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### W MASS

To obtain the world average, common systematics between experiments are properly taken into account. The procedure for averaging the LEP data is given in the note LEPEWWG/MASS/2002-01 (March 11, 2002), accessible at [http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg\\_2002/](http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg_2002/). The LEP average  $W$  mass based on published results is  $80.400 \pm 0.056$  GeV. The combined  $p\bar{p}$  collider data yields an average  $W$  mass of  $80.454 \pm 0.059$  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>
<b>80.425 ± 0.038 OUR FIT</b>				
80.41 ± 0.41 ± 0.13	1101	<sup>1</sup> ABBIENDI	03C OPAL	$E_{cm}^{ee} = 183\text{--}207$ GeV
80.483 ± 0.084	49247	<sup>2</sup> ABAZOV	02D D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
80.432 ± 0.066 ± 0.045	2789	<sup>3</sup> ABBIENDI	01F OPAL	$E_{cm}^{ee} = 161+172+183$ +189 GeV
80.359 ± 0.074 ± 0.049	3077	<sup>4</sup> ABREU	01K DLPH	$E_{cm}^{ee} = 161+172+183$ +189 GeV
80.433 ± 0.079	53841	<sup>5</sup> AFFOLDER	01E CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
80.418 ± 0.061 ± 0.047	2977	<sup>6</sup> BARATE	00T ALEP	$E_{cm}^{ee} = 161+172+183$ +189 GeV
80.61 ± 0.15	801	<sup>7</sup> ACCIARRI	99 L3	$E_{cm}^{ee} = 161+172+183$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
80.3 ± 2.1 ± 1.2 ± 1.0	645	<sup>8</sup> CHEKANOV	02C ZEUS	$e^- p \rightarrow \nu_e X$ , $\sqrt{s} = 318$ GeV
79.9 ± 2.2 ± 2.3	700	<sup>9</sup> ADLOFF	01A H1	$e^- p \rightarrow \nu_e X$ , $\sqrt{s} \approx$ 320 GeV
80.482 ± 0.091	45394	<sup>10</sup> ABBOTT	00 D0	Repl. by ABAZOV 02D
80.9 ± 3.7 ± 3.7	700	<sup>11</sup> ADLOFF	00B H1	$e^+ p \rightarrow \bar{\nu}_e X$ , $\sqrt{s} \approx$ 300 GeV
81.4 <sup>+2.7</sup> <sub>-2.6</sub> ± 2.0 <sup>+3.3</sup> <sub>-3.0</sub>	1086	<sup>12</sup> BREITWEG	00D ZEUS	$e^+ p \rightarrow \bar{\nu}_e X$ , $\sqrt{s} \approx$ 300 GeV
80.38 ± 0.12 ± 0.05	701	<sup>13</sup> ABBIENDI	99C OPAL	Repl. by ABBIENDI 01F
80.270 ± 0.137 ± 0.048	809	<sup>14</sup> ABREU	99T DLPH	Repl. by ABREU 01K
80.423 ± 0.112 ± 0.054	812	<sup>15</sup> BARATE	99 ALEP	Repl. by BARATE 00T
80.80 <sup>+0.48</sup> <sub>-0.42</sub> ± 0.03	20	<sup>16</sup> ACCIARRI	97 L3	Repl. by ACCIARRI 99
80.5 <sup>+1.4</sup> <sub>-2.4</sub> ± 0.3	94	<sup>17</sup> ACCIARRI	97M L3	Repl. by ACCIARRI 99
80.71 <sup>+0.34</sup> <sub>-0.35</sub> ± 0.09	101	<sup>18</sup> ACCIARRI	97S L3	Repl. by ACCIARRI 99

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

- <sup>1</sup> ABBIENDI 03C determine the mass of the  $W$  boson using fully leptonic decays  $W^+ W^- \rightarrow \ell \nu_\ell \ell' \nu_{\ell'}$ . They use the measured energies of the charged leptons and an approximate kinematic reconstruction of the event (both neutrinos are assumed in the same plane as the charged leptons) to get a  $W$  pseudo-mass. All these variables are combined in a simultaneous maximum likelihood fit. The systematic error is dominated by the uncertainty on the lepton energy.
- <sup>2</sup> ABAZOV 02D improve the measurement of the  $W$ -boson mass including  $W \rightarrow e \nu_e$  events in which the electron is close to a boundary of a central electromagnetic calorimeter module. Properly combining the results obtained by fitting  $m_T(W)$ ,  $p_T(e)$ , and  $p_T(\nu)$ , this sample provides a mass value of  $80.574 \pm 0.405$  GeV. The value reported here is a combination of this measurement with all previous  $D\bar{O}$   $W$ -boson mass measurements.
- <sup>3</sup> ABBIENDI 01F obtain this value properly combining results obtained from a direct  $W$  mass reconstruction at 172, 183, and 189 GeV with that from measurement of the  $W$ -pair production cross section at 161 GeV. The systematic error includes  $\pm 0.017$  GeV due to LEP energy uncertainty and  $\pm 0.028$  GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- <sup>4</sup> 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  $\pm 0.017$  GeV due to the beam energy uncertainty and  $\pm 0.033$  GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- <sup>5</sup> 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.
- <sup>6</sup> BARATE 00T obtain this value properly combining results obtained from a direct  $W$  mass reconstruction at 172, 183, and 189 GeV with those from measurements of  $W$ -pair production cross sections at 161 and 172 GeV. The systematic error includes  $\pm 0.017$  GeV due to LEP energy uncertainty and  $\pm 0.019$  GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- <sup>7</sup> ACCIARRI 99 obtain this value properly combining results obtained from a direct  $W$  mass reconstruction at 172 and 183 GeV with those from the measurements of the total  $W$ -pair production cross sections at 161 and 172 GeV. The value of the mass obtained from the direct reconstruction at 172 and 183 GeV is  $M(W) = 80.58 \pm 0.14 \pm 0.08$  GeV.
- <sup>8</sup> CHEKANOV 02C fit the  $Q^2$  dependence ( $200 < Q^2 < 60000$  GeV<sup>2</sup>) 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.
- <sup>9</sup> ADLOFF 01A fit the  $Q^2$  dependence ( $150 < Q^2 < 30000$  GeV<sup>2</sup>) of the charged-current double-differential cross sections with a propagator mass fit. The second error includes 2.1 GeV due to the theoretical uncertainties.

- <sup>10</sup> ABBOTT 00 use  $W \rightarrow e\nu_e$  events to measure the  $W$  mass with a fit to the transverse mass distribution. The result quoted here corresponds to electrons detected both in the forward and in the central calorimeters for the data recorded in 1992–1995. For the large rapidity electrons recorded in 1994–1995, the analysis combines results obtained from  $m_T$ ,  $p_T(e)$ , and  $p_T(\nu)$ .
- <sup>11</sup> ADLOFF 00B fit the  $Q^2$  dependence ( $300 < Q^2 < 15000 \text{ GeV}^2$ ) of the charged-current double-differential cross sections with a propagator mass fit. The second error is due to the theoretical uncertainties.
- <sup>12</sup> BREITWEG 00D fit the  $Q^2$  dependence ( $200 < Q^2 < 22500 \text{ GeV}^2$ ) 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.
- <sup>13</sup> ABBIENDI 99C obtain this value properly combining results from a direct  $W$  mass reconstruction at 172 and 183 GeV with that from the measurement of the total  $W$ -pair production cross section at 161 GeV. The systematic error includes an uncertainty of  $\pm 0.02 \text{ GeV}$  due to the possible color-reconnection and Bose-Einstein effects in the purely hadronic final states and an uncertainty of  $\pm 0.02 \text{ GeV}$  due to the beam energy.
- <sup>14</sup> ABREU 99T obtain this value properly combining results obtained from a direct  $W$  mass reconstruction at 172 and 183 GeV with those from measurement of  $W$ -pair production cross sections at 161, 172, and 183 GeV. The systematic error includes  $\pm 0.021 \text{ GeV}$  due to the beam energy uncertainty and  $\pm 0.030 \text{ GeV}$  due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- <sup>15</sup> BARATE 99 obtain this value properly combining results from a direct  $W$  mass reconstruction at 172 and 183 GeV with those from the measurements of the total  $W$ -pair production cross sections at 161 and 172 GeV. The systematic error includes  $\pm 0.023 \text{ GeV}$  due to LEP energy uncertainty and  $\pm 0.021 \text{ GeV}$  due to theory uncertainty on account of possible color reconnection and Bose-Einstein correlations.
- <sup>16</sup> ACCIARRI 97 derive this value from their measured  $W$ - $W$  production cross section  $\sigma_{WW} = 2.89^{+0.81}_{-0.70} \pm 0.14 \text{ pb}$  using the Standard Model dependence of  $\sigma_{WW}$  on  $M_W$  at the given c.m. energy. Statistical and systematic errors are added in quadrature and the last error of  $\pm 0.03 \text{ GeV}$  arises from the beam energy uncertainty. The same result is given by a fit of the production cross sections to the data.
- <sup>17</sup> ACCIARRI 97M derive this value from their measured  $W$   $W$  production cross section  $\sigma_{WW} = 12.27^{+1.41}_{-1.32} \pm 0.23 \text{ pb}$  using the Standard Model dependence of  $\sigma_{WW}$  on  $M_W$  at the given c.m. energy. Combining with ACCIARRI 97 authors find  $M(W) = 80.78^{+0.45}_{-0.41} \pm 0.03 \text{ GeV}$  where the last error is due to beam energy uncertainty.
- <sup>18</sup> ACCIARRI 97S obtain this value from a fit to the reconstructed  $W$  mass distribution. The  $W$  width was taken as its Standard Model value at the fitted  $W$  mass. When both  $W$  mass and width are varied they obtain  $M(W) = 80.72^{+0.31}_{-0.33} \pm 0.09 \text{ GeV}$ . The systematic error includes  $\pm 0.03 \text{ GeV}$  due to the beam energy uncertainty and  $\pm 0.05 \text{ GeV}$  due to the possible color reconnection and Bose-Einstein effects in the purely hadronic final state. Combining with ACCIARRI 97 and ACCIARRI 97M authors find:  $M(W) = 80.75^{+0.26}_{-0.27} \pm 0.03 \text{ (LEP) GeV}$ .
- <sup>19</sup> ABE 95P use 3268  $W \rightarrow \mu\nu_\mu$  events to find  $M = 80.310 \pm 0.205 \pm 0.130 \text{ GeV}$  and 5718  $W \rightarrow e\nu_e$  events to find  $M = 80.490 \pm 0.145 \pm 0.175 \text{ GeV}$ . The result given here combines these while accounting for correlated uncertainties.
- <sup>20</sup> ALITTI 92B result has two contributions to the systematic error ( $\pm 0.83$ ); one ( $\pm 0.81$ ) cancels in  $m_W/m_Z$  and one ( $\pm 0.17$ ) 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.
- <sup>21</sup> 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.
- <sup>22</sup> ABE 89I systematic error dominated by the uncertainty in the absolute energy scale.
- <sup>23</sup> ALBAJAR 89 result is from a total sample of 299  $W \rightarrow e\nu$  events.
- <sup>24</sup> ALBAJAR 89 result is from a total sample of 67  $W \rightarrow \mu\nu$  events.
- <sup>25</sup> ALBAJAR 89 result is from  $W \rightarrow \tau\nu$  events.

## 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>
<b>0.88197 ± 0.00042 OUR FIT</b>				
0.8821 ± 0.0011 ± 0.0008	28323	<sup>26</sup> ABBOTT	98N D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
0.88114 ± 0.00154 ± 0.00252	5982	<sup>27</sup> ABBOTT	98P D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
0.8813 ± 0.0036 ± 0.0019	156	<sup>28</sup> ALITTI	92B UA2	$E_{cm}^{p\bar{p}} = 630$ GeV

<sup>26</sup> 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.

<sup>27</sup> 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.

<sup>28</sup> 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>
<b>10.763 ± 0.038 OUR FIT</b>			
<b>10.4 ± 1.4 ± 0.8</b>	ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
11.3 ± 1.3 ± 0.9	ANSARI	87 UA2	$E_{cm}^{p\bar{p}} = 546,630$ 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>
<b>-0.19 ± 0.58</b>	1722	ABE	90G CDF	$E_{cm}^{p\bar{p}} = 1.8$ 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  $2.0921 \pm 0.0025$  GeV (see Review on "Electroweak model and constraints on new physics" in this Edition).

To obtain OUR FIT, the correlation between systematics within LEP experiments and within Tevatron experiments is properly taken into account as given in the LEP note LEPEWWG/MASS/2002-01 ([http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg\\_2002/](http://lepewwg.web.cern.ch/LEPEWWG/lepww/mw/pdg_2002/)) and the combined Tevatron paper of ABAZOV 04D. The respective average values ( $2.17 \pm 0.12$  GeV from LEP and  $2.115 \pm 0.105$  GeV from Tevatron)

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

They further combine the Tevatron direct and extracted  $W$  widths to obtain an average Tevatron width of  $2.135 \pm 0.050$  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
<b>2.138±0.044 OUR FIT</b>					
2.23 $\begin{smallmatrix} +0.15 \\ -0.14 \end{smallmatrix}$ ±0.10		294	<sup>29</sup> ABAZOV	02E D0	Direct meas.
2.04 ±0.16 ±0.09		2756	<sup>30</sup> ABBIENDI	01F OPAL	$E_{cm}^{ee} = 172+183$ +189 GeV
2.266±0.176±0.076		3005	<sup>31</sup> ABREU	01K DLPH	$E_{cm}^{ee} = 183+189$ GeV
2.152±0.066		79176	<sup>32</sup> ABBOTT	00B D0	Extracted value
2.05 ±0.10 ±0.08		662	<sup>33</sup> AFFOLDER	00M CDF	Direct meas.
2.24 ±0.20 ±0.13		1711	<sup>34</sup> BARATE	00T ALEP	$E_{cm}^{ee} = 189$ GeV
1.97 ±0.34 ±0.17		687	<sup>35</sup> ACCIARRI	99 L3	$E_{cm}^{ee} = 172+183$ GeV
2.064±0.060±0.059			<sup>36</sup> ABE	95W CDF	Extracted value
2.10 $\begin{smallmatrix} +0.14 \\ -0.13 \end{smallmatrix}$ ±0.09		3559	<sup>37</sup> ALITTI	92 UA2	Extracted value
2.18 $\begin{smallmatrix} +0.26 \\ -0.24 \end{smallmatrix}$ ±0.04			<sup>38</sup> ALBAJAR	91 UA1	Extracted value
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
1.84 ±0.32 ±0.20		674	<sup>39</sup> ABBIENDI	99C OPAL	Repl. by ABBI- ENDI 01F
2.044±0.097		11858	<sup>40</sup> ABBOTT	99H D0	Repl. by AB- BOTT 00B
2.48 ±0.40 ±0.10		737	<sup>41</sup> ABREU	99T DLPH	Repl. by ABREU 01K
2.126 $\begin{smallmatrix} +0.052 \\ -0.048 \end{smallmatrix}$ ±0.035			<sup>42</sup> BARATE	99I ALEP	$E_{cm}^{ee} =$ 161+172+183 GeV
1.74 $\begin{smallmatrix} +0.88 \\ -0.78 \end{smallmatrix}$ ±0.25		101	<sup>43</sup> ACCIARRI	97S L3	Repl. by ACCIA- RRI 99
2.11 ±0.28 ±0.16		58	<sup>44</sup> ABE	95C CDF	Repl. by AF- FOLDER 00M
2.30 ±0.19 ±0.06			<sup>45</sup> ALITTI	90C UA2	Extracted value
2.8 $\begin{smallmatrix} +1.4 \\ -1.5 \end{smallmatrix}$ ±1.3		149	<sup>46</sup> 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	<sup>47</sup> ARNISON	86 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV

<sup>29</sup> 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.

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

<sup>31</sup> 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  $\pm 0.052$  GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- 32 ABBOTT 00B measure  $R = 10.43 \pm 0.27$  for the  $W \rightarrow e\nu_e$  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  $B(Z \rightarrow ee)$ . The value quoted here is obtained combining this result ( $2.169 \pm 0.070$  GeV) with that of ABBOTT 99H.
- 33 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.
- 34 BARATE 00T obtain this value using  $WW \rightarrow q\bar{q}q\bar{q}$ ,  $WW \rightarrow e\nu_e q\bar{q}$ , and  $WW \rightarrow \mu\nu_\mu q\bar{q}$  decays. The systematic error includes  $\pm 0.015$  GeV due to LEP energy uncertainty and  $\pm 0.080$  GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- 35 ACCIARRI 99 obtain this value from a fit to the reconstructed  $W$  mass distribution using data at 172 and 183 GeV.
- 36 ABE 95W measured  $R = 10.90 \pm 0.32 \pm 0.29$ . They use  $m_W = 80.23 \pm 0.18$  GeV,  $\sigma(W)/\sigma(Z) = 3.35 \pm 0.03$ ,  $\Gamma(W \rightarrow e\nu) = 225.9 \pm 0.9$  MeV,  $\Gamma(Z \rightarrow e^+e^-) = 83.98 \pm 0.18$  MeV, and  $\Gamma(Z) = 2.4969 \pm 0.0038$  GeV.
- 37 ALITTI 92 measured  $R = 10.4^{+0.7}_{-0.6} \pm 0.3$ . The values of  $\sigma(Z)$  and  $\sigma(W)$  come from  $O(\alpha_s^2)$  calculations using  $m_W = 80.14 \pm 0.27$  GeV, and  $m_Z = 91.175 \pm 0.021$  GeV along with the corresponding value of  $\sin^2\theta_W = 0.2274$ . They use  $\sigma(W)/\sigma(Z) = 3.26 \pm 0.07 \pm 0.05$  and  $\Gamma(Z) = 2.487 \pm 0.010$  GeV.
- 38 ALBAJAR 91 measured  $R = 9.5^{+1.1}_{-1.0}$  (stat. + syst.).  $\sigma(W)/\sigma(Z)$  is calculated in QCD at the parton level using  $m_W = 80.18 \pm 0.28$  GeV and  $m_Z = 91.172 \pm 0.031$  GeV along with  $\sin^2\theta_W = 0.2322 \pm 0.0014$ . They use  $\sigma(W)/\sigma(Z) = 3.23 \pm 0.05$  and  $\Gamma(Z) = 2.498 \pm 0.020$  GeV. This measurement is obtained combining both the electron and muon channels.
- 39 ABBIENDI 99C obtain this value from a fit to the reconstructed  $W$  mass distribution using data at 172 and 183 GeV. The systematic error includes an uncertainty of  $\pm 0.12$  GeV due to the possible color-reconnection and Bose-Einstein effects in the purely hadronic final states and an uncertainty of  $\pm 0.01$  GeV due to the beam energy.
- 40 ABBOTT 99H measure  $R = 10.90 \pm 0.52$  combining electron and muon channels. They use  $M_W = 80.39 \pm 0.06$  GeV and the SM theoretical predictions for  $\sigma(W)/\sigma(Z)$ ,  $B(Z \rightarrow \ell\ell)$ , and  $\Gamma(W \rightarrow \ell\nu_\ell)$ .
- 41 ABREU 99T obtain this value using  $WW \rightarrow \ell\nu_\ell q\bar{q}$  and  $WW \rightarrow q\bar{q}q\bar{q}$  events. The systematic error includes an uncertainty of  $\pm 0.080$  GeV due to possible color reconnection and Bose-Einstein effects in the purely hadronic final state.
- 42 BARATE 99I obtain this result with a fit to the  $WW$  measured cross sections at 161, 172, and 183 GeV. The theoretical prediction takes into account the sensitivity to the  $W$  total width.
- 43 ACCIARRI 97S obtain this value from a fit to the reconstructed  $W$  mass distribution.
- 44 ABE 95C use the tail of the transverse mass distribution of  $W \rightarrow e\nu_e$  decays.
- 45 ALITTI 90C used the same technique as described for ABE 90. They measured  $R = 9.38^{+0.82}_{-0.72} \pm 0.25$ , obtained  $\Gamma(W)/\Gamma(Z) = 0.902 \pm 0.074 \pm 0.024$ . Using  $\Gamma(Z) = 2.546 \pm 0.032$  GeV, they obtained the  $\Gamma(W)$  value quoted above and the limits  $\Gamma(W) < 2.56$  (2.64) GeV at the 90% (95%) CL.  $E_{\text{cm}}^{p\bar{p}} = 546,630$  GeV.
- 46 ALBAJAR 89 result is from a total sample of 299  $W \rightarrow e\nu$  events.
- 47 If systematic error is neglected, result is  $2.7^{+1.4}_{-1.5}$  GeV. This is enhanced subsample of 172 total events.

## W<sup>+</sup> DECAY MODES

W<sup>-</sup> modes are charge conjugates of the modes below.

Mode	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level
$\Gamma_1$ $\ell^+ \nu$	[a] $(10.80 \pm 0.09) \%$	
$\Gamma_2$ $e^+ \nu$	$(10.75 \pm 0.13) \%$	
$\Gamma_3$ $\mu^+ \nu$	$(10.57 \pm 0.15) \%$	
$\Gamma_4$ $\tau^+ \nu$	$(11.25 \pm 0.20) \%$	
$\Gamma_5$ hadrons	$(67.60 \pm 0.27) \%$	
$\Gamma_6$ $\pi^+ \gamma$	$< 8 \times 10^{-5}$	95%
$\Gamma_7$ $D_s^+ \gamma$	$< 1.3 \times 10^{-3}$	95%
$\Gamma_8$ $cX$	$(33.4 \pm 2.6) \%$	
$\Gamma_9$ $c\bar{s}$	$(31^{+13}_{-11}) \%$	
$\Gamma_{10}$ invisible	[b] $(1.4 \pm 2.8) \%$	

[a]  $\ell$  indicates each type of lepton ( $e$ ,  $\mu$ , and  $\tau$ ), 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

**$\Gamma(\text{invisible})$**

**$\Gamma_{10}$**

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
$30^{+52}_{-48} \pm 33$	<sup>48</sup> BARATE	99I ALEP	$E_{\text{cm}}^{ee} = 161+172+183$ GeV
	• • • We do not use the following data for averages, fits, limits, etc. • • •		
	<sup>49</sup> BARATE	99L ALEP	$E_{\text{cm}}^{ee} = 161+172+183$ GeV

<sup>48</sup> BARATE 99I measure this quantity using the dependence of the total cross section  $\sigma_{WW}$  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.

<sup>49</sup> 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  $B(W \rightarrow \text{hadrons}) = 1 - 3B(W \rightarrow \ell\nu)$ . 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.

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

$\ell$  indicates average over  $e, \mu,$  and  $\tau$  modes, not sum over modes.

$\Gamma_1/\Gamma$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b>0.1080 ± 0.0009 OUR FIT</b>				
0.1085 ± 0.0014 ± 0.0008	13600	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1083 ± 0.0014 ± 0.0010	11246	ACHARD	04J L3	$E_{\text{cm}}^{ee} = 161\text{--}209$ GeV
0.1096 ± 0.0012 ± 0.0005	16116	SCHAEL	04A ALEP	$E_{\text{cm}}^{ee} = 183\text{--}209$ 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	<sup>50</sup> ABBOTT	99H D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
0.104 ± 0.008	3642	<sup>51</sup> ABE	92I CDF	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
0.1071 ± 0.0024 ± 0.0014	4843	ABREU	00K DLPH	Repl. by ABDAL- LAH 04G
0.1060 ± 0.0023 ± 0.0011	5328	ACCIARRI	00V L3	Repl. by ACHARD 04J
0.1101 ± 0.0022 ± 0.0011	5258	BARATE	00J ALEP	Repl. by SCHAEL 04A
0.107 ± 0.004 ± 0.002	1440	ABBIENDI	99D OPAL	Repl. by ABBI- ENDI,G 00

<sup>50</sup> 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  $B(Z \rightarrow \ell\ell)$ .

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

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

$\Gamma_2/\Gamma$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b>0.1075 ± 0.0013 OUR FIT</b>				
0.1061 ± 0.0028		<sup>52</sup> 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	<sup>53</sup> ANSARI	87C UA2	$E_{\text{cm}}^{p\bar{p}} = 546,630$ GeV



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

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

<sup>52</sup> 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  $[\sigma_W \cdot B(W \rightarrow e\nu_e)] / [\sigma_Z \cdot B(Z \rightarrow ee)]$ . The combination gives  $R^{Tevatron} = 10.59 \pm 0.23$ .  $\sigma_W / \sigma_Z$  is calculated at next-to-next-to-leading order ( $3.360 \pm 0.051$ ). The branching fraction  $B(Z \rightarrow ee)$  is taken from this Review as  $(3.363 \pm 0.004)\%$ .

<sup>53</sup> 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.

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

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

$\Gamma(\mu^+\nu) / \Gamma_{total}$				$\Gamma_3 / \Gamma$
<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.1057 ± 0.0015 OUR FIT</b>				
0.1065 ± 0.0026 ± 0.0008	1998	ABDALLAH	04G DLPH	$E_{cm}^{ee} = 161-209$ GeV
0.1003 ± 0.0029 ± 0.0012	1423	ACHARD	04J L3	$E_{cm}^{ee} = 161-209$ GeV
0.1087 ± 0.0025 ± 0.0008	2216	SCHAEEL	04A ALEP	$E_{cm}^{ee} = 183-209$ GeV
0.1050 ± 0.0041 ± 0.0012	803	ABBIENDI,G	00 OPAL	$E_{cm}^{ee} = 161+172+183$ $+189$ GeV
0.10 ± 0.01	1216	<sup>56</sup> ABE	92I CDF	$E_{cm}^{pp} = 1.8$ TeV

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

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

<sup>56</sup> ABE 92I quote the inverse quantity as  $9.9 \pm 1.2$  which we have inverted.

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

$\Gamma_4/\Gamma$

VALUE                      EVTS                      DOCUMENT ID                      TECN                      COMMENT

**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

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

0.1105 ± 0.0075 ± 0.0032	579	ABREU	00K DLPH	Repl. by ABDAL- LAH 04G
0.1124 ± 0.0062 ± 0.0022	536	ACCIARRI	00V L3	Repl. by ACHARD 04J
0.1051 ± 0.0055 ± 0.0022	607	BARATE	00J ALEP	Repl. by SCHAEEL 04A
0.101 ± 0.010 ± 0.003	183	ABBIENDI	99D OPAL	Repl. by ABBI- ENDI,G 00

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

$\Gamma_5/\Gamma$

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

VALUE                      EVTS                      DOCUMENT ID                      TECN                      COMMENT

**0.6760 ± 0.0027 OUR FIT**

0.6745 ± 0.0041 ± 0.0024	13600	ABDALLAH	04G DLPH	$E_{\text{cm}}^{ee} = 161\text{--}209$ 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	SCHAEL	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

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

0.6789 ± 0.0073 ± 0.0043	4843	ABREU	00K DLPH	Repl. by ABDAL- LAH 04G
0.6820 ± 0.0068 ± 0.0033	5328	ACCIARRI	00V L3	Repl. by ACHARD 04J
0.6697 ± 0.0065 ± 0.0032	5258	BARATE	00J ALEP	Repl. by SCHAEEL 04A
0.679 ± 0.012 ± 0.005	1440	ABBIENDI	99D OPAL	Repl. by ABBI- ENDI,G 00

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

$\Gamma_3/\Gamma_2$

VALUE                      EVTS                      DOCUMENT ID                      TECN                      COMMENT

**0.983 ± 0.018 OUR FIT**

0.89 ± 0.10	13k	<sup>57</sup> ABACHI	95D D0	$E_{\text{cm}}^{p\bar{p}} = 1.8$ TeV
1.02 ± 0.08	1216	<sup>58</sup> 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 <sup>+0.6</sup> <sub>-0.4</sub>	14	ARNISON	84D UA1	Repl. by ALBAJAR 89
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<sup>57</sup> 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.

<sup>58</sup> 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.

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

$\Gamma_4/\Gamma_2$

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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**1.046 ± 0.023 OUR FIT**

0.961 ± 0.061	980	<sup>59</sup> ABBOTT	00D D0	$E_{cm}^{p\bar{p}} = 1.8$ TeV
0.94 ± 0.14	179	<sup>60</sup> ABE	92E CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
1.04 ± 0.08 ± 0.08	754	<sup>61</sup> ALITTI	92F UA2	$E_{cm}^{p\bar{p}} = 630$ GeV
1.02 ± 0.20 ± 0.12	32	ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ 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 ALBAJAR 89

<sup>59</sup> 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.

<sup>60</sup> 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  $\tau$  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.

<sup>61</sup> This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

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

$\Gamma_6/\Gamma_2$

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

<sup>62</sup> ALITTI 92D limit is  $3.8 \times 10^{-3}$  at 90%CL.

<sup>63</sup> ALBAJAR 90 obtain  $< 0.048$  at 90%CL.

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

$\Gamma_7/\Gamma_2$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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$< 1.2 \times 10^{-2}$	95	ABE	98P CDF	$E_{cm}^{p\bar{p}} = 1.8$ TeV
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### $\Gamma(cX)/\Gamma(\text{hadrons})$

$\Gamma_8/\Gamma_5$

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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**0.49 ± 0.04 OUR AVERAGE**

0.481 ± 0.042 ± 0.032	3005	<sup>64</sup> ABBIENDI	00V OPAL	$E_{cm}^{ee} = 183 + 189$ GeV
0.51 ± 0.05 ± 0.03	746	<sup>65</sup> BARATE	99M ALEP	$E_{cm}^{ee} = 172 + 183$ GeV

<sup>64</sup> 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  $0.969 \pm 0.045 \pm 0.036$ .

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

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

$$\Gamma_9/\Gamma_5$$

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

<sup>66</sup> 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
$15.70 \pm 0.35$	<sup>67</sup> ABREU,P	00F DLPH	$E_{cm}^{ee} = 189$ GeV

<sup>67</sup> 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
$2.20 \pm 0.19$	<sup>68</sup> ABREU,P	00F DLPH	$E_{cm}^{ee} = 189$ GeV

<sup>68</sup> 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
$0.92 \pm 0.14$	<sup>69</sup> ABREU,P	00F DLPH	$E_{cm}^{ee} = 189$ GeV

<sup>69</sup> 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
<b><math>19.41 \pm 0.15</math> OUR AVERAGE</b>			
$19.44 \pm 0.17$	<sup>70</sup> ABREU,P	00F DLPH	$E_{cm}^{ee} = 183+189$ GeV
$19.3 \pm 0.3 \pm 0.3$	<sup>71</sup> ABBIENDI	99N OPAL	$E_{cm}^{ee} = 183$ GeV
$19.23 \pm 0.74$	<sup>72</sup> ABREU	98C DLPH	$E_{cm}^{ee} = 172$ GeV

<sup>70</sup> 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.

<sup>71</sup> ABBIENDI 99N use the final states  $W^+ W^- \rightarrow q\bar{q}\ell\bar{\nu}_\ell$  to derive this value.

<sup>72</sup> 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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### $\Delta g_1^Z$

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>).

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

<sup>73</sup> 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.

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

<sup>75</sup> 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.

<sup>76</sup> 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  $-0.16 < \Delta g_1^Z < 0.13$ .

<sup>77</sup> 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  $-0.37 < \Delta g_1^Z < 0.57$ , fixing  $\lambda_Z = \Delta\kappa_Z = 0$  and assuming Standard Model values for the  $WW\gamma$  couplings.

### $\Delta\kappa_\gamma$

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

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

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

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

78 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.

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

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

81 ABREU 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. The 95% confidence interval is  $-0.13 < \Delta\kappa_\gamma < 0.68$ .

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

83 ABBOTT 99l 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  $-0.25 < \Delta\kappa_\gamma < 0.39$ .

### $\lambda_\gamma$

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

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

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

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

84 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.

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

<sup>86</sup> 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.

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

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

<sup>89</sup> 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  $-0.18 < \lambda_\gamma < 0.19$ .

### $\Delta\kappa_Z$

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.076^{+0.059}_{-0.056} \pm 0.024$	7171	<sup>90</sup> ACHARD	04D L3	$E_{cm}^{ee} = 189-209$ GeV

<sup>90</sup> 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.

### $\lambda_Z$

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	<sup>91</sup> ACHARD	04D L3	$E_{cm}^{ee} = 189-209$ GeV

<sup>91</sup> 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.

### $\Delta g_5^Z$

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.07 \pm 0.09$ <b>OUR AVERAGE</b>				Error includes scale factor of 1.1.
$-0.04^{+0.13}_{-0.12}$	9800	<sup>92</sup> ABBIENDI	04D OPAL	$E_{cm}^{ee} = 183-209$ GeV
$0.00 \pm 0.13 \pm 0.05$	7171	<sup>93</sup> ACHARD	04D L3	$E_{cm}^{ee} = 189-209$ GeV
$-0.44^{+0.23}_{-0.22} \pm 0.12$	1154	<sup>94</sup> ACCIARRI	99Q L3	$E_{cm}^{ee} = 161+172+ 183$ GeV

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

$-0.16 \pm 0.23$		<sup>95</sup> EBOLI	00 THEO	LEP1, SLC+ Tevatron
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<sup>92</sup> ABBIENDI 04D combine results from  $W^+W^-$  in all decay channels. Only  $CP$ -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is  $-0.28 < \Delta g_5^Z < 0.21$ .

<sup>93</sup> 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.

<sup>94</sup> ACCIARRI 99Q study  $W$ -pair, single- $W$ , and single photon events.

<sup>95</sup> 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	<sup>96</sup> ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

<sup>96</sup> 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	<sup>97</sup> ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

<sup>97</sup> 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	<sup>98</sup> ABBIENDI	01H OPAL	$E_{cm}^{ee} = 189$ GeV

<sup>98</sup> 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  $\Lambda$  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	<sup>99</sup> ABREU	01i DLPH	$E_{cm}^{ee} = 183+189$ GeV



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

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

- 99 ABREU 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  $\Delta g_1^Z$ ,  $\Delta \kappa_\gamma$ , and  $\lambda_\gamma$ .  $\Delta \kappa_\gamma$  and  $\lambda_\gamma$  are simultaneously floated in the fit to determine  $\mu_W$ .
- 100 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.
- 101 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  $-3.6 < \lambda < 3.5$ .
- 102 SAMUEL 92 use preliminary CDF and UA2 data and find  $-2.4 < \kappa < 3.7$  at 96%CL and  $-3.1 < \kappa < 4.2$  at 95%CL respectively. They use data for  $W\gamma$  production and radiative  $W$  decay.
- 103 SAMUEL 91 use preliminary CDF data for  $p\bar{p} \rightarrow W\gamma X$  to obtain  $-11.3 \leq \Delta\kappa \leq 10.9$ . Note that their  $\kappa = 1 - \Delta\kappa$ .
- 104 GRIFOLS 88 uses deviation from  $\rho$  parameter to set limit  $\Delta\kappa \lesssim 65 (M_W^2/\Lambda^2)$ .
- 105 GROTCH 87 finds the limit  $-37 < \Delta\kappa < 73.5$  (90% CL) from the experimental limits on  $e^+e^- \rightarrow \nu\bar{\nu}\gamma$  assuming three neutrino generations and  $-19.5 < \Delta\kappa < 56$  for four generations. Note their  $\Delta\kappa$  has the opposite sign as our definition.
- 106 VANDERBIJ 87 uses existing limits to the photon structure to obtain  $|\Delta\kappa| < 33 (m_W/\Lambda)$ . In addition VANDERBIJ 87 discusses problems with using the  $\rho$  parameter of the Standard Model to determine  $\Delta\kappa$ .
- 107 GRAU 85 uses the muon anomaly to derive a coupled limit on the anomalous magnetic dipole and electric quadrupole ( $\lambda$ ) moments  $1.05 > \Delta\kappa \ln(\Lambda/m_W) + \lambda/2 > -2.77$ . In the Standard Model  $\lambda = 0$ .
- 108 SUZUKI 85 uses partial-wave unitarity at high energies to obtain  $|\Delta\kappa| \lesssim 190 (m_W/\Lambda)^2$ . From the anomalous magnetic moment of the muon, SUZUKI 85 obtains  $|\Delta\kappa| \lesssim 2.2/\ln(\Lambda/m_W)$ . Finally SUZUKI 85 uses deviations from the  $\rho$  parameter and obtains a very qualitative, order-of-magnitude limit  $|\Delta\kappa| \lesssim 150 (m_W/\Lambda)^4$  if  $|\Delta\kappa| \ll 1$ .
- 109 HERZOG 84 consider the contribution of  $W$ -boson to muon magnetic moment including anomalous coupling of  $WW\gamma$ . Obtain a limit  $-1 < \Delta\kappa < 3$  for  $\Lambda \gtrsim 1$  TeV.

## ANOMALOUS W/Z QUARTIC COUPLINGS

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### $a_0/\Lambda^2$ , $a_c/\Lambda^2$ , $a_n/\Lambda^2$

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. • • •

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

- 110 ABBIENDI 04B select 187  $e^+e^- \rightarrow W^+W^-\gamma$  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  $-0.16 \text{ GeV}^{-2} < a_n/\Lambda^2 < 0.15 \text{ GeV}^{-2}$ .
- 111 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:  $-0.007 < a_0^Z/\Lambda^2 < 0.023 \text{ GeV}^{-2}$ ,  $-0.029 < a_c^Z/\Lambda^2 < 0.029 \text{ GeV}^{-2}$ ,  $-0.020 < a_0^W/\Lambda^2 < 0.020 \text{ GeV}^{-2}$ ,  $-0.052 < a_c^W/\Lambda^2 < 0.037 \text{ GeV}^{-2}$ .
- 112 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  $> 0.2\sqrt{s}$ ),  $p_{T\gamma}/E_{beam} > 0.05$  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:  $-0.012 < a_0^Z/\Lambda^2 < 0.019 \text{ GeV}^{-2}$ ,  $-0.041 < a_c^Z/\Lambda^2 < 0.044 \text{ GeV}^{-2}$ ,  $-0.060 < a_0^W/\Lambda^2 < 0.055 \text{ GeV}^{-2}$ ,  $-0.099 < a_c^W/\Lambda^2 < 0.093 \text{ GeV}^{-2}$ .
- 113 ABDALLAH 03I select 122  $e^+e^- \rightarrow W^+W^-\gamma$  events in the C.M. energy range 189–209 GeV, where  $E_\gamma > 5$  GeV, the photon has a polar angle  $|\cos\theta_\gamma| < 0.95$  and is well isolated from the nearest charged fermion. A fit to the photon energy spectra yields  $a_c/\Lambda^2 = 0.000^{+0.019}_{-0.040} \text{ GeV}^{-2}$ ,  $a_0/\Lambda^2 = -0.004^{+0.018}_{-0.010} \text{ GeV}^{-2}$ ,  $\tilde{a}_0/\Lambda^2 = -0.007^{+0.019}_{-0.008} \text{ GeV}^{-2}$ ,  $a_n/\Lambda^2 = -0.09^{+0.16}_{-0.05} \text{ GeV}^{-2}$ , and  $\tilde{a}_n/\Lambda^2 = +0.05^{+0.07}_{-0.15} \text{ GeV}^{-2}$ , keeping the other parameters fixed to their Standard Model values (0). The 95% CL limits are:  $-0.063 \text{ GeV}^{-2} < a_c/\Lambda^2 < +0.032 \text{ GeV}^{-2}$ ,  $-0.020 \text{ GeV}^{-2} < a_0/\Lambda^2 < +0.020 \text{ GeV}^{-2}$ ,  $-0.020 \text{ GeV}^{-2} < \tilde{a}_0/\Lambda^2 < +0.020 \text{ GeV}^{-2}$ ,  $-0.18 \text{ GeV}^{-2} < a_n/\Lambda^2 < +0.14 \text{ GeV}^{-2}$ ,  $-0.16 \text{ GeV}^{-2} < \tilde{a}_n/\Lambda^2 < +0.17 \text{ GeV}^{-2}$ .
- 114 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  $14^\circ$  and  $166^\circ$ . 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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ABAZOV	04D	PR D70 092008	V.M. Abazov <i>et al.</i>	(CDF, D0 Collab.)
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ABBIENDI	04D	EPJ C33 463	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
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CHEKANOV	02C	PL B539 197	S. Chekanov <i>et al.</i>	(ZEUS Collab.)
ABBIENDI	01F	PL B507 29	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	01H	EPJ C19 229	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABREU	01I	PL B502 9	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	01K	PL B511 159	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ADLOFF	01A	EPJ C19 269	C. Adloff <i>et al.</i>	(H1 Collab.)
AFFOLDER	01E	PR D64 052001	T. Affolder <i>et al.</i>	(CDF Collab.)
ABBIENDI	00V	PL B490 71	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI,G	00	PL B493 249	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	00	PRL 84 222	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	00B	PR D61 072001	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	00D	PRL 84 5710	B. Abbott <i>et al.</i>	(D0 Collab.)
ABREU	00K	PL B479 89	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU,P	00F	EPJ C18 203	P. Abreu <i>et al.</i>	(DELPHI Collab.)
Also	02	EPJ C25 493 (erratum)	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	00T	PL B490 187	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00V	PL B496 19	M. Acciarri <i>et al.</i>	(L3 Collab.)
ADLOFF	00B	EPJ C13 609	C. Adloff <i>et al.</i>	(H1 Collab.)
AFFOLDER	00M	PRL 85 3347	T. Affolder <i>et al.</i>	(CDF Collab.)
BARATE	00J	PL B484 205	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	00T	EPJ C17 241	R. Barate <i>et al.</i>	(ALEPH Collab.)
BREITWEG	00	PL B471 411	J. Breitweg <i>et al.</i>	(ZEUS Collab.)
BREITWEG	00D	EPJ C12 411	J. Breitweg <i>et al.</i>	(ZEUS Collab.)
EBOLI	00	MPL A15 1	O. Eboli, M. Gonzalez-Garcia, S. Novaes	
ABBIENDI	99C	PL B453 138	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	99D	EPJ C8 191	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	99N	PL B453 153	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBOTT	99H	PR D60 052003	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	99I	PR D60 072002	B. Abbott <i>et al.</i>	(D0 Collab.)
ABREU	99L	PL B459 382	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	99T	PL B462 410	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	99	PL B454 386	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	99Q	PL B467 171	M. Acciarri <i>et al.</i>	(L3 Collab.)
BARATE	99	PL B453 121	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	99I	PL B453 107	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	99L	PL B462 389	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	99M	PL B465 349	R. Barate <i>et al.</i>	(ALEPH Collab.)
ABBOTT	98N	PR D58 092003	B. Abbott <i>et al.</i>	(D0 Collab.)
ABBOTT	98P	PR D58 012002	B. Abbott <i>et al.</i>	(D0 Collab.)
ABE	98H	PR D58 031101	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	98P	PR D58 091101	F. Abe <i>et al.</i>	(CDF Collab.)
ABREU	98C	PL B416 233	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	98N	PL B439 209	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	97	PL B398 223	M. Acciarri <i>et al.</i>	(L3 Collab.)

ACCIARRI	97M	PL B407 419	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	97S	PL B413 176	M. Acciarri <i>et al.</i>	(L3 Collab.)
ABACHI	95D	PRL 75 1456	S. Abachi <i>et al.</i>	(D0 Collab.)
ABE	95C	PRL 74 341	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	95G	PRL 74 1936	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	95P	PRL 75 11	F. Abe <i>et al.</i>	(CDF Collab.)
Also	95Q	PR D52 4784	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	95W	PR D52 2624	F. Abe <i>et al.</i>	(CDF Collab.)
Also	94B	PRL 73 220	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	92E	PRL 68 3398	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	92I	PRL 69 28	F. Abe <i>et al.</i>	(CDF Collab.)
ALITTI	92	PL B276 365	J. Alitti <i>et al.</i>	(UA2 Collab.)
ALITTI	92B	PL B276 354	J. Alitti <i>et al.</i>	(UA2 Collab.)
ALITTI	92C	PL B277 194	J. Alitti <i>et al.</i>	(UA2 Collab.)
ALITTI	92D	PL B277 203	J. Alitti <i>et al.</i>	(UA2 Collab.)
ALITTI	92F	PL B280 137	J. Alitti <i>et al.</i>	(UA2 Collab.)
SAMUEL	92	PL B280 124	M.A. Samuel <i>et al.</i>	(OKSU, CARL)
ABE	91C	PR D44 29	F. Abe <i>et al.</i>	(CDF Collab.)
ALBAJAR	91	PL B253 503	C. Albajar <i>et al.</i>	(UA1 Collab.)
ALITTI	91C	ZPHY C52 209	J. Alitti <i>et al.</i>	(UA2 Collab.)
SAMUEL	91	PRL 67 9	M.A. Samuel <i>et al.</i>	(OKSU, CARL)
Also	91C	PRL 67 2920 erratum	M.A. Samuel <i>et al.</i>	
ABE	90	PRL 64 152	F. Abe <i>et al.</i>	(CDF Collab.)
Also	91C	PR D44 29	F. Abe <i>et al.</i>	(CDF Collab.)
ABE	90G	PRL 65 2243	F. Abe <i>et al.</i>	(CDF Collab.)
Also	91B	PR D43 2070	F. Abe <i>et al.</i>	(CDF Collab.)
ALBAJAR	90	PL B241 283	C. Albajar <i>et al.</i>	(UA1 Collab.)
ALITTI	90B	PL B241 150	J. Alitti <i>et al.</i>	(UA2 Collab.)
ALITTI	90C	ZPHY C47 11	J. Alitti <i>et al.</i>	(UA2 Collab.)
ABE	89I	PRL 62 1005	F. Abe <i>et al.</i>	(CDF Collab.)
ALBAJAR	89	ZPHY C44 15	C. Albajar <i>et al.</i>	(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	87	PL B197 437	J.A. Grifols, S. Peris, J. Sola	(BARC, DESY)
ALBAJAR	87	PL B185 233	C. Albajar <i>et al.</i>	(UA1 Collab.)
ANSARI	87	PL B186 440	R. Ansari <i>et al.</i>	(UA2 Collab.)
ANSARI	87C	PL B194 158	R. Ansari <i>et al.</i>	(UA2 Collab.)
GROTCH	87	PR D36 2153	H. Grotch, R.W. Robinett	(PSU)
HAGIWARA	87	NP B282 253	K. Hagiwara <i>et al.</i>	(KEK, UCLA, FSU)
VANDERBIJ	87	PR D35 1088	J.J. van der Bij	(FNAL)
APPEL	86	ZPHY C30 1	J.A. Appel <i>et al.</i>	(UA2 Collab.)
ARNISON	86	PL 166B 484	G.T.J. Arnison <i>et al.</i>	(UA1 Collab.)
ALTARELLI	85B	ZPHY C27 617	G. Altarelli, R.K. Ellis, G. Martinelli	(CERN+)
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 <i>et al.</i>	(UA1 Collab.)
HERZOG	84	PL 148B 355	F. Herzog	(WISC)
Also	84B	PL 155B 468 erratum	F. Herzog	(WISC)
ARNISON	83	PL 122B 103	G.T.J. Arnison <i>et al.</i>	(UA1 Collab.)
BANNER	83B	PL 122B 476	M. Banner <i>et al.</i>	(UA2 Collab.)