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W MASS

To obtain the world average, common systematics between experiments are properly taken into account. The LEP average W mass based on published results is 80.383 ± 0.035 GeV. The combined $p\bar{p}$ collider data yields an average W mass of 80.454 ± 0.059 GeV (ABAZOV 04D).

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

<u>VALUE (GeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
80.403 ± 0.029 OUR FIT				
80.415 ± 0.042 ± 0.031	11830	¹ ABBIENDI	06 OPAL	$E_{cm}^{ee} = 170\text{--}209$ GeV
80.270 ± 0.046 ± 0.031	9909	² ACHARD	06 L3	$E_{cm}^{ee} = 161\text{--}209$ GeV
80.440 ± 0.043 ± 0.027	8692	³ SCHAEEL	06 ALEP	$E_{cm}^{ee} = 161\text{--}209$ GeV
80.483 ± 0.084	49247	⁴ ABAZOV	02D D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
80.359 ± 0.074 ± 0.049	3077	⁵ ABREU	01K DLPH	$E_{cm}^{ee} = 161+172+183$ $+189$ GeV
80.433 ± 0.079	53841	⁶ AFFOLDER	01E CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
82.87 ± 1.82 $\begin{smallmatrix} +0.30 \\ -0.16 \end{smallmatrix}$	1500	⁷ AKTAS	06 H1	$e^{\pm} p \rightarrow \bar{\nu}_e(\nu_e)X$, $\sqrt{s} \approx 300$ GeV
80.3 ± 2.1 ± 1.2 ± 1.0	645	⁸ CHEKANOV	02C ZEUS	$e^{-} p \rightarrow \nu_e X$, $\sqrt{s} =$ 318 GeV
81.4 $\begin{smallmatrix} +2.7 \\ -2.6 \end{smallmatrix}$ ± 2.0 $\begin{smallmatrix} +3.3 \\ -3.0 \end{smallmatrix}$	1086	⁹ BREITWEG	00D ZEUS	$e^{+} p \rightarrow \bar{\nu}_e X$, $\sqrt{s} \approx$ 300 GeV
80.84 ± 0.22 ± 0.83	2065	¹⁰ ALITTI	92B UA2	See W/Z ratio below
80.79 ± 0.31 ± 0.84		¹¹ ALITTI	90B UA2	$E_{cm}^{p\bar{p}} = 546,630$ GeV
80.0 ± 3.3 ± 2.4	22	¹² ABE	89I CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
82.7 ± 1.0 ± 2.7	149	¹³ ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
81.8 $\begin{smallmatrix} +6.0 \\ -5.3 \end{smallmatrix}$ ± 2.6	46	¹⁴ ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
89 ± 3 ± 6	32	¹⁵ ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
81. ± 5.	6	ARNISON	83 UA1	$E_{cm}^{ee} = 546$ GeV
80. $\begin{smallmatrix} +10. \\ -6. \end{smallmatrix}$	4	BANNER	83B UA2	Repl. by ALITTI 90B

¹ ABBIENDI 06 use direct reconstruction of the kinematics of $W^{+}W^{-} \rightarrow q\bar{q}l\nu_l$ and $W^{+}W^{-} \rightarrow q\bar{q}q\bar{q}$ events. The result quoted here is obtained combining this mass value with the results using $W^{+}W^{-} \rightarrow l\nu_l l'\nu_{l'}$ events in the energy range 183–207 GeV (ABBIENDI 03C) and the dependence of the WW production cross-section on m_{WW} at threshold. The systematic error includes ± 0.009 GeV due to the uncertainty on the LEP beam energy.

- ² ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ 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).
 - ³ SCHAELE 06 use direct reconstruction of the kinematics of $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ and $W^+W^- \rightarrow q\bar{q}q\bar{q}$ 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 $q\bar{q}q\bar{q}$ channel and ± 0.009 GeV due to the uncertainty on the LEP beam energy.
 - ⁴ 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 $D\bar{D}$ W -boson mass measurements.
 - ⁵ ABREU 01K obtain this value properly combining results obtained from a direct W mass reconstruction at 172, 183, and 189 GeV with those from measurements of W -pair production cross sections at 161, 172, and 183 GeV. The systematic error includes ± 0.017 GeV due to the beam energy uncertainty and ± 0.033 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
 - ⁶ 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.
 - ⁷ AKTAS 06 fit the Q^2 dependence ($300 < Q^2 < 30,000$ GeV²) 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.
 - ⁸ CHEKANOV 02C fit the Q^2 dependence ($200 < Q^2 < 60000$ GeV²) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.
 - ⁹ BREITWEG 00D fit the Q^2 dependence ($200 < Q^2 < 22500$ GeV²) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.
 - ¹⁰ 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.
 - ¹¹ There are two contributions to the systematic error (± 0.84): one (± 0.81) which cancels in m_W/m_Z and one (± 0.21) which is non-cancelling. These were added in quadrature.
 - ¹² ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.
 - ¹³ ALBAJAR 89 result is from a total sample of 299 $W \rightarrow e\nu$ events.
 - ¹⁴ ALBAJAR 89 result is from a total sample of 67 $W \rightarrow \mu\nu$ events.
 - ¹⁵ ALBAJAR 89 result is from $W \rightarrow \tau\nu$ events.
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W/Z MASS RATIO

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

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0.88173 ± 0.00032 OUR FIT				
0.8821 ± 0.0011 ± 0.0008	28323	¹⁶ ABBOTT	98N D0	$E_{cm}^{p\bar{p}} = 1.8 \text{ TeV}$
0.88114 ± 0.00154 ± 0.00252	5982	¹⁷ ABBOTT	98P D0	$E_{cm}^{p\bar{p}} = 1.8 \text{ TeV}$
0.8813 ± 0.0036 ± 0.0019	156	¹⁸ ALITTI	92B UA2	$E_{cm}^{p\bar{p}} = 630 \text{ GeV}$

¹⁶ 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.

¹⁷ ABBOTT 98P obtain this from a study of 5982 $W \rightarrow e\nu_e$ events. The systematic error includes an uncertainty of ±0.00175 due to the electron energy scale.

¹⁸ Scale error cancels in this ratio.

$m_Z - m_W$

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

<u>VALUE (GeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
10.785 ± 0.029 OUR FIT			
10.4 ± 1.4 ± 0.8	ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630 \text{ GeV}$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
11.3 ± 1.3 ± 0.9	ANSARI	87 UA2	$E_{cm}^{p\bar{p}} = 546,630 \text{ GeV}$

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

Test of CPT invariance.

<u>VALUE (GeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
-0.19 ± 0.58	1722	ABE	90G CDF	$E_{cm}^{p\bar{p}} = 1.8 \text{ TeV}$

W WIDTH

The CDF and $D\emptyset$ widths labelled “extracted value” are obtained by measuring $R = [\sigma(W)/\sigma(Z)] [\Gamma(W \rightarrow \ell\nu_\ell)] / (B(Z \rightarrow \ell\ell)\Gamma(W))$ where the bracketed quantities can be calculated with plausible reliability. $\Gamma(W)$ is then extracted by using a value of $B(Z \rightarrow \ell\ell)$ measured at LEP. The UA1 and UA2 widths used $R = [\sigma(W)/\sigma(Z)] [\Gamma(W \rightarrow \ell\nu_\ell)] / \Gamma(Z \rightarrow \ell\ell) \Gamma(Z)/\Gamma(W)$ and the measured value of $\Gamma(Z)$. The Standard Model prediction is $2.0910 \pm 0.0015 \text{ GeV}$ (see Review on “Electroweak model and constraints on new physics” in this Edition).

To obtain OUR FIT, the correlation between systematics within LEP experiments and within Tevatron experiments is properly taken into account as given in the LEP note accessible at http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg_2006/ and in the combined Tevatron paper of ABAZOV 04D. The respective average

values (2.164 ± 0.085 GeV from LEP and 2.115 ± 0.105 GeV from Tevatron) yield an average W width of 2.145 ± 0.066 GeV coming from direct measurements. ABAZOV 04D also determine the average extracted W width using CDF and DØ data to obtain a value of 2.141 ± 0.057 GeV.

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

VALUE (GeV)	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
2.141±0.041 OUR FIT					
$1.996 \pm 0.096 \pm 0.102$		10729	¹⁹ ABBIENDI	06 OPAL	$E_{cm}^{ee} = 170\text{--}209$ GeV
$2.18 \pm 0.11 \pm 0.09$		9795	²⁰ ACHARD	06 L3	$E_{cm}^{ee} = 172\text{--}209$ GeV
$2.14 \pm 0.09 \pm 0.06$		8717	²¹ SCHAEEL	06 ALEP	$E_{cm}^{ee} = 183\text{--}209$ GeV
$2.23 \begin{smallmatrix} +0.15 \\ -0.14 \end{smallmatrix} \pm 0.10$		294	²² ABAZOV	02E D0	Direct meas.
$2.266 \pm 0.176 \pm 0.076$		3005	²³ ABREU	01K DLPH	$E_{cm}^{ee} = 183,189$ GeV
2.152 ± 0.066		79176	²⁴ ABBOTT	00B D0	Extracted value
$2.05 \pm 0.10 \pm 0.08$		662	²⁵ AFFOLDER	00M CDF	Direct meas.
$2.064 \pm 0.060 \pm 0.059$			²⁶ ABE	95W CDF	Extracted value
$2.10 \begin{smallmatrix} +0.14 \\ -0.13 \end{smallmatrix} \pm 0.09$		3559	²⁷ ALITTI	92 UA2	Extracted value
$2.18 \begin{smallmatrix} +0.26 \\ -0.24 \end{smallmatrix} \pm 0.04$			²⁸ ALBAJAR	91 UA1	Extracted value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
$2.30 \pm 0.19 \pm 0.06$			²⁹ ALITTI	90C UA2	Extracted value
$2.8 \begin{smallmatrix} +1.4 \\ -1.5 \end{smallmatrix} \pm 1.3$		149	³⁰ ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
< 7		90 119	APPEL	86 UA2	$E_{cm}^{p\bar{p}} = 546,630$ GeV
< 6.5		90 86	³¹ ARNISON	86 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV

¹⁹ ABBIENDI 06 use direct reconstruction of the kinematics of $W^+ W^- \rightarrow q\bar{q}l\nu_l$ and $W^+ W^- \rightarrow q\bar{q}q\bar{q}$ events. The systematic error includes ± 0.003 GeV due to the uncertainty on the LEP beam energy.

²⁰ ACHARD 06 use direct reconstruction of the kinematics of $W^+ W^- \rightarrow q\bar{q}l\nu_l$ and $W^+ W^- \rightarrow q\bar{q}q\bar{q}$ 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).

²¹ SCHAEEL 06 use direct reconstruction of the kinematics of $W^+ W^- \rightarrow q\bar{q}l\nu_l$ and $W^+ W^- \rightarrow q\bar{q}q\bar{q}$ events. The systematic error includes ± 0.05 GeV due to possible effects of final state interactions in the $q\bar{q}q\bar{q}$ channel and ± 0.01 GeV due to the uncertainty on the LEP beam energy.

²² ABAZOV 02E obtain this result fitting the high-end tail (90–200 GeV) of the transverse-mass spectrum in semileptonic $W \rightarrow e\nu_e$ decays.

²³ ABREU 01K obtain this value properly combining results obtained at 183 and 189 GeV using $W W \rightarrow \ell\bar{\nu}_\ell q\bar{q}$ and $W W \rightarrow q\bar{q}q\bar{q}$ decays. The systematic error includes an uncertainty of ± 0.052 GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.

²⁴ ABBOTT 00B measure $R = 10.43 \pm 0.27$ for the $W \rightarrow e\nu_e$ decay channel. They use the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $\Gamma(W \rightarrow e\nu_e)$ and the world average for $B(Z \rightarrow e e)$. The value quoted here is obtained combining this result (2.169 ± 0.070 GeV) with that of ABBOTT 99H.

- ²⁵ AFFOLDER 00M fit the high transverse mass (100–200 GeV) $W \rightarrow e\nu_e$ and $W \rightarrow \mu\nu_\mu$ events to obtain $\Gamma(W) = 2.04 \pm 0.11(\text{stat}) \pm 0.09(\text{syst})$ GeV. This is combined with the earlier CDF measurement (ABE 95C) to obtain the quoted result.
- ²⁶ ABE 95W measured $R = 10.90 \pm 0.32 \pm 0.29$. They use $m_W = 80.23 \pm 0.18$ GeV, $\sigma(W)/\sigma(Z) = 3.35 \pm 0.03$, $\Gamma(W \rightarrow e\nu) = 225.9 \pm 0.9$ MeV, $\Gamma(Z \rightarrow e^+e^-) = 83.98 \pm 0.18$ MeV, and $\Gamma(Z) = 2.4969 \pm 0.0038$ GeV.
- ²⁷ ALITTI 92 measured $R = 10.4^{+0.7}_{-0.6} \pm 0.3$. The values of $\sigma(Z)$ and $\sigma(W)$ come from $O(\alpha_s^2)$ calculations using $m_W = 80.14 \pm 0.27$ GeV, and $m_Z = 91.175 \pm 0.021$ GeV along with the corresponding value of $\sin^2\theta_W = 0.2274$. They use $\sigma(W)/\sigma(Z) = 3.26 \pm 0.07 \pm 0.05$ and $\Gamma(Z) = 2.487 \pm 0.010$ GeV.
- ²⁸ ALBAJAR 91 measured $R = 9.5^{+1.1}_{-1.0}$ (stat. + syst.). $\sigma(W)/\sigma(Z)$ is calculated in QCD at the parton level using $m_W = 80.18 \pm 0.28$ GeV and $m_Z = 91.172 \pm 0.031$ GeV along with $\sin^2\theta_W = 0.2322 \pm 0.0014$. They use $\sigma(W)/\sigma(Z) = 3.23 \pm 0.05$ and $\Gamma(Z) = 2.498 \pm 0.020$ GeV. This measurement is obtained combining both the electron and muon channels.
- ²⁹ ALITTI 90C used the same technique as described for ABE 90. They measured $R = 9.38^{+0.82}_{-0.72} \pm 0.25$, obtained $\Gamma(W)/\Gamma(Z) = 0.902 \pm 0.074 \pm 0.024$. Using $\Gamma(Z) = 2.546 \pm 0.032$ GeV, they obtained the $\Gamma(W)$ value quoted above and the limits $\Gamma(W) < 2.56$ (2.64) GeV at the 90% (95%) CL. $E_{\text{cm}}^{\text{P}\bar{\text{P}}} = 546,630$ GeV.
- ³⁰ ALBAJAR 89 result is from a total sample of 299 $W \rightarrow e\nu$ events.
- ³¹ If systematic error is neglected, result is $2.7^{+1.4}_{-1.5}$ GeV. This is enhanced subsample of 172 total events.

W⁺ DECAY MODES

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

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

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

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

W PARTIAL WIDTHS

$\Gamma(\text{invisible})$

Γ_{10}

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

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
$30^{+52}_{-48} \pm 33$	³² BARATE	99I ALEP	$E_{\text{cm}}^{ee} = 161+172+183$ GeV
	³³ BARATE	99L ALEP	$E_{\text{cm}}^{ee} = 161+172+183$ GeV

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

³² 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.

³³ BARATE 99L use W -pair production to search for effectively invisible W decays, tagging with the decay of the other W boson to Standard Model particles. The partial width for effectively invisible decay is < 27 MeV at 95%CL.

W BRANCHING RATIOS

Overall fits are performed to determine the branching ratios of the W . LEP averages on $W \rightarrow e\nu_e$, $W \rightarrow \mu\nu_\mu$, and $W \rightarrow \tau\nu_\tau$, and their correlations are first obtained by combining results from the four experiments taking properly into account the common systematics. The procedure is described in the note LEPEWWG/XSEC/2001-02, 30 March 2001, at <http://lepewwg.web.cern.ch/LEPEWWG/lepww/4f/PDG01>. The LEP average values so obtained, using published data, are given in the note LEPEWWG/XSEC/2005-01 accessible at <http://lepewwg.web.cern.ch/LEPEWWG/lepww/4f/PDG05/>. These results, together with results from the $p\bar{p}$ colliders are then used in fits to obtain the world average W branching ratios. A first fit determines three individual leptonic branching ratios, $B(W \rightarrow e\nu_e)$, $B(W \rightarrow \mu\nu_\mu)$, and $B(W \rightarrow \tau\nu_\tau)$. This fit has a $\chi^2 = 4.7$ for 10 degrees of freedom. A second fit assumes lepton universality and determines the leptonic branching ratio $B(W \rightarrow \ell\nu_\ell)$ and the hadronic branching ratio is derived as $B(W \rightarrow \text{hadrons}) = 1-3 B(W \rightarrow \ell\nu)$. This fit has a $\chi^2 = 11.3$ for 12 degrees of freedom.

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

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

Γ_1 / Γ

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.1080 ± 0.0009 OUR FIT				
0.1085 ± 0.0014 ± 0.0008	13600	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161-209$ GeV
0.1083 ± 0.0014 ± 0.0010	11246	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161-209$ GeV
0.1096 ± 0.0012 ± 0.0005	16116	SCHAEL	04A ALEP	$E_{\text{cm}}^{ee} = 183-209$ GeV
0.1056 ± 0.0020 ± 0.0009	5778	ABBIENDI,G	00 OPAL	$E_{\text{cm}}^{ee} = 161+172+183$ $+189$ GeV
0.1102 ± 0.0052	11858	³⁴ ABBOTT	99H D0	$E_{\text{cm}}^{pp} = 1.8$ TeV
0.104 ± 0.008	3642	³⁵ ABE	92I CDF	$E_{\text{cm}}^{pp} = 1.8$ TeV

- ³⁴ ABBOTT 99H measure $R \equiv [\sigma_W B(W \rightarrow \ell\nu_\ell)]/[\sigma_Z B(Z \rightarrow \ell\ell)] = 10.90 \pm 0.52$ combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $B(Z \rightarrow \ell\ell)$.
- ³⁵ $1216 \pm 38^{+27}_{-31}$ $W \rightarrow \mu\nu$ events from ABE 92I and $2426 W \rightarrow e\nu$ events of ABE 91C. ABE 92I give the inverse quantity as 9.6 ± 0.7 and we have inverted.

$\Gamma(e^+\nu)/\Gamma_{\text{total}}$					Γ_2/Γ
<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>	
0.1075 ± 0.0013 OUR FIT					
0.1061 ± 0.0028		³⁶ ABAZOV	04D	TEVA	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
0.1055 ± 0.0031 ± 0.0014	1804	ABDALLAH	04G	DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1078 ± 0.0029 ± 0.0013	1576	ACHARD	04J	L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1078 ± 0.0027 ± 0.0010	2142	SCHAEL	04A	ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
0.1046 ± 0.0042 ± 0.0014	801	ABBIENDI,G	00	OPAL	$E_{\text{cm}}^{ee} = 161+172+183$ +189 GeV
0.10 ± 0.014 ^{+0.02} _{-0.03}	248	³⁷ ANSARI	87C	UA2	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
seen	119	APPEL	86	UA2	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
seen	172	ARNISON	86	UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV

- ³⁶ ABAZOV 04D take into account all correlations to properly combine the CDF (ABE 95W) and $D\bar{D}$ (ABBOTT 00B) measurements of the ratio R in the electron channel. The ratio R is defined as $[\sigma_W \cdot B(W \rightarrow e\nu_e)] / [\sigma_Z \cdot B(Z \rightarrow ee)]$. The combination gives $R^{\text{TeVatron}} = 10.59 \pm 0.23$. σ_W / σ_Z is calculated at next-to-next-to-leading order (3.360 ± 0.051). The branching fraction $B(Z \rightarrow ee)$ is taken from this Review as (3.363 ± 0.004)%.
- ³⁷ The first error was obtained by adding the statistical and systematic experimental uncertainties in quadrature. The second error reflects the dependence on theoretical prediction of total W cross section: $\sigma(546 \text{ GeV}) = 4.7^{+1.4}_{-0.7}$ nb and $\sigma(630 \text{ GeV}) = 5.8^{+1.8}_{-1.0}$ nb. See ALTARELLI 85B.

$\Gamma(\mu^+\nu)/\Gamma_{\text{total}}$					Γ_3/Γ
<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>	
0.1057 ± 0.0015 OUR FIT					
0.1065 ± 0.0026 ± 0.0008	1998	ABDALLAH	04G	DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1003 ± 0.0029 ± 0.0012	1423	ACHARD	04J	L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1087 ± 0.0025 ± 0.0008	2216	SCHAEL	04A	ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
0.1050 ± 0.0041 ± 0.0012	803	ABBIENDI,G	00	OPAL	$E_{\text{cm}}^{ee} =$ $161+172+183$ +189 GeV
0.10 ± 0.01	1216	³⁸ ABE	92I	CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
³⁸ ABE 92I quote the inverse quantity as 9.9 ± 1.2 which we have inverted.					

$\Gamma(\tau^+\nu)/\Gamma_{\text{total}}$					Γ_4/Γ
<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>	
0.1125 ± 0.0020 OUR FIT					
0.1146 ± 0.0039 ± 0.0019	2034	ABDALLAH	04G	DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1189 ± 0.0040 ± 0.0020	1375	ACHARD	04J	L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1125 ± 0.0032 ± 0.0020	2070	SCHAEL	04A	ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
0.1075 ± 0.0052 ± 0.0021	794	ABBIENDI,G	00	OPAL	$E_{\text{cm}}^{ee} =$ $161+172+183$ +189 GeV

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

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

Γ_5/Γ

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0.6760±0.0027 OUR FIT				
0.6745±0.0041±0.0024	13600	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.6750±0.0042±0.0030	11246	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.6713±0.0037±0.0015	16116	SCHAELE	04A ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
0.6832±0.0061±0.0028	5778	ABBIENDI,G	00 OPAL	$E_{\text{cm}}^{ee} = 161+172+183$ +189 GeV

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

Γ_3/Γ_2

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0.983±0.018 OUR FIT				
0.89 ±0.10	13k	³⁹ ABACHI	95D D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
1.02 ±0.08	1216	⁴⁰ ABE	92I CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
1.00 ±0.14 ±0.08	67	ALBAJAR	89 UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.24 ^{+0.6} _{-0.4}	14	ARNISON	84D UA1	Repl. by ALBA- JAR 89

³⁹ ABACHI 95D obtain this result from the measured $\sigma_W B(W \rightarrow \mu\nu) = 2.09 \pm 0.23 \pm 0.11$ nb and $\sigma_W B(W \rightarrow e\nu) = 2.36 \pm 0.07 \pm 0.13$ nb in which the first error is the combined statistical and systematic uncertainty, the second reflects the uncertainty in the luminosity.

⁴⁰ ABE 92I obtain $\sigma_W B(W \rightarrow \mu\nu) = 2.21 \pm 0.07 \pm 0.21$ and combine with ABE 91C $\sigma_W B(W \rightarrow e\nu)$ to give a ratio of the couplings from which we derive this measurement.

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

Γ_4/Γ_2

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1.046±0.023 OUR FIT				
0.961±0.061	980	⁴¹ ABBOTT	00D D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
0.94 ±0.14	179	⁴² ABE	92E CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
1.04 ±0.08 ±0.08	754	⁴³ ALITTI	92F UA2	$E_{\text{cm}}^{p\bar{p}} = 630$ GeV
1.02 ±0.20 ±0.12	32	ALBAJAR	89 UA1	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.995±0.112±0.083	198	ALITTI	91C UA2	Repl. by ALITTI 92F
1.02 ±0.20 ±0.10	32	ALBAJAR	87 UA1	Repl. by ALBA- JAR 89

⁴¹ ABBOTT 00D measure $\sigma_W \times B(W \rightarrow \tau\nu_\tau) = 2.22 \pm 0.09 \pm 0.10 \pm 0.10$ nb. Using the ABBOTT 00B result $\sigma_W \times B(W \rightarrow e\nu_e) = 2.31 \pm 0.01 \pm 0.05 \pm 0.10$ nb, they quote the ratio of the couplings from which we derive this measurement.

⁴² ABE 92E use two procedures for selecting $W \rightarrow \tau\nu_\tau$ events. The missing E_T trigger leads to $132 \pm 14 \pm 8$ events and the τ trigger to $47 \pm 9 \pm 4$ events. Proper statistical and systematic correlations are taken into account to arrive at $\sigma B(W \rightarrow \tau\nu) = 2.05 \pm 0.27$ nb. Combined with ABE 91C result on $\sigma B(W \rightarrow e\nu)$, ABE 92E quote a ratio of the couplings from which we derive this measurement.

⁴³ This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

$\Gamma(\pi^+\gamma)/\Gamma(e^+\nu)$					Γ_6/Γ_2
VALUE	CL%	DOCUMENT ID	TECN	COMMENT	
$< 7 \times 10^{-4}$	95	ABE	98H CDF	$E_{cm}^{p\bar{p}} = 1.8 \text{ TeV}$	
$< 4.9 \times 10^{-3}$	95	44 ALITTI	92D UA2	$E_{cm}^{p\bar{p}} = 630 \text{ GeV}$	
$< 58 \times 10^{-3}$	95	45 ALBAJAR	90 UA1	$E_{cm}^{p\bar{p}} = 546, 630 \text{ GeV}$	
44 ALITTI 92D limit is 3.8×10^{-3} at 90%CL.					
45 ALBAJAR 90 obtain < 0.048 at 90%CL.					

$\Gamma(D_s^+\gamma)/\Gamma(e^+\nu)$					Γ_7/Γ_2
VALUE	CL%	DOCUMENT ID	TECN	COMMENT	
$< 1.2 \times 10^{-2}$	95	ABE	98P CDF	$E_{cm}^{p\bar{p}} = 1.8 \text{ TeV}$	

$\Gamma(cX)/\Gamma(\text{hadrons})$					Γ_8/Γ_5
VALUE	EVTS	DOCUMENT ID	TECN	COMMENT	
0.49 ± 0.04 OUR AVERAGE					
$0.481 \pm 0.042 \pm 0.032$	3005	46 ABBIENDI	00V OPAL	$E_{cm}^{ee} = 183 + 189 \text{ GeV}$	
$0.51 \pm 0.05 \pm 0.03$	746	47 BARATE	99M ALEP	$E_{cm}^{ee} = 172 + 183 \text{ GeV}$	
46 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 $B(W \rightarrow \text{hadrons})$, $ V_{cs} $ is determined to be $0.969 \pm 0.045 \pm 0.036$.					
47 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		
$0.46^{+0.18}_{-0.14} \pm 0.07$	48 ABREU	98N DLPH	$E_{cm}^{ee} = 161+172 \text{ GeV}$		
48 ABREU 98N tag c and s jets by identifying a charged kaon as the highest momentum particle in a hadronic jet. They also use a lifetime tag to independently identify a c jet, based on the impact parameter distribution of charged particles in a jet. From this measurement $ V_{cs} $ is determined to be $0.94^{+0.32}_{-0.26} \pm 0.13$.					

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC W DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_{\pi^\pm} \rangle$				
VALUE	DOCUMENT ID	TECN	COMMENT	
15.70 ± 0.35	49 ABREU,P	00F DLPH	$E_{cm}^{ee} = 189 \text{ GeV}$	
49 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	50 ABREU,P	00F DLPH	$E_{cm}^{ee} = 189 \text{ GeV}$	
50 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	51 ABREU,P	00F	DLPH $E_{cm}^{ee} = 189$ GeV

⁵¹ 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	52 ABBIENDI	06A	OPAL $E_{cm}^{ee} = 189-209$ GeV
19.44 ± 0.17	53 ABREU,P	00F	DLPH $E_{cm}^{ee} = 183+189$ GeV
19.3 ± 0.3 ± 0.3	54 ABBIENDI	99N	OPAL $E_{cm}^{ee} = 183$ GeV
19.23 ± 0.74	55 ABREU	98C	DLPH $E_{cm}^{ee} = 172$ GeV

⁵² ABBIENDI 06A measure $\langle N_{\text{charged}} \rangle = 38.74 \pm 0.12 \pm 0.26$ when both W bosons decay hadronically and $\langle N_{\text{charged}} \rangle = 19.39 \pm 0.11 \pm 0.09$ when one W boson decays semileptonically. The value quoted here is obtained under the assumption that there is no color reconnection between W bosons; the value is a weighted average taking into account correlations in the systematic uncertainties.

⁵³ ABREU,P 00F measure $\langle N_{\text{charged}} \rangle = 39.12 \pm 0.33 \pm 0.36$ and $38.11 \pm 0.57 \pm 0.44$ in the fully hadronic final states at 189 and 183 GeV respectively, and $\langle N_{\text{charged}} \rangle = 19.49 \pm 0.31 \pm 0.27$ and $19.78 \pm 0.49 \pm 0.43$ in the semileptonic final states. The value quoted is a weighted average without assuming any correlations.

⁵⁴ ABBIENDI 99N use the final states $W^+ W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$ to derive this value.

⁵⁵ ABREU 98C combine results from both the fully hadronic as well semileptonic $W W$ final states after demonstrating that the W decay charged multiplicity is independent of the topology within errors.

TRIPLE GAUGE COUPLINGS (TGC'S)

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g_1^Z

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.984^{+0.022}_{-0.019} OUR FIT				
1.001 ± 0.027 ± 0.013	9310	56 SCHAEL	05A	ALEP $E_{cm}^{ee} = 183-209$ GeV
0.987 ^{+0.034} _{-0.033}	9800	57 ABBIENDI	04D	OPAL $E_{cm}^{ee} = 183-209$ GeV
0.966 ^{+0.034} _{-0.032} ± 0.015	8325	58 ACHARD	04D	L3 $E_{cm}^{ee} = 161-209$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	2.3	59 ABAZOV	05s	D0 $E_{cm}^{p\bar{p}} = 1.96$ TeV
0.98 ± 0.07 ± 0.01	2114	60 ABREU	01i	DLPH $E_{cm}^{ee} = 183+189$ GeV
	331	61 ABBOTT	99i	D0 $E_{cm}^{p\bar{p}} = 1.8$ TeV

- ⁵⁶ 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.
- ⁵⁷ 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 $0.923 < g_1^Z < 1.054$.
- ⁵⁸ 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.
- ⁵⁹ ABAZOV 05S study $\bar{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\bar{\ell}'$ (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.
- ⁶⁰ ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to W^+W^- and $W e \nu_e$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.84 < g_1^Z < 1.13$.
- ⁶¹ ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.63 < g_1^Z < 1.57$, fixing λ_Z and κ_Z to their Standard Model values, and assuming Standard Model values for the $WW\gamma$ couplings.

κ_γ

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.973^{+0.044}_{-0.045}$ OUR FIT				
$0.971 \pm 0.055 \pm 0.030$	10689	62 SCHAEL 05A	ALEP	$E_{cm}^{ee} = 183-209$ GeV
$0.88^{+0.09}_{-0.08}$	9800	63 ABBIENDI 04D	OPAL	$E_{cm}^{ee} = 183-209$ GeV
$1.013^{+0.067}_{-0.064} \pm 0.026$	10575	64 ACHARD 04D	L3	$E_{cm}^{ee} = 161-209$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
	17	65 ABAZOV 06H	D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
	141	66 ABAZOV 05J	D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
$1.25^{+0.21}_{-0.20} \pm 0.06$	2298	67 ABREU 01I	DLPH	$E_{cm}^{ee} = 183+189$ GeV
		68 BREITWEG 00	ZEUS	$e^+p \rightarrow e^+W^\pm X$, $\sqrt{s} \approx 300$ GeV
0.92 ± 0.34	331	69 ABBOTT 99I	D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV

- ⁶² 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.
- ⁶³ 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 $0.73 < \kappa_\gamma < 1.07$.
- ⁶⁴ 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.
- ⁶⁵ ABAZOV 06H study $\bar{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+ \nu_e e^- \bar{\nu}_e$, $WW \rightarrow e^\pm \nu_e \mu^\mp \nu_\mu$ or $WW \rightarrow \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 1$ TeV is $-0.05 < \kappa_\gamma < 2.29$, fixing $\lambda_\gamma = 0$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $0.68 < \kappa < 1.45$.
- ⁶⁶ 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.
- ⁶⁷ ABREU 01I combine results from $e^+ e^-$ interactions at 189 GeV leading to $W^+ W^-$, $W e \nu_e$, and $\nu \bar{\nu} \gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.87 < \kappa_\gamma < 1.68$.
- ⁶⁸ BREITWEG 00 search for W production in events with large hadronic p_T . For $p_T > 20$ GeV, the upper limit on the cross section gives the 95%CL limit $-3.7 < \kappa_\gamma < 2.5$ (for $\lambda_\gamma = 0$).
- ⁶⁹ 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 obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at <http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc>).

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.028^{+0.020}_{-0.021}$ OUR FIT				
$-0.012 \pm 0.027 \pm 0.011$	10689	⁷⁰ SCHAEL 05A	ALEP	$E_{cm}^{ee} = 183-209$ GeV
$-0.060^{+0.034}_{-0.033}$	9800	⁷¹ ABBIENDI 04D	OPAL	$E_{cm}^{ee} = 183-209$ GeV
$-0.021^{+0.035}_{-0.034} \pm 0.017$	10575	⁷² ACHARD 04D	L3	$E_{cm}^{ee} = 161-209$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
	17	⁷³ ABAZOV 06H	D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
	141	⁷⁴ ABAZOV 05J	D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
$0.05 \pm 0.09 \pm 0.01$	2298	⁷⁵ ABREU 01I	DLPH	$E_{cm}^{ee} = 183+189$ GeV
		⁷⁶ BREITWEG 00	ZEUS	$e^+ p \rightarrow e^+ W^\pm X$, $\sqrt{s} \approx 300$ GeV
$0.00^{+0.10}_{-0.09}$	331	⁷⁷ ABBOTT 99I	D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV

- ⁷⁰ SCHAEEL 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.
- ⁷¹ 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 $-0.13 < \lambda_\gamma < 0.01$.
- ⁷² 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.
- ⁷³ ABAZOV 06H study $\bar{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+ \nu_e e^- \bar{\nu}_e$, $WW \rightarrow e^\pm \nu_e \mu^\mp \nu_\mu$ or $WW \rightarrow \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 1$ TeV is $-0.97 < \lambda_\gamma < 1.04$, fixing $\kappa_\gamma=1$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.
- ⁷⁴ ABAZOV 05J perform a likelihood fit to the photon E_T spectrum of $W\gamma + X$ events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda = 2.0$ TeV the 95% CL limits are $-0.20 < \lambda_\gamma < 0.20$. In the fit κ_γ is kept fixed to its Standard Model value.
- ⁷⁵ ABREU 01I combine results from $e^+ e^-$ interactions at 189 GeV leading to $W^+ W^-$, $W e \nu_e$, and $\nu \bar{\nu} \gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $-0.11 < \lambda_\gamma < 0.23$.
- ⁷⁶ BREITWEG 00 search for W production in events with large hadronic p_T . For $p_T > 20$ GeV, the upper limit on the cross section gives the 95%CL limit $-3.2 < \lambda_\gamma < 3.2$ for κ_γ fixed to its Standard Model value.
- ⁷⁷ ABBOTT 99I perform a simultaneous fit to the $W\gamma$, $WW \rightarrow$ dilepton, $WW/WZ \rightarrow e\nu jj$, $WW/WZ \rightarrow \mu\nu jj$, and $WZ \rightarrow$ trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $-0.18 < \lambda_\gamma < 0.19$.

κ_Z

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.924^{+0.059}_{-0.056} \pm 0.024$	7171	⁷⁸ ACHARD	04D L3	$E_{cm}^{ee} = 189\text{--}209$ GeV
	17	⁷⁹ ABAZOV	06H D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV
	2.3	⁸⁰ ABAZOV	05s D0	$E_{cm}^{p\bar{p}} = 1.96$ TeV

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

- ⁷⁸ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW -pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.
- ⁷⁹ ABAZOV 06H study $\bar{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+ \nu_e e^- \bar{\nu}_e$, $WW \rightarrow e^\pm \nu_e \mu^\mp \nu_\mu$ or $WW \rightarrow \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $0.55 < \kappa_Z < 1.55$, fixing $\lambda_Z=0$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $0.68 < \kappa < 1.45$.
- ⁸⁰ ABAZOV 05S study $\bar{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\bar{\ell}'$ (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
$-0.088^{+0.060}_{-0.057} \pm 0.023$	7171	81 ACHARD	04D L3	$E_{\text{cm}}^{ee} = 189\text{--}209$ GeV
	17	82 ABAZOV	06H D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV
	2.3	83 ABAZOV	05S D0	$E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV

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

⁸¹ ACHARD 04D study WW -pair production, single- W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW -pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

⁸² ABAZOV 06H study $\bar{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow e^+ \nu_e e^- \bar{\nu}_e$, $WW \rightarrow e^\pm \nu_e \mu^\mp \nu_\mu$ or $WW \rightarrow \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $-0.39 < \lambda_Z < 0.39$, fixing $\kappa_Z = 1$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.

⁸³ ABAZOV 05S study $\bar{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell \nu \ell' \bar{\ell}'$ (ℓ and $\ell' = e$ or μ). Three events (estimated background 0.71 ± 0.08 events) with WZ decay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda = 1.5$ TeV is $-0.48 < \lambda_Z < 0.48$, fixing g_1^Z and κ_Z to their Standard Model values.

g_5^Z

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
0.93 ± 0.09 OUR AVERAGE				Error includes scale factor of 1.1.
$0.96^{+0.13}_{-0.12}$	9800	84 ABBIENDI	04D OPAL	$E_{\text{cm}}^{ee} = 183\text{--}209$ GeV
$1.00 \pm 0.13 \pm 0.05$	7171	85 ACHARD	04D L3	$E_{\text{cm}}^{ee} = 189\text{--}209$ GeV
$0.56^{+0.23}_{-0.22} \pm 0.12$	1154	86 ACCIARRI	99Q L3	$E_{\text{cm}}^{ee} = 161+172+183$ GeV

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

0.84 ± 0.23 ⁸⁷ EBOLI 00 THEO LEP1, SLC+ Tevatron

⁸⁴ ABBIENDI 04D combine results from $W^+ W^-$ in all decay channels. Only CP -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $0.72 < g_5^Z < 1.21$.

⁸⁵ 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.

⁸⁶ ACCIARRI 99Q study W -pair, single- W , and single photon events.

⁸⁷ EBOLI 00 extract this indirect value of the coupling studying the non-universal one-loop contributions to the experimental value of the $Z \rightarrow b\bar{b}$ width ($\Lambda=1$ TeV is assumed).

g_4^Z

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.02^{+0.32}_{-0.33}$	1065	88 ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

⁸⁸ 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*.

$\tilde{\kappa}_Z$

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.20^{+0.10}_{-0.07}$	1065	89 ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

⁸⁹ ABBIENDI 01H study *W*-pair events, with one leptonically and one hadronically decaying *W*. The coupling is extracted using information from the *W* production angle together with decay angles from the leptonically decaying *W*.

$\tilde{\lambda}_Z$

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.18^{+0.24}_{-0.16}$	1065	90 ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

⁹⁰ ABBIENDI 01H study *W*-pair events, with one leptonically and one hadronically decaying *W*. The coupling is extracted using information from the *W* production angle together with decay angles from the leptonically decaying *W*.

W ANOMALOUS MAGNETIC MOMENT

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

VALUE ($e/2m_W$)	EVTS	DOCUMENT ID	TECN	COMMENT
$2.22^{+0.20}_{-0.19}$	2298	91 ABREU	01i DLPH	$E_{cm}^{ee} = 183+189$ GeV

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

92 ABE	95G	CDF
93 ALITTI	92C	UA2
94 SAMUEL	92	THEO
95 SAMUEL	91	THEO
96 GRIFOLS	88	THEO
97 GROTCH	87	THEO
98 VANDERBIJ	87	THEO
99 GRAU	85	THEO
100 SUZUKI	85	THEO
101 HERZOG	84	THEO

- 91 ABREU 01l combine results from e^+e^- interactions at 189 GeV leading to W^+W^- , $W e \nu_e$, and $\nu \bar{\nu} \gamma$ 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^+} .
- 92 ABE 95G report $-1.3 < \kappa < 3.2$ for $\lambda=0$ and $-0.7 < \lambda < 0.7$ for $\kappa=1$ in $p\bar{p} \rightarrow e\nu_e\gamma X$ and $\mu\nu_\mu\gamma X$ at $\sqrt{s} = 1.8$ TeV.
- 93 ALITTI 92C measure $\kappa = 1^{+2.6}_{-2.2}$ and $\lambda = 0^{+1.7}_{-1.8}$ in $p\bar{p} \rightarrow e\nu\gamma + X$ at $\sqrt{s} = 630$ GeV. At 95%CL they report $-3.5 < \kappa < 5.9$ and $-3.6 < \lambda < 3.5$.
- 94 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.
- 95 SAMUEL 91 use preliminary CDF data for $p\bar{p} \rightarrow W\gamma X$ to obtain $-11.3 \leq \Delta\kappa \leq 10.9$. Note that their $\kappa = 1 - \Delta\kappa$.
- 96 GRIFOLS 88 uses deviation from ρ parameter to set limit $\Delta\kappa \lesssim 65 (M_W^2/\Lambda^2)$.
- 97 GROTCHE 87 finds the limit $-37 < \Delta\kappa < 73.5$ (90% CL) from the experimental limits on $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ assuming three neutrino generations and $-19.5 < \Delta\kappa < 56$ for four generations. Note their $\Delta\kappa$ has the opposite sign as our definition.
- 98 VANDERBIJ 87 uses existing limits to the photon structure to obtain $|\Delta\kappa| < 33 (m_W/\Lambda)$. In addition VANDERBIJ 87 discusses problems with using the ρ parameter of the Standard Model to determine $\Delta\kappa$.
- 99 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 $\lambda = 0$.
- 100 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 $|\Delta\kappa| \ll 1$.
- 101 HERZOG 84 consider the contribution of W -boson to muon magnetic moment including anomalous coupling of $WW\gamma$. Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV.

ANOMALOUS W/Z QUARTIC COUPLINGS

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a_0/Λ^2 , a_c/Λ^2 , a_n/Λ^2

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

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

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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
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• • • We do not use the following data for averages, fits, limits, etc. • • •

102	ABBIENDI	04B	OPAL
103	ABBIENDI	04L	OPAL
104	HEISTER	04A	ALEP
105	ABDALLAH	03I	DLPH
106	ACHARD	02F	L3

- 102 ABBIENDI 04B select 187 $e^+e^- \rightarrow W^+W^-\gamma$ events in the C.M. energy range 180–209 GeV, where $E_\gamma > 2.5$ GeV, the photon has a polar angle $|\cos\theta_\gamma| < 0.975$ and is well isolated from the nearest jet and charged lepton, and the effective masses of both fermion-antifermion systems agree with the W mass within $3\Gamma_W$. The measured differential cross section as a function of the photon energy and photon polar angle is used to extract the 95% CL limits: $-0.020 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.020 \text{ GeV}^{-2}$, $-0.053 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.037 \text{ GeV}^{-2}$ and $-0.16 \text{ GeV}^{-2} < a_n/\Lambda^2 < 0.15 \text{ GeV}^{-2}$.
- 103 ABBIENDI 04L select 20 $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+e^- \rightarrow q\bar{q}\gamma\gamma$ 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: $-0.007 < a_0^Z/\Lambda^2 < 0.023 \text{ GeV}^{-2}$, $-0.029 < a_c^Z/\Lambda^2 < 0.029 \text{ GeV}^{-2}$, $-0.020 < a_0^W/\Lambda^2 < 0.020 \text{ GeV}^{-2}$, $-0.052 < a_c^W/\Lambda^2 < 0.037 \text{ GeV}^{-2}$.
- 104 In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon-photon acoplanarity is required to be $> 5^\circ$, $E_\gamma/\sqrt{s} > 0.025$ (the more energetic photon having energy $> 0.2\sqrt{s}$), $p_{T\gamma}/E_{\text{beam}} > 0.05$ and $|\cos\theta_\gamma| < 0.94$. A likelihood fit to the photon energy and recoil missing mass yields the following one-parameter 95% CL limits: $-0.012 < a_0^Z/\Lambda^2 < 0.019 \text{ GeV}^{-2}$, $-0.041 < a_c^Z/\Lambda^2 < 0.044 \text{ GeV}^{-2}$, $-0.060 < a_0^W/\Lambda^2 < 0.055 \text{ GeV}^{-2}$, $-0.099 < a_c^W/\Lambda^2 < 0.093 \text{ GeV}^{-2}$.
- 105 ABDALLAH 03I select 122 $e^+e^- \rightarrow W^+W^-\gamma$ events in the C.M. energy range 189–209 GeV, where $E_\gamma > 5$ GeV, the photon has a polar angle $|\cos\theta_\gamma| < 0.95$ and is well isolated from the nearest charged fermion. A fit to the photon energy spectra yields $a_c/\Lambda^2 = 0.000_{-0.040}^{+0.019} \text{ GeV}^{-2}$, $a_0/\Lambda^2 = -0.004_{-0.010}^{+0.018} \text{ GeV}^{-2}$, $\tilde{a}_0/\Lambda^2 = -0.007_{-0.008}^{+0.019} \text{ GeV}^{-2}$, $a_n/\Lambda^2 = -0.09_{-0.05}^{+0.16} \text{ GeV}^{-2}$, and $\tilde{a}_n/\Lambda^2 = +0.05_{-0.15}^{+0.07} \text{ GeV}^{-2}$, keeping the other parameters fixed to their Standard Model values (0). The 95% CL limits are: $-0.063 \text{ GeV}^{-2} < a_c/\Lambda^2 < +0.032 \text{ GeV}^{-2}$, $-0.020 \text{ GeV}^{-2} < a_0/\Lambda^2 < +0.020 \text{ GeV}^{-2}$, $-0.020 \text{ GeV}^{-2} < \tilde{a}_0/\Lambda^2 < +0.020 \text{ GeV}^{-2}$, $-0.18 \text{ GeV}^{-2} < a_n/\Lambda^2 < +0.14 \text{ GeV}^{-2}$, $-0.16 \text{ GeV}^{-2} < \tilde{a}_n/\Lambda^2 < +0.17 \text{ GeV}^{-2}$.
- 106 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 $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ 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: $a_0/\Lambda^2 = 0.000 \pm 0.010 \text{ GeV}^{-2}$, $a_c/\Lambda^2 = -0.013 \pm 0.023 \text{ GeV}^{-2}$, and $a_n/\Lambda^2 = -0.002 \pm 0.076 \text{ GeV}^{-2}$. Further combining the analyses of $W^+W^-\gamma$ events with the low recoil mass region of $\nu\bar{\nu}\gamma\gamma$ events (including samples collected at 183 + 189 GeV), they obtain the following one-parameter 95% CL limits: $-0.015 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.015 \text{ GeV}^{-2}$, $-0.048 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.026 \text{ GeV}^{-2}$, and $-0.14 \text{ GeV}^{-2} < a_n/\Lambda^2 < 0.13 \text{ GeV}^{-2}$.

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