,6}/\Lambda^4 < 0.68$, $-1.16 < f_{T,7}/\Lambda^4 < 1.16$. In the Z production channel, the observed limits are: $-5.70 < f_{T,0}/\Lambda^4 < 5.46$, $-5.70 < f_{T,1}/\Lambda^4 < 5.46$, $-11.4 < f_{T,2}/\Lambda^4 < 10.9$, $-2.92 < f_{T,5}/\Lambda^4 < 2.92$, $-3.80 < f_{T,6}/\Lambda^4 < 3.88$, $-7.88 < f_{T,7}/\Lambda^4 < 7.72$, $-1.06 < f_{T,8}/\Lambda^4 < 1.10$, $-1.82 < f_{T,9}/\Lambda^4 < 1.82$, in units of TeV^{-4}.

[9] SIRUNAYN 20 study WZ and same-sign WW production in association with two jets, using the leptonic decays modes of the W and Z bosons with electrons or muons. Overall, 524 WW events and 229 WZ events are selected, with a Standard Model expectation of 535 ± 52 and 216 ± 21 events, respectively. Analyzing the transverse mass spectrum of the di-boson system and the di-jet invariant mass, the following 95% C.L. limits are derived, not using any unitarization procedure: $-0.25 < f_{T,0}/\Lambda^4 < 0.28$, $-0.12 <$

$f_{T,1}/\Lambda^4 < 0.14$, $-0.35 < f_{T,2}/\Lambda^4 < 0.48$, $-2.7 < f_{M,0}/\Lambda^4 < 2.9$, $-4.1 < f_{M,1}/\Lambda^4 < 4.2$, $-5.4 < f_{M,6}/\Lambda^4 < 5.8$, $-5.7 < f_{M,7}/\Lambda^4 < 6.0$, $-5.7 < f_{S,0}/\Lambda^4 < 6.1$, $-16 < f_{S,1}/\Lambda^4 < 17$, in units of TeV^{-4}. The article also reports limits on these couplings by cutting the EFT expansion at the unitarity limit.

[10] SIRUNYAN 20AL study electroweak production of a Z boson and a photon in association with two jets in the electron and muon decay modes of the Z. A signal with a significance of 3.9 standard deviations is observed, compared to a Standard Model expectation of 5.2 standard deviations. Combining with KHACHATRYAN 17AA data at 8 TeV the final observed and expected signal significance is 4.7 and 5.5 standard deviations. Analyzing the Z-photon invariant mass distribution, the following 95% C.L. limits are derived: $-19.5 < f_{M,0}/\Lambda^4 < 20.3$, $-40.5 < f_{M,1}/\Lambda^4 < 39.5$, $-8.22 < f_{M,2}/\Lambda^4 < 8.10$, $-17.7 < f_{M,3}/\Lambda^4 < 17.9$, $-15.3 < f_{M,4}/\Lambda^4 < 15.8$, $-25.1 < f_{M,5}/\Lambda^4 < 24.5$, $-38.9 < f_{M,6}/\Lambda^4 < 40.6$, $-60.3 < f_{M,7}/\Lambda^4 < 62.5$, $-0.74 < f_{T,0}/\Lambda^4 < 0.69$, $-0.98 < f_{T,1}/\Lambda^4 < 0.96$, $-1.97 < f_{T,2}/\Lambda^4 < 1.86$, $-0.70 < f_{T,5}/\Lambda^4 < 0.75$, $-1.64 < f_{T,6}/\Lambda^4 < 1.68$, $-2.59 < f_{T,7}/\Lambda^4 < 2.82$, $-0.47 < f_{T,8}/\Lambda^4 < 0.47$, $-1.27 < f_{T,9}/\Lambda^4 < 1.27$, in units of TeV^{-4}.

[11] SIRUNYAN 20BD study electroweak $W\gamma$ production in association with two jets, where the W boson decays to electron or muon and the two jets have high invariant mass. The number of observed (expected) electron events with the photon in the barrel and endcap regions are 393 (397.1 ± 18.5) and 159 (145.2 ± 10.0) respectively, while for muon events the respective numbers are 565 (537.9 ± 21.4) and 201 (188.2 ± 10.5). Analyzing the $W\gamma$ invariant mass distribution, the following 95% C.L. limits are derived: $-8.1 < f_{M,0}/\Lambda^4 < 8.0$, $-12 < f_{M,1}/\Lambda^4 < 12$, $-2.8 < f_{M,2}/\Lambda^4 < 2.8$, $-4.4 < f_{M,3}/\Lambda^4 < 4.4$, $-5.0 < f_{M,4}/\Lambda^4 < 5.0$, $-8.3 < f_{M,5}/\Lambda^4 < 8.3$, $-16 < f_{M,6}/\Lambda^4 < 16$, $-21 < f_{M,7}/\Lambda^4 < 20$, $-0.6 < f_{T,0}/\Lambda^4 < 0.6$, $-0.4 < f_{T,1}/\Lambda^4 < 0.4$, $-1.0 < f_{T,2}/\Lambda^4 < 1.2$, $-0.5 < f_{T,5}/\Lambda^4 < 0.5$, $-0.4 < f_{T,6}/\Lambda^4 < 0.4$, $-0.9 < f_{T,7}/\Lambda^4 < 0.9$, in units of TeV^{-4}.

[12] SIRUNYAN 19BM search for the final state $W^+ W^- W^\pm$ using W decays to electrons or muons. Two event samples are considered, events with three leptons, or events with two oppositely charged leptons accompanied by two jets. In a kinematic region selected to enhance the effect of anomalous couplings, no events are selected in the data, and 95% C.L. upper limits are obtained as follows: $-1.2 < f_{T,0}/\Lambda^4 < 1.2$, $-3.3 < f_{T,1}/\Lambda^4 < 3.3$, $-2.7 < f_{T,2}/\Lambda^4 < 2.6$, in units of TeV^{-4} and without application of a form factor.

[13] SIRUNYAN 19BP study WZ plus 2 jets production, using W and Z decay channels with electrons or muons. In the data, 75 events are selected, with a fitted SM signal of 15.1 ± 1.6 events and a fitted background of 62.4 ± 2.8 events. The transverse mass distribution of the WZ system is analyzed to set the following limits at 95% C.L., in units of TeV^{-4}: $-9.15 < f_{M,0}/\Lambda^4 < 9.15$, $-9.15 < f_{M,1}/\Lambda^4 < 9.45$, $-26.5 < f_{S,0}/\Lambda^4 < 27.5$, $-41.2 < f_{S,1}/\Lambda^4 < 42.8$, $-0.75 < f_{T,0}/\Lambda^4 < 0.81$, $-0.49 < f_{T,1}/\Lambda^4 < 0.55$, $-1.49 < f_{T,2}/\Lambda^4 < 1.85$.

[14] SIRUNYAN 19CQ search for anomalous electroweak production of vector boson pairs in association with two jets. Events are selected by requiring two jets with a large invariant mass and rapidity separation, one or two leptons (electrons or muons), and a W or Z boson decaying hadronically. In the WV (ZV) channel, 347 (47) events are selected in the data, with a total expected background of 352 ± 19 (50.3 ± 5.8) events. Analysing the mass distribution of the WV or ZV system, the following 95% C.L. limits are obtained: $-2.7 < f_{S,0}/\Lambda^4 < 2.7$, $-3.4 < f_{S,1}/\Lambda^4 < 3.4$, $-0.69 < f_{M,0}/\Lambda^4 < 0.70$, $-2.0 < f_{M,1}/\Lambda^4 < 2.1$, $-1.3 < f_{M,6}/\Lambda^4 < 1.3$, $-3.4 < f_{M,7}/\Lambda^4 < 3.4$,

$-0.12 < f_{T,0}/\Lambda^4 < 0.11$, $-0.12 < f_{T,1}/\Lambda^4 < 0.13$, $-0.28 < f_{T,2}/\Lambda^4 < 0.28$, in units of TeV^{-4}.

[15] SIRUNYAN 18CC study pp collisions at $\sqrt{s} = 13$ TeV leading to a pair of same-sign W pairs decaying leptonically (e or μ) associated with a pair of jets. Isolated leptons with $p_T > 25$ (20) GeV for the leading (trailing) lepton, with $|\eta| < 2.5$ (2.4) for e (μ) and jets with $p_T > 30$ GeV, $|\eta| < 5.0$, $|\Delta\eta_{jj}| > 2.5$ and $m_{jj} > 500$ GeV is required. Further cuts are applied to minimize $Z \rightarrow ee$ events, non-prompt leptons and hadronically decaying taus. The number of selected events is 201, with an expected SM signal of 66.9 ± 2.4 and background of 138 ± 13 events. Analysing the dilepton invariant mass spectrum the following 95% C.L. limits are derived: $-7.7 < f_{S,0}/\Lambda^4 < 7.7$, $-21.6 < f_{S,1}/\Lambda^4 < 21.8$, $-6.0 < f_{M,0}/\Lambda^4 < 5.9$, $-8.7 < f_{M,1}/\Lambda^4 < 9.1$, $-11.9 < f_{M,6}/\Lambda^4 < 11.8$, $-13.3 < f_{M,7}/\Lambda^4 < 12.9$, $-0.62 < f_{T,0}/\Lambda^4 < 0.65$, $-0.28 < f_{T,1}/\Lambda^4 < 0.31$, $-0.89 < f_{T,2}/\Lambda^4 < 1.02$.

[16] AABOUD 17AA analyze $W^\pm W^\pm$ production in association with two jets and W decay modes with electrons or muons. In the kinematic region of VBS the effect of anomalous QGCs is enhanced by requiring the transverse mass of the WW system to be larger than 400 GeV. In the data, 8 events are selected with a total background expected from SM processes of 3.8 ± 0.6 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 QGCs: $-0.14 < \alpha_4 < 0.15$ and $-0.22 < \alpha_5 < 0.22$. Supersedes AAD 14AM.

[17] AABOUD 17AG determine the $WW\gamma$ and $WZ\gamma$ cross sections in 8 TeV pp interactions by studying the final states $e\nu\mu\nu\gamma$ and $e\nu jj\gamma$ or $\mu\nu jj\gamma$. Upper limits on the production cross sections are derived in a fiducial region optimized for BSM physics. These are used to derive the following 95% C.L. upper limits for quartic couplings assuming the form scale factor, $\Lambda_{FF} = \infty$ (all in units of 10^3 TeV^{-4}): $-0.3 < f_{M,0}/\Lambda^4 < 0.3$, $-0.5 < f_{M,1}/\Lambda^4 < 0.5$, $-1.8 < f_{M,2}/\Lambda^4 < 1.8$, $-1.1 < f_{M,4}/\Lambda^4 < 1.1$, $-1.7 < f_{M,5}/\Lambda^4 < 1.7$, $-0.6 < f_{M,6}/\Lambda^4 < 0.6$, $-1.1 < f_{M,7}/\Lambda^4 < 1.1$, $-0.1 < f_{T,0}/\Lambda^4 < 0.1$, $-0.2 < f_{T,1}/\Lambda^4 < 0.2$, $-0.4 < f_{T,4}/\Lambda^4 < 0.4$, $-1.5 < f_{T,5}/\Lambda^4 < 1.6$, $-1.9 < f_{T,6}/\Lambda^4 < 1.9$, $-4.3 < f_{T,7}/\Lambda^4 < 4.3$.

[18] AABOUD 17D analyze electroweak diboson (WV, $V = W$, Z) production in association with a high-mass dijet system. In the data, 32 events are selected with an expected total background of 32 ± 12 events. Analysing the transverse mass distribution of the WV system, the following limits are set at 95% C.L.: $-0.024 < \alpha_4 < 0.030$ and $-0.028 < \alpha_5 < 0.033$.

[19] AABOUD 17J analyze the $Z\gamma$ production in association with a high-mass dijet system, with the Z boson decaying into a pair of electrons, muons, or neutrinos. In the charged lepton (neutrino) channel, events are selected with a dijet mass larger than 500 (600) GeV and a transverse photon energy larger than 250 (150) GeV, with 2 (4) events selected in the data and 0.30 ± 0.08 (1.6 ± 0.5) expected background events. The observed event yield is used to determine 95% CL limits as follows: $-4.1 \times 10^3 < f_{T,9}/\Lambda^4 < 4.2 \times 10^3$, $-1.9 \times 10^3 < f_{T,8}/\Lambda^4 < 2.1 \times 10^3$, $-1.9 \times 10^1 < f_{T,0}/\Lambda^4 < 1.6 \times 10^1$, $-1.6 \times 10^2 < f_{M,0}/\Lambda^4 < 1.8 \times 10^2$, $-3.5 \times 10^2 < f_{M,1}/\Lambda^4 < 3.4 \times 10^2$, $-8.9 \times 10^2 < f_{M,2}/\Lambda^4 < 8.9 \times 10^2$, $-1.7 \times 10^3 < f_{M,3}/\Lambda^4 < 1.7 \times 10^3$, in units of TeV^{-4} and without application of a form factor.

[20] AABOUD 17M analyze tri-boson $W^\pm W^\pm W^\mp$ production in decay channels with three charged leptons or two like-sign charged leptons with two jets, where the lepton can be an electron or muon. In the data, 24 tri-lepton events and 21 di-lepton plus jets events are selected, compared to a total event yield expected in the SM of 30.8 ± 3.0 and 21.9 ± 2.0, respectively. Analysing the tri-lepton transverse mass or the transverse momentum sum of the two leptons, two jets and the missing transverse energy, the following limits at 95%

CL are derived for the form factor cut-off scale $\Lambda_{FF} \to \infty$: $-0.13 < f_{S,0}/\Lambda^4 < 0.18$, $-0.21 < f_{S,1}/\Lambda^4 < 0.27$, in units of 10^4 TeV^{-4}, which are converted into the following limits: $-0.49 < \alpha_4 < 0.75$ and $-0.48 < \alpha_5 < 0.62$.

[21] KHACHATRYAN 17AA analyse electroweak production of $Z\gamma$ in association with two hadronic jets, with the Z boson decaying to electron or muon pairs. Events with photon transverse momentum larger than 60 GeV and di-jet invariant mass larger than 400 GeV are selected. The $Z\gamma$ inavariant mass spectrum is analysed to set 95% C.L. limits as follows: $-71 < f_{M,0}/\Lambda^4 < 75$, $-190 < f_{M,1}/\Lambda^4 < 182$, $-32 < f_{M,2}/\Lambda^4 < 31$, $-58 < f_{M,3}/\Lambda^4 < 59$, $-3.8 < f_{T,0}/\Lambda^4 < 3.4$, $-4.4 < f_{T,1}/\Lambda^4 < 4.4$, $-9.9 < f_{T,2}/\Lambda^4 < 9.0$, $-1.8 < f_{T,8}/\Lambda^4 < 1.8$, $-4.0 < f_{T,9}/\Lambda^4 < 4.0$, in units of TeV^{-4} and without application of a form factor.

[22] KHACHATRYAN 17M analyse electroweak production of $W\gamma$ in association with two hadronic jets, with the W boson decaying to electrons or muons. Events with photon transverse momentum larger than 200 GeV and di-jet invariant mass larger than 200 GeV are selected. The W transverse momentum spectrum is analysed to set 95% C.L. limits as follows: $-77 < f_{M,0}/\Lambda^4 < 74$, $-125 < f_{M,1}/\Lambda^4 < 129$, $-26 < f_{M,2}/\Lambda^4 < 26$, $-43 < f_{M,3}/\Lambda^4 < 44$, $-40 < f_{M,4}/\Lambda^4 < 40$, $-65 < f_{M,5}/\Lambda^4 < 65$, $-129 < f_{M,6}/\Lambda^4 < 129$, $-164 < f_{M,7}/\Lambda^4 < 162$, $-5.4 < f_{T,0}/\Lambda^4 < 5.6$, $-3.7 < f_{T,1}/\Lambda^4 < 4.0$, $-11 < f_{T,2}/\Lambda^4 < 12$, $-3.8 < f_{T,5}/\Lambda^4 < 3.8$, $-2.8 < f_{T,6}/\Lambda^4 < 3.0$, $-7.3 < f_{T,7}/\Lambda^4 < 7.7$, in units of TeV^{-4} and without application of a form factor.

[23] SIRUNYAN 17AD study pp collisions at $\sqrt{s} = 13$ TeV to determine the cross section of $ZZjj$ with the Z decaying to ee or $\mu\mu$. The ZZ mass distribution is used to set upper limits on the anomalous quartic couplings. The 95% upper limits for the relevant quartic couplings in units of TeV^{-4} are: $-0.46 < f_{T,0}/\Lambda^4 < 0.44$, $-0.61 < f_{T,1}/\Lambda^4 < 0.61$, $-1.2 < f_{T,2}/\Lambda^4 < 1.2$, $-0.84 < f_{T,8}/\Lambda^4 < 0.84$, $-1.8 < f_{T,9}/\Lambda^4 < 1.8$.

[24] SIRUNYAN 17AR study pp collisions at $\sqrt{s} = 8$ TeV to determine the cross section of $pp \to W\gamma\gamma$ and $pp \to Z\gamma\gamma$ where $W \to \ell\nu$ and $Z \to \ell^+\ell^-$, ℓ being an electron or a muon. The number of W events in the e and μ channels is 63 and 108 respectively, and the number of Z events in the e and μ channels is 117 and 141. To increase sensitivity, the transverse momentum of the leading photon is required to be larger than 70 GeV. The 95% C.L. upper limits in units of TeV^{-4} are $-701 < f_{M,2}/\Lambda^4 < 683$, $-1170 < f_{M,3}/\Lambda^4 < 1220$, $-33.5 < f_{T,0}/\Lambda^4 < 34.0$, $-44.3 < f_{T,1}/\Lambda^4 < 44.8$, $-93.8 < f_{T,2}/\Lambda^4 < 93.2$.

[25] AABOUD 16E study WW production in two-photon mediated pp collisions at 8 TeV where the W boson decays into an electron or muon, probing the $\gamma\gamma WW$ vertex for anomalous quartic gauge couplings. The lepton p_T is required to be larger than 30 GeV. Limits on anomalous couplings are determined from events with p_T larger than 120 GeV where the aQGC effect is enhanced and the SM background reduced; in the data corresponding to an integrated luminosity of 20.2fb^{-1}, 1 event is selected with an expected SM background of 0.37 ± 0.13 events. The 95% C.L. limits without a form-factor cutoff ($\Lambda_{\text{cutoff}} \to \infty$) are as follows: $-1.7 < a_0^W/\Lambda^2 < 1.7$ and $-6.4 < a_C^W/\Lambda^2 < 6.3$ in units of 10^{-6} GeV^{-2}. In terms of another set of variables: $-6.6 < f_{M,0}/\Lambda^4 < 6.6$ and $-24 < f_{M,1}/\Lambda^4 < 25$ in units of 10^{-11} GeV^{-4}.

[26] AAD 16Q study $Z\gamma\gamma$ production in pp collisions. In events with no additional jets, 29 (22) Z decays to electron (muon) pairs are selected, with an expected background of 3.3 ± 1.1 (6.5 ± 2.0) events, as well as 19 Z decays to netrino pairs with an expected background of 8.3 ± 4.4 events. Analysing the photon transverse momentum distribution for $m_{\gamma\gamma}$ above 200 GeV (300 GeV) for lepton (neutrino) events, yields the 95% C.L.

limits: $-1.6 \times 10^4 < f_{M,2}/\Lambda^4 < 1.6 \times 10^4$, $-2.9 \times 10^4 < f_{M,3}/\Lambda^4 < 2.7 \times 10^4$, $-0.86 \times 10^2 < f_{T,0}/\Lambda^4 < 1.03 \times 10^2$, $-0.69 \times 10^3 < f_{T,5}/\Lambda^4 < 0.68 \times 10^3$, $-0.74 \times 10^4 < f_{T,9}/\Lambda^4 < 0.74 \times 10^4$ in units of TeV^{-4} and without application of a form factor Λ_{FF}.

[27] KHACHATRYAN 16AX searches for anomalous $WW\gamma\gamma$ quartic gauge couplings in the two-photon-mediated process $pp \to ppWW$, assuming the $WW\gamma$ triple gauge boson couplings to be at their Standard Model values. 13 events containing an $e^{\pm}\mu^{\mp}$ pair with $p_T(e, \mu) > 30$ GeV are selected in a total luminosity of 19.7 fb^{-1}, with an expected $\gamma\gamma \to WW$ signal of 5.3 ± 0.1 events and an expected background of 3.9 ± 0.5 events. When combining with the data collected at 7 TeV (CHATRCHYAN 13AA), and not assuming a form factor, the following 1-parameter limits at 95% C.L. are obtained from the $p_T(e, \mu)$ spectrum: $|a_0^W/\Lambda^2| < 1.1 \times 10^{-6}$ GeV^{-2} ($a_C^W = 0$), and $|a_C^W/\Lambda^2| < 4.1 \times 10^{-6}$ GeV^{-2} ($a_0^W = 0$). In terms of another set of variables: $|f_{M,0}/\Lambda^4| < 4.2 \times 10^{-12}$ GeV^{-4}, $|f_{M,1}/\Lambda^4| < 16 \times 10^{-12}$ GeV^{-4}, $|f_{M,2}/\Lambda^4| < 2.1 \times 10^{-12}$ GeV^{-4}, $|f_{M,3}/\Lambda^4| < 7.8 \times 10^{-12}$ GeV^{-4}.

[28] 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) ≥ 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}.

[29] 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}: $-38 < F_{S,0}/\Lambda^4 < 40$, $-118 < F_{S,1}/\Lambda^4 < 120$, $-33 < F_{M,0}/\Lambda^4 < 32$, $-44 < F_{M,1}/\Lambda^4 < 47$, $-65 < F_{M,6}/\Lambda^4 < 63$, $-70 < F_{M,7}/\Lambda^4 < 66$, $-4.2 < F_{T,0}/\Lambda^4 < 4.6$, $-1.9 < F_{T,1}/\Lambda^4 < 2.2$, $-5.2 < F_{T,2}/\Lambda^4 < 6.4$.

[30] 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 $-0.23 < \alpha_5 < 0.24$.

[31] CHATRCHYAN 14Q study $WV\gamma$ production in 8 TeV pp collisions, in the single lepton final state, with $W \to \ell\nu$, $Z \to$ dijet or $W \to \ell\nu$, $W \to$ 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 70–100 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}.

[32] ABAZOV 13D searches for anomalous $WW\gamma\gamma$ quartic gauge couplings in the two-photon-mediated process $pp \to ppWW$, 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 $\pm$ 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} ($a_0^W = 0$).

[33] CHATRCHYAN 13AA searches for anomalous $WW\gamma\gamma$ quartic gauge couplings in the two-photon-mediated process $pp \to ppWW$, 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 $\pm$ 0.4 events and an expected background of 0.84 $\pm$ 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} ($a_0^W = 0$).

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

[35] 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}.

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

[37] 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}, $\widetilde{a}_0/\Lambda^2 = -0.007^{+0.019}_{-0.008}$ GeV^{-2}, $a_n/\Lambda^2 = -0.09^{+0.16}_{-0.05}$ GeV^{-2}, and $\widetilde{a}_n/\Lambda^2 = +0.05^{+0.07}_{-0.15}$ 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} $< \widetilde{a}_0/\Lambda^2 < +0.020$ GeV^{-2}, -0.18 GeV^{-2} $< a_n/\Lambda^2 < +0.14$ GeV^{-2}, -0.16 GeV^{-2} $< \widetilde{a}_n/\Lambda^2 < +0.17$ GeV^{-2}.

[38] 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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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 (errat.)	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 (errat.)	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.)