



$$J = 1$$

See the related review(s):

[Z Boson](#)

## Z MASS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06). The fit is performed using the Z mass and width, the Z hadronic pole cross section, the ratios of hadronic to leptonic partial widths, and the Z pole forward-backward lepton asymmetries. This set is believed to be most free of correlations.

The Z-boson mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass dependent width. The value is 34 MeV greater than the real part of the position of the pole (in the energy-squared plane) in the Z-boson propagator. Also the LEP experiments have generally assumed a fixed value of the  $\gamma - Z$  interferences term based on the standard model. Keeping this term as free parameter leads to a somewhat larger error on the fitted Z mass. See ACCIARRI 00Q and ABBIENDI 04G for a detailed investigation of both these issues.

| <u>VALUE (GeV)</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u>       | <u>TECN</u> | <u>COMMENT</u>                               |
|---|-------------|--------------------------|-------------|--|
| <b>91.1876 ± 0.0021 OUR FIT</b>   |             |                          |             |  |
| 91.1852 ± 0.0030  | 4.57M       | <sup>1</sup> ABBIENDI    | 01A OPAL    | $E_{cm}^{ee} = 88-94$ GeV                    |
| 91.1863 ± 0.0028  | 4.08M       | <sup>2</sup> ABREU       | 00F DLPH    | $E_{cm}^{ee} = 88-94$ GeV                    |
| 91.1898 ± 0.0031  | 3.96M       | <sup>3</sup> ACCIARRI    | 00C L3      | $E_{cm}^{ee} = 88-94$ GeV                    |
| 91.1885 ± 0.0031  | 4.57M       | <sup>4</sup> BARATE      | 00C ALEP    | $E_{cm}^{ee} = 88-94$ GeV                    |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |             |                          |             |  |
| 91.084 ± 0.107  |             | <sup>5</sup> ANDREEV     | 18A H1      | $e^{\pm} p$                                  |
| 91.1872 ± 0.0033  |             | <sup>6</sup> ABBIENDI    | 04G OPAL    | $E_{cm}^{ee} = \text{LEP1} +$<br>130–209 GeV |
| 91.272 ± 0.032 ± 0.033  |             | <sup>7</sup> ACHARD      | 04C L3      | $E_{cm}^{ee} = 183-209$ GeV                  |
| 91.1875 ± 0.0039  | 3.97M       | <sup>8</sup> ACCIARRI    | 00Q L3      | $E_{cm}^{ee} = \text{LEP1} +$<br>130–189 GeV |
| 91.151 ± 0.008  |             | <sup>9</sup> MIYABAYASHI | 95 TOPZ     | $E_{cm}^{ee} = 57.8$ GeV                     |
| 91.74 ± 0.28 ± 0.93   | 156         | <sup>10</sup> ALITTI     | 92B UA2     | $E_{cm}^{p\bar{p}} = 630$ GeV                |
| 90.9 ± 0.3 ± 0.2  | 188         | <sup>11</sup> ABE        | 89C CDF     | $E_{cm}^{p\bar{p}} = 1.8$ TeV                |
| 91.14 ± 0.12  | 480         | <sup>12</sup> ABRAMS     | 89B MRK2    | $E_{cm}^{ee} = 89-93$ GeV                    |
| 93.1 ± 1.0 ± 3.0  | 24          | <sup>13</sup> ALBAJAR    | 89 UA1      | $E_{cm}^{p\bar{p}} = 546,630$ GeV            |

<sup>1</sup> ABBIENDI 01A error includes approximately 2.3 MeV due to statistics and 1.8 MeV due to LEP energy uncertainty.

<sup>2</sup> The error includes 1.6 MeV due to LEP energy uncertainty.

<sup>3</sup> The error includes 1.8 MeV due to LEP energy uncertainty.

<sup>4</sup> BARATE 00C error includes approximately 2.4 MeV due to statistics, 0.2 MeV due to experimental systematics, and 1.7 MeV due to LEP energy uncertainty.

- <sup>5</sup> ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic  $e^+p$  and  $e^-p$  neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.
- <sup>6</sup> ABBIENDI 04G obtain this result using the S-matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit–Wigner fits.
- <sup>7</sup> ACHARD 04C select  $e^+e^- \rightarrow Z\gamma$  events with hard initial-state radiation. Z decays to  $q\bar{q}$  and muon pairs are considered. The fit results obtained in the two samples are found consistent to each other and combined considering the uncertainty due to ISR modelling as fully correlated.
- <sup>8</sup> ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00C) as constraints. The 130–189 GeV data constrains the  $\gamma/Z$  interference term. The authors have corrected the measurement for the 34.1 MeV shift with respect to the Breit-Wigner fits. The error contains a contribution of  $\pm 2.3$  MeV due to the uncertainty on the  $\gamma Z$  interference.
- <sup>9</sup> MIYABAYASHI 95 combine their low energy total hadronic cross-section measurement with the ACTON 93D data and perform a fit using an S-matrix formalism. As expected, this result is below the mass values obtained with the standard Breit-Wigner parametrization.
- <sup>10</sup> Enters fit through  $W/Z$  mass ratio given in the W Particle Listings. The ALITTI 92B systematic error ( $\pm 0.93$ ) has two contributions: one ( $\pm 0.92$ ) cancels in  $m_W/m_Z$  and one ( $\pm 0.12$ ) is noncancelling. These were added in quadrature.
- <sup>11</sup> First error of ABE 89 is combination of statistical and systematic contributions; second is mass scale uncertainty.
- <sup>12</sup> ABRAMS 89B uncertainty includes 35 MeV due to the absolute energy measurement.
- <sup>13</sup> ALBAJAR 89 result is from a total sample of 33  $Z \rightarrow e^+e^-$  events.

## Z WIDTH

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06).

| VALUE (GeV)   | EVTS  | DOCUMENT ID               | TECN | COMMENT   |
|---|-------|---------------------------|------|---|
| <b>2.4952 ± 0.0023 OUR FIT</b>  |       |                           |      |   |
| 2.4948 ± 0.0041   | 4.57M | <sup>1</sup> ABBIENDI 01A | OPAL | $E_{cm}^{ee} = 88\text{--}94$ GeV                 |
| 2.4876 ± 0.0041   | 4.08M | <sup>2</sup> ABREU 00F    | DLPH | $E_{cm}^{ee} = 88\text{--}94$ GeV                 |
| 2.5024 ± 0.0042   | 3.96M | <sup>3</sup> ACCIARRI 00C | L3   | $E_{cm}^{ee} = 88\text{--}94$ GeV                 |
| 2.4951 ± 0.0043   | 4.57M | <sup>4</sup> BARATE 00C   | ALEP | $E_{cm}^{ee} = 88\text{--}94$ GeV                 |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |       |                           |      |   |
| 2.4943 ± 0.0041   |       | <sup>5</sup> ABBIENDI 04G | OPAL | $E_{cm}^{ee} = \text{LEP1} + 130\text{--}209$ GeV |
| 2.5025 ± 0.0041   | 3.97M | <sup>6</sup> ACCIARRI 00Q | L3   | $E_{cm}^{ee} = \text{LEP1} + 130\text{--}189$ GeV |
| 2.50 ± 0.21 ± 0.06  |       | <sup>7</sup> ABREU 96R    | DLPH | $E_{cm}^{ee} = 91.2$ GeV                          |
| 3.8 ± 0.8 ± 1.0   | 188   | ABE 89C                   | CDF  | $E_{cm}^{p\bar{p}} = 1.8$ TeV                     |
| 2.42 $\begin{smallmatrix} +0.45 \\ -0.35 \end{smallmatrix}$                   | 480   | <sup>8</sup> ABRAMS 89B   | MRK2 | $E_{cm}^{ee} = 89\text{--}93$ GeV                 |
| 2.7 $\begin{smallmatrix} +1.2 \\ -1.0 \end{smallmatrix}$ ± 1.3                | 24    | <sup>9</sup> ALBAJAR 89   | UA1  | $E_{cm}^{p\bar{p}} = 546,630$ GeV                 |
| 2.7 ± 2.0 ± 1.0   | 25    | <sup>10</sup> ANSARI 87   | UA2  | $E_{cm}^{p\bar{p}} = 546,630$ GeV                 |

- <sup>1</sup> ABBIENDI 01A error includes approximately 3.6 MeV due to statistics, 1 MeV due to event selection systematics, and 1.3 MeV due to LEP energy uncertainty.
- <sup>2</sup> The error includes 1.2 MeV due to LEP energy uncertainty.
- <sup>3</sup> The error includes 1.3 MeV due to LEP energy uncertainty.
- <sup>4</sup> BARATE 00C error includes approximately 3.8 MeV due to statistics, 0.9 MeV due to experimental systematics, and 1.3 MeV due to LEP energy uncertainty.
- <sup>5</sup> ABBIENDI 04G obtain this result using the S-matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 1 MeV shift with respect to the Breit–Wigner fits.
- <sup>6</sup> ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00C) as constraints. The 130–189 GeV data constrains the  $\gamma/Z$  interference term. The authors have corrected the measurement for the 0.9 MeV shift with respect to the Breit-Wigner fits.
- <sup>7</sup> ABREU 96R obtain this value from a study of the interference between initial and final state radiation in the process  $e^+e^- \rightarrow Z \rightarrow \mu^+\mu^-$ .
- <sup>8</sup> ABRAMS 89B uncertainty includes 50 MeV due to the miniSAM background subtraction error.
- <sup>9</sup> ALBAJAR 89 result is from a total sample of 33  $Z \rightarrow e^+e^-$  events.
- <sup>10</sup> Quoted values of ANSARI 87 are from direct fit. Ratio of Z and W production gives either  $\Gamma(Z) < (1.09 \pm 0.07) \times \Gamma(W)$ , CL = 90% or  $\Gamma(Z) = (0.82^{+0.19}_{-0.14} \pm 0.06) \times \Gamma(W)$ . Assuming Standard-Model value  $\Gamma(W) = 2.65$  GeV then gives  $\Gamma(Z) < 2.89 \pm 0.19$  or  $= 2.17^{+0.50}_{-0.37} \pm 0.16$ .

## Z DECAY MODES

| Mode   | Fraction ( $\Gamma_i/\Gamma$ )        | Scale factor/<br>Confidence level |
|--|---------------------------------------|-----------------------------------|
| $\Gamma_1$ $e^+e^-$                                | [a] ( 3.3632±0.0042 ) %               |                                   |
| $\Gamma_2$ $\mu^+\mu^-$                            | [a] ( 3.3662±0.0066 ) %               |                                   |
| $\Gamma_3$ $\tau^+\tau^-$                          | [a] ( 3.3696±0.0083 ) %               |                                   |
| $\Gamma_4$ $\ell^+\ell^-$                          | [a,b] ( 3.3658±0.0023 ) %             |                                   |
| $\Gamma_5$ $\mu^+\mu^-\mu^+\mu^-$                  |                                       |                                   |
| $\Gamma_6$ $\ell^+\ell^-\ell^+\ell^-$              | [c] ( 4.58 ±0.26 ) × 10 <sup>-6</sup> |                                   |
| $\Gamma_7$ invisible                               | [a] (20.000 ±0.055 ) %                |                                   |
| $\Gamma_8$ hadrons                                 | [a] (69.911 ±0.056 ) %                |                                   |
| $\Gamma_9$ $(u\bar{u} + c\bar{c})/2$               | (11.6 ±0.6 ) %                        |                                   |
| $\Gamma_{10}$ $(d\bar{d} + s\bar{s} + b\bar{b})/3$ | (15.6 ±0.4 ) %                        |                                   |
| $\Gamma_{11}$ $c\bar{c}$                           | (12.03 ±0.21 ) %                      |                                   |
| $\Gamma_{12}$ $b\bar{b}$                           | (15.12 ±0.05 ) %                      |                                   |
| $\Gamma_{13}$ $b\bar{b}b\bar{b}$                   | ( 3.6 ±1.3 ) × 10 <sup>-4</sup>       |                                   |
| $\Gamma_{14}$ $ggg$                                | < 1.1                                 | % CL=95%                          |
| $\Gamma_{15}$ $\pi^0\gamma$                        | < 2.01                                | × 10 <sup>-5</sup> CL=95%         |
| $\Gamma_{16}$ $\eta\gamma$                         | < 5.1                                 | × 10 <sup>-5</sup> CL=95%         |
| $\Gamma_{17}$ $\rho^0\gamma$                       | < 2.5                                 | × 10 <sup>-5</sup> CL=95%         |
| $\Gamma_{18}$ $\omega\gamma$                       | < 6.5                                 | × 10 <sup>-4</sup> CL=95%         |
| $\Gamma_{19}$ $\eta'(958)\gamma$                   | < 4.2                                 | × 10 <sup>-5</sup> CL=95%         |

|               |  |   |                  |        |
|---------------|--|---|------------------|--------|
| $\Gamma_{20}$ | $\phi\gamma$   | $< 9$   | $\times 10^{-7}$ | CL=95% |
| $\Gamma_{21}$ | $\gamma\gamma$                                       | $< 1.46$  | $\times 10^{-5}$ | CL=95% |
| $\Gamma_{22}$ | $\pi^0\pi^0$   | $< 1.52$  | $\times 10^{-5}$ | CL=95% |
| $\Gamma_{23}$ | $\gamma\gamma\gamma$                                 | $< 2.2$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{24}$ | $\pi^\pm W^\mp$                                      | [d] $< 7$   | $\times 10^{-5}$ | CL=95% |
| $\Gamma_{25}$ | $\rho^\pm W^\mp$                                     | [d] $< 8.3$   | $\times 10^{-5}$ | CL=95% |
| $\Gamma_{26}$ | $J/\psi(1S)X$  | ( 3.51 $\begin{smallmatrix} +0.23 \\ -0.25 \end{smallmatrix}$ ) | $\times 10^{-3}$ | S=1.1  |
| $\Gamma_{27}$ | $J/\psi(1S)\gamma$                                   | $< 2.3$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{28}$ | $\psi(2S)X$  | ( 1.60 $\pm 0.29$ )   | $\times 10^{-3}$ |        |
| $\Gamma_{29}$ | $\psi(2S)\gamma$                                     | $< 4.5$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{30}$ | $J/\psi(1S)\ell^+\ell^-$                             |   |                  |        |
| $\Gamma_{31}$ | $\chi_{c1}(1P)X$                                     | ( 2.9 $\pm 0.7$ )   | $\times 10^{-3}$ |        |
| $\Gamma_{32}$ | $\chi_{c2}(1P)X$                                     | $< 3.2$   | $\times 10^{-3}$ | CL=90% |
| $\Gamma_{33}$ | $\Upsilon(1S)X + \Upsilon(2S)X$<br>$+ \Upsilon(3S)X$ | ( 1.0 $\pm 0.5$ )   | $\times 10^{-4}$ |        |
| $\Gamma_{34}$ | $\Upsilon(1S)X$                                      | $< 3.4$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{35}$ | $\Upsilon(1S)\gamma$                                 | $< 2.8$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{36}$ | $\Upsilon(2S)X$                                      | $< 6.5$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{37}$ | $\Upsilon(2S)\gamma$                                 | $< 1.7$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{38}$ | $\Upsilon(3S)X$                                      | $< 5.4$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{39}$ | $\Upsilon(3S)\gamma$                                 | $< 4.8$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{40}$ | $(D^0/\bar{D}^0)X$                                   | (20.7 $\pm 2.0$ )   | %                |        |
| $\Gamma_{41}$ | $D^\pm X$  | (12.2 $\pm 1.7$ )   | %                |        |
| $\Gamma_{42}$ | $D^*(2010)^\pm X$                                    | [d] (11.4 $\pm 1.3$ )   | %                |        |
| $\Gamma_{43}$ | $D_{s1}(2536)^\pm X$                                 | ( 3.6 $\pm 0.8$ )   | $\times 10^{-3}$ |        |
| $\Gamma_{44}$ | $D_{sJ}(2573)^\pm X$                                 | ( 5.8 $\pm 2.2$ )   | $\times 10^{-3}$ |        |
| $\Gamma_{45}$ | $D^{*l}(2629)^\pm X$                                 | searched for  |                  |        |
| $\Gamma_{46}$ | $BX$   |   |                  |        |
| $\Gamma_{47}$ | $B^*X$   |   |                  |        |
| $\Gamma_{48}$ | $B^+X$   | [e] ( 6.08 $\pm 0.13$ )   | %                |        |
| $\Gamma_{49}$ | $B_s^0X$   | [e] ( 1.59 $\pm 0.13$ )   | %                |        |
| $\Gamma_{50}$ | $B_c^+X$   | searched for  |                  |        |
| $\Gamma_{51}$ | $\Lambda_c^+X$                                       | ( 1.54 $\pm 0.33$ )   | %                |        |
| $\Gamma_{52}$ | $\Xi_c^0X$   | seen  |                  |        |
| $\Gamma_{53}$ | $\Xi_b X$  | seen  |                  |        |
| $\Gamma_{54}$ | $b$ -baryon X  | [e] ( 1.38 $\pm 0.22$ )   | %                |        |
| $\Gamma_{55}$ | anomalous $\gamma$ + hadrons                         | [f] $< 3.2$   | $\times 10^{-3}$ | CL=95% |
| $\Gamma_{56}$ | $e^+e^-\gamma$                                       | [f] $< 5.2$   | $\times 10^{-4}$ | CL=95% |
| $\Gamma_{57}$ | $\mu^+\mu^-\gamma$                                   | [f] $< 5.6$   | $\times 10^{-4}$ | CL=95% |
| $\Gamma_{58}$ | $\tau^+\tau^-\gamma$                                 | [f] $< 7.3$   | $\times 10^{-4}$ | CL=95% |
| $\Gamma_{59}$ | $\ell^+\ell^-\gamma\gamma$                           | [g] $< 6.8$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{60}$ | $q\bar{q}\gamma\gamma$                               | [g] $< 5.5$   | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{61}$ | $\nu\bar{\nu}\gamma\gamma$                           | [g] $< 3.1$   | $\times 10^{-6}$ | CL=95% |

|               |                    |            |             |                  |        |
|---------------|--------------------|------------|-------------|------------------|--------|
| $\Gamma_{62}$ | $e^\pm \mu^\mp$    | <i>LF</i>  | $[d] < 7.5$ | $\times 10^{-7}$ | CL=95% |
| $\Gamma_{63}$ | $e^\pm \tau^\mp$   | <i>LF</i>  | $[d] < 9.8$ | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{64}$ | $\mu^\pm \tau^\mp$ | <i>LF</i>  | $[d] < 1.2$ | $\times 10^{-5}$ | CL=95% |
| $\Gamma_{65}$ | $p e$              | <i>L,B</i> | $< 1.8$     | $\times 10^{-6}$ | CL=95% |
| $\Gamma_{66}$ | $p \mu$            | <i>L,B</i> | $< 1.8$     | $\times 10^{-6}$ | CL=95% |

[a] This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The Z boson” and ref. LEP-SLC 06 (Physics Reports (Physics Letters C) **427** 257 (2006)).

[b]  $\ell$  indicates each type of lepton ( $e$ ,  $\mu$ , and  $\tau$ ), not sum over them.

[c] Here  $\ell$  indicates  $e$  or  $\mu$ .

[d] The value is for the sum of the charge states or particle/antiparticle states indicated.

[e] This value is updated using the product of (i) the  $Z \rightarrow b\bar{b}$  fraction from this listing and (ii) the  $b$ -hadron fraction in an unbiased sample of weakly decaying  $b$ -hadrons produced in  $Z$ -decays provided by the Heavy Flavor Averaging Group (HFLAV, [http://www.slac.stanford.edu/xorg/hflav/osc/PDG\\_2009/#FRACZ](http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009/#FRACZ)).

[f] See the Particle Listings below for the  $\gamma$  energy range used in this measurement.

[g] For  $m_{\gamma\gamma} = (60 \pm 5)$  GeV.

## Z PARTIAL WIDTHS

### $\Gamma(e^+ e^-)$ $\Gamma_1$

For the LEP experiments, this parameter is not directly used in the overall fit but is derived using the fit results; see the note “The Z boson” and ref. LEP-SLC 06.

| <u>VALUE (MeV)</u>        | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>            |
|---------------------------|-------------|--------------------|-------------|---------------------------|
| <b>83.91±0.12 OUR FIT</b> |             |                    |             |                           |
| 83.66±0.20                | 137.0K      | ABBIENDI           | 01A OPAL    | $E_{cm}^{ee} = 88-94$ GeV |
| 83.54±0.27                | 117.8k      | ABREU              | 00F DLPH    | $E_{cm}^{ee} = 88-94$ GeV |
| 84.16±0.22                | 124.4k      | ACCIARRI           | 00C L3      | $E_{cm}^{ee} = 88-94$ GeV |
| 83.88±0.19                |             | BARATE             | 00C ALEP    | $E_{cm}^{ee} = 88-94$ GeV |
| 82.89±1.20±0.89           |             | <sup>1</sup> ABE   | 95J SLD     | $E_{cm}^{ee} = 91.31$ GeV |

<sup>1</sup> ABE 95J obtain this measurement from Bhabha events in a restricted fiducial region to improve systematics. They use the values 91.187 and 2.489 GeV for the Z mass and total decay width to extract this partial width.

### $\Gamma(\mu^+ \mu^-)$ $\Gamma_2$

This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The Z boson” and ref. LEP-SLC 06.

| <u>VALUE (MeV)</u>        | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>            |
|---------------------------|-------------|--------------------|-------------|---------------------------|
| <b>83.99±0.18 OUR FIT</b> |             |                    |             |                           |
| 84.03±0.30                | 182.8K      | ABBIENDI           | 01A OPAL    | $E_{cm}^{ee} = 88-94$ GeV |
| 84.48±0.40                | 157.6k      | ABREU              | 00F DLPH    | $E_{cm}^{ee} = 88-94$ GeV |
| 83.95±0.44                | 113.4k      | ACCIARRI           | 00C L3      | $E_{cm}^{ee} = 88-94$ GeV |
| 84.02±0.28                |             | BARATE             | 00C ALEP    | $E_{cm}^{ee} = 88-94$ GeV |

**$\Gamma(\tau^+\tau^-)$**   **$\Gamma_3$**   
 This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The Z boson” and ref. LEP-SLC 06.

| <u>VALUE (MeV)</u>        | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>            |
|---------------------------|-------------|--------------------|-------------|---------------------------|
| <b>84.08±0.22 OUR FIT</b> |             |                    |             |                           |
| 83.94±0.41                | 151.5K      | ABBIENDI           | 01A OPAL    | $E_{cm}^{ee} = 88-94$ GeV |
| 83.71±0.58                | 104.0k      | ABREU              | 00F DLPH    | $E_{cm}^{ee} = 88-94$ GeV |
| 84.23±0.58                | 103.0k      | ACCIARRI           | 00C L3      | $E_{cm}^{ee} = 88-94$ GeV |
| 84.38±0.31                |             | BARATE             | 00C ALEP    | $E_{cm}^{ee} = 88-94$ GeV |

**$\Gamma(\ell^+\ell^-)$**   **$\Gamma_4$**   
 $\ell$  indicates each type of lepton ( $e$ ,  $\mu$ , and  $\tau$ ), not sum over them.

In our fit  $\Gamma(\ell^+\ell^-)$  is defined as the partial Z width for the decay into a pair of massless charged leptons. This parameter is not directly used in the 5-parameter fit assuming lepton universality but is derived using the fit results. See the note “The Z boson” and ref. LEP-SLC 06.

| <u>VALUE (MeV)</u>          | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>            |
|-----------------------------|-------------|--------------------|-------------|---------------------------|
| <b>83.984±0.086 OUR FIT</b> |             |                    |             |                           |
| 83.82 ±0.15                 | 471.3K      | ABBIENDI           | 01A OPAL    | $E_{cm}^{ee} = 88-94$ GeV |
| 83.85 ±0.17                 | 379.4k      | ABREU              | 00F DLPH    | $E_{cm}^{ee} = 88-94$ GeV |
| 84.14 ±0.17                 | 340.8k      | ACCIARRI           | 00C L3      | $E_{cm}^{ee} = 88-94$ GeV |
| 84.02 ±0.15                 | 500k        | BARATE             | 00C ALEP    | $E_{cm}^{ee} = 88-94$ GeV |

**$\Gamma(\text{invisible})$**   **$\Gamma_7$**   
 We use only direct measurements of the invisible partial width using the single photon channel to obtain the average value quoted below. OUR FIT value is obtained as a difference between the total and the observed partial widths assuming lepton universality.

| <u>VALUE (MeV)</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                      |
|---|-------------|-----------------------|-------------|-------------------------------------|
| <b>499.0± 1.5 OUR FIT</b>   |             |                       |             |                                     |
| <b>503 ±16 OUR AVERAGE</b>  |             |                       |             | Error includes scale factor of 1.2. |
| 498 ±12 ±12   | 1791        | ACCIARRI              | 98G L3      | $E_{cm}^{ee} = 88-94$ GeV           |
| 539 ±26 ±17   | 410         | AKERS                 | 95C OPAL    | $E_{cm}^{ee} = 88-94$ GeV           |
| 450 ±34 ±34   | 258         | BUSKULIC              | 93L ALEP    | $E_{cm}^{ee} = 88-94$ GeV           |
| 540 ±80 ±40   | 52          | ADEVA                 | 92 L3       | $E_{cm}^{ee} = 88-94$ GeV           |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |             |                       |             |                                     |
| 498.1± 2.6  |             | <sup>1</sup> ABBIENDI | 01A OPAL    | $E_{cm}^{ee} = 88-94$ GeV           |
| 498.1± 3.2  |             | <sup>1</sup> ABREU    | 00F DLPH    | $E_{cm}^{ee} = 88-94$ GeV           |
| 499.1± 2.9  |             | <sup>1</sup> ACCIARRI | 00C L3      | $E_{cm}^{ee} = 88-94$ GeV           |
| 499.1± 2.5  |             | <sup>1</sup> BARATE   | 00C ALEP    | $E_{cm}^{ee} = 88-94$ GeV           |

<sup>1</sup>This is an indirect determination of  $\Gamma(\text{invisible})$  from a fit to the visible  $Z$  decay modes.

## $\Gamma(\text{hadrons})$

$\Gamma_8$

This parameter is not directly used in the 5-parameter fit assuming lepton universality, but is derived using the fit results. See the note “The  $Z$  boson” and ref. LEP-SLC 06.

| <u>VALUE (MeV)</u>        | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                           |
|---------------------------|-------------|--------------------|-------------|--|
| <b>1744.4±2.0 OUR FIT</b> |             |                    |             |  |
| 1745.4±3.5                | 4.10M       | ABBIENDI           | 01A OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 1738.1±4.0                | 3.70M       | ABREU              | 00F DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 1751.1±3.8                | 3.54M       | ACCIARRI           | 00C L3      | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 1744.0±3.4                | 4.07M       | BARATE             | 00C ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

## Z BRANCHING RATIOS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The  $Z$  boson” and ref. LEP-SLC 06).

## $\Gamma(\mu^+ \mu^-)/\Gamma(e^+ e^-)$

$\Gamma_2/\Gamma_1$

This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The  $Z$  boson” and ref. LEP-SLC 06.

| <u>VALUE</u>                 | <u>DOCUMENT ID</u> |
|------------------------------|--------------------|
| <b>1.0009±0.0028 OUR FIT</b> |                    |

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

$\Gamma_3/\Gamma_1$

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>   | <u>TECN</u> | <u>COMMENT</u>                           |
|----------------------------------|----------------------|-------------|--|
| <b>1.0020±0.0032 OUR AVERAGE</b> |                      |             |  |
| 1.02 ±0.06                       | <sup>1</sup> AAIJ    | 18AR LHCB   | $E_{\text{cm}}^{pp} = 8$ TeV             |
| 1.0019±0.0032                    | <sup>2</sup> LEP-SLC | 06          | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> AAIJ 18AR obtain the result from the ratio of the measured  $pp \rightarrow Z + X$  cross sections in the corresponding  $Z$  decay channels.

<sup>2</sup> This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The  $Z$  boson” and ref. LEP-SLC 06.

## $\Gamma(\tau^+ \tau^-)/\Gamma(\mu^+ \mu^-)$

$\Gamma_3/\Gamma_2$

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>   | <u>TECN</u> | <u>COMMENT</u>                           |
|----------------------------------|----------------------|-------------|--|
| <b>1.0010±0.0026 OUR AVERAGE</b> |                      |             |  |
| 1.01 ±0.05                       | <sup>1</sup> AAIJ    | 18AR LHCB   | $E_{\text{cm}}^{pp} = 8$ TeV             |
| 1.0010±0.0026                    | <sup>2</sup> LEP-SLC | 06          | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> AAIJ 18AR obtain the result from the ratio of the measured  $pp \rightarrow Z + X$  cross sections in the corresponding  $Z$  decay channels.

<sup>2</sup> This parameter is not directly used in the overall fit but is derived using the fit results; see the note “The  $Z$  boson” and ref. LEP-SLC 06.

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

$\Gamma_6 / \Gamma$

Here  $\ell$  indicates either  $e$  or  $\mu$ . The branching fractions in this node are given within the phase-space defined by the requirements that (i) the 4-lepton invariant mass is between 80 GeV and 100 GeV, and (ii) any opposite-sign same-flavor lepton pair has a di-lepton invariant mass larger than 4 GeV.

OUR EVALUATION below is presented in RAINBOLT 19, assessing and including correlated systematic uncertainties between the measurements.

| <u>VALUE (units <math>10^{-6}</math>)</u>        | <u>EVTS</u> | <u>DOCUMENT ID</u>              | <u>TECN</u> | <u>COMMENT</u>                  |
|--|-------------|---------------------------------|-------------|---------------------------------|
| <b>4.58 ± 0.26 OUR EVALUATION</b>                |             |                                 |             |                                 |
| 4.83 <sup>+0.23+0.35</sup> <sub>-0.22-0.32</sub> | 509         | <sup>1</sup> SIRUNYAN           | 18BT CMS    | $E_{\text{cm}}^{pp} = 13$ TeV   |
| 4.9 <sup>+0.8+0.4</sup> <sub>-0.7-0.2</sub>      | 39          | <sup>2</sup> KHACHATRYAN...16CC | CMS         | $E_{\text{cm}}^{pp} = 13$ TeV   |
| 4.31 ± 0.34 ± 0.17                               | 172         | AAD                             | 14N ATLS    | $E_{\text{cm}}^{pp} = 7, 8$ TeV |
| 4.6 <sup>+1.0</sup> <sub>-0.9</sub> ± 0.2        | 28          | <sup>3</sup> CHATRCHYAN 12BN    | CMS         | $E_{\text{cm}}^{pp} = 7$ TeV    |

<sup>1</sup> SIRUNYAN 18BT report the  $Z \rightarrow 4\ell$  branching fraction =  $(4.83^{+0.23+0.32}_{-0.22-0.29} \pm 0.08 \pm 0.12) \times 10^{-6}$ , where the uncertainties are statistical, systematic, due to theory, and luminosity. The last three have been added in quadrature to obtain the total systematic error.

<sup>2</sup> KHACHATRYAN 16CC reports  $(4.9^{+0.8+0.3+0.2+0.1}_{-0.7-0.2-0.1-0.1}) \times 10^{-6}$  value, where the uncertainties are statistical, systematic, theory, and due to luminosity. We have combined uncertainties in quadrature.

<sup>3</sup> CHATRCHYAN 12BN reports  $(4.2^{+0.9}_{-0.8} \pm 0.2) \times 10^{-6}$  value. Their result (both central value and uncertainties) is scaled up by 10% to account for the different phase-space definition used here (see RAINBOLT 19).

$\Gamma(\text{hadrons}) / \Gamma(e^+ e^-)$

$\Gamma_8 / \Gamma_1$

| <u>VALUE</u>                  | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                   |
|-------------------------------|-------------|-----------------------|-------------|----------------------------------|
| <b>20.804 ± 0.050 OUR FIT</b> |             |                       |             |                                  |
| 20.902 ± 0.084                | 137.0K      | <sup>1</sup> ABBIENDI | 01A OPAL    | $E_{\text{cm}}^{ee} = 88-94$ GeV |
| 20.88 ± 0.12                  | 117.8k      | ABREU                 | 00F DLPH    | $E_{\text{cm}}^{ee} = 88-94$ GeV |
| 20.816 ± 0.089                | 124.4k      | ACCIARRI              | 00C L3      | $E_{\text{cm}}^{ee} = 88-94$ GeV |
| 20.677 ± 0.075                |             | <sup>2</sup> BARATE   | 00C ALEP    | $E_{\text{cm}}^{ee} = 88-94$ GeV |

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

|                                       |    |                     |          |                                  |
|---------------------------------------|----|---------------------|----------|----------------------------------|
| 27.0 <sup>+11.7</sup> <sub>-8.8</sub> | 12 | <sup>3</sup> ABRAMS | 89D MRK2 | $E_{\text{cm}}^{ee} = 89-93$ GeV |
|---------------------------------------|----|---------------------|----------|----------------------------------|

<sup>1</sup> ABBIENDI 01A error includes approximately 0.067 due to statistics, 0.040 due to event selection systematics, 0.027 due to the theoretical uncertainty in  $t$ -channel prediction, and 0.014 due to LEP energy uncertainty.

<sup>2</sup> BARATE 00C error includes approximately 0.062 due to statistics, 0.033 due to experimental systematics, and 0.026 due to the theoretical uncertainty in  $t$ -channel prediction.

<sup>3</sup> ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.



$\Gamma(\text{hadrons})/\Gamma(\mu^+\mu^-)$   $\Gamma_8/\Gamma_2$ 

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06).

| <u>VALUE</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                           |
|---|-------------|-----------------------|-------------|--|
| <b>20.785 ± 0.033 OUR FIT</b>   |             |                       |             |  |
| 20.811 ± 0.058  | 182.8K      | <sup>1</sup> ABBIENDI | 01A OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.65 ± 0.08  | 157.6k      | ABREU                 | 00F DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.861 ± 0.097  | 113.4k      | ACCIARRI              | 00C L3      | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.799 ± 0.056  |             | <sup>2</sup> BARATE   | 00C ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |             |                       |             |  |
| 18.9 $\begin{smallmatrix} +7.1 \\ -5.3 \end{smallmatrix}$                     | 13          | <sup>3</sup> ABRAMS   | 89D MRK2    | $E_{\text{cm}}^{ee} = 89\text{--}93$ GeV |

<sup>1</sup> ABBIENDI 01A error includes approximately 0.050 due to statistics and 0.027 due to event selection systematics.

<sup>2</sup> BARATE 00C error includes approximately 0.053 due to statistics and 0.021 due to experimental systematics.

<sup>3</sup> ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

 $\Gamma(\text{hadrons})/\Gamma(\tau^+\tau^-)$   $\Gamma_8/\Gamma_3$ 

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06).

| <u>VALUE</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                           |
|---|-------------|-----------------------|-------------|--|
| <b>20.764 ± 0.045 OUR FIT</b>   |             |                       |             |  |
| 20.832 ± 0.091  | 151.5K      | <sup>1</sup> ABBIENDI | 01A OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.84 ± 0.13  | 104.0k      | ABREU                 | 00F DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.792 ± 0.133  | 103.0k      | ACCIARRI              | 00C L3      | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.707 ± 0.062  |             | <sup>2</sup> BARATE   | 00C ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |             |                       |             |  |
| 15.2 $\begin{smallmatrix} +4.8 \\ -3.9 \end{smallmatrix}$                     | 21          | <sup>3</sup> ABRAMS   | 89D MRK2    | $E_{\text{cm}}^{ee} = 89\text{--}93$ GeV |

<sup>1</sup> ABBIENDI 01A error includes approximately 0.055 due to statistics and 0.071 due to event selection systematics.

<sup>2</sup> BARATE 00C error includes approximately 0.054 due to statistics and 0.033 due to experimental systematics.

<sup>3</sup> ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

 $\Gamma(\text{hadrons})/\Gamma(\ell^+\ell^-)$   $\Gamma_8/\Gamma_4$ 

$\ell$  indicates each type of lepton ( $e$ ,  $\mu$ , and  $\tau$ ), not sum over them.

Our fit result is obtained requiring lepton universality.

| <u>VALUE</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                           |
|---|-------------|-----------------------|-------------|--|
| <b>20.767 ± 0.025 OUR FIT</b>   |             |                       |             |  |
| 20.823 ± 0.044  | 471.3K      | <sup>1</sup> ABBIENDI | 01A OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.730 ± 0.060  | 379.4k      | ABREU                 | 00F DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.810 ± 0.060  | 340.8k      | ACCIARRI              | 00C L3      | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 20.725 ± 0.039  | 500k        | <sup>2</sup> BARATE   | 00C ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |             |                       |             |  |
| 18.9 $\begin{smallmatrix} +3.6 \\ -3.2 \end{smallmatrix}$                     | 46          | ABRAMS                | 89B MRK2    | $E_{\text{cm}}^{ee} = 89\text{--}93$ GeV |

- <sup>1</sup> ABBIENDI 01A error includes approximately 0.034 due to statistics and 0.027 due to event selection systematics.  
<sup>2</sup> BARATE 00C error includes approximately 0.033 due to statistics, 0.020 due to experimental systematics, and 0.005 due to the theoretical uncertainty in  $t$ -channel prediction.

### $\Gamma((u\bar{u}+c\bar{c})/2)/\Gamma(\text{hadrons})$

$\Gamma_9/\Gamma_8$

This quantity is the branching ratio of  $Z \rightarrow$  “up-type” quarks to  $Z \rightarrow$  hadrons. Except ACKERSTAFF 97T the values of  $Z \rightarrow$  “up-type” and  $Z \rightarrow$  “down-type” branchings are extracted from measurements of  $\Gamma(\text{hadrons})$ , and  $\Gamma(Z \rightarrow \gamma + \text{jets})$  where  $\gamma$  is a high-energy ( $>5$  or  $7$  GeV) isolated photon. As the experiments use different procedures and slightly different values of  $M_Z$ ,  $\Gamma(\text{hadrons})$  and  $\alpha_s$  in their extraction procedures, our average has to be taken with caution.

| <u>VALUE</u>                              | <u>DOCUMENT ID</u>      | <u>TECN</u> | <u>COMMENT</u>                           |
|---|-------------------------|-------------|--|
| <b>0.166±0.009 OUR AVERAGE</b>            |                         |             |  |
| 0.172 <sup>+0.011</sup> <sub>-0.010</sub> | <sup>1</sup> ABBIENDI   | 04E OPAL    | $E_{\text{cm}}^{ee} = 91.2$ GeV          |
| 0.160±0.019±0.019                         | <sup>2</sup> ACKERSTAFF | 97T OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.137 <sup>+0.038</sup> <sub>-0.054</sub> | <sup>3</sup> ABREU      | 95X DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.137±0.033                               | <sup>4</sup> ADRIANI    | 93 L3       | $E_{\text{cm}}^{ee} = 91.2$ GeV          |

- <sup>1</sup> ABBIENDI 04E select photons with energy  $> 7$  GeV and use  $\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$  MeV and  $\alpha_s = 0.1172 \pm 0.002$  to obtain  $\Gamma_u = 300^{+19}_{-18}$  MeV.  
<sup>2</sup> ACKERSTAFF 97T measure  $\Gamma_{u\bar{u}}/(\Gamma_{d\bar{d}}+\Gamma_{u\bar{u}}+\Gamma_{s\bar{s}}) = 0.258 \pm 0.031 \pm 0.032$ . To obtain this branching ratio authors use  $R_c+R_b = 0.380 \pm 0.010$ . This measurement is fully negatively correlated with the measurement of  $\Gamma_{d\bar{d},s\bar{s}}/(\Gamma_{d\bar{d}}+\Gamma_{u\bar{u}}+\Gamma_{s\bar{s}})$  given in the next data block.  
<sup>3</sup> ABREU 95X use  $M_Z = 91.187 \pm 0.009$  GeV,  $\Gamma(\text{hadrons}) = 1725 \pm 12$  MeV and  $\alpha_s = 0.123 \pm 0.005$ . To obtain this branching ratio we divide their value of  $C_{2/3} = 0.91^{+0.25}_{-0.36}$  by their value of  $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$ .  
<sup>4</sup> ADRIANI 93 use  $M_Z = 91.181 \pm 0.022$  GeV,  $\Gamma(\text{hadrons}) = 1742 \pm 19$  MeV and  $\alpha_s = 0.125 \pm 0.009$ . To obtain this branching ratio we divide their value of  $C_{2/3} = 0.92 \pm 0.22$  by their value of  $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$ .

### $\Gamma((d\bar{d}+s\bar{s}+b\bar{b})/3)/\Gamma(\text{hadrons})$

$\Gamma_{10}/\Gamma_8$

This quantity is the branching ratio of  $Z \rightarrow$  “down-type” quarks to  $Z \rightarrow$  hadrons. Except ACKERSTAFF 97T the values of  $Z \rightarrow$  “up-type” and  $Z \rightarrow$  “down-type” branchings are extracted from measurements of  $\Gamma(\text{hadrons})$ , and  $\Gamma(Z \rightarrow \gamma + \text{jets})$  where  $\gamma$  is a high-energy ( $>5$  or  $7$  GeV) isolated photon. As the experiments use different procedures and slightly different values of  $M_Z$ ,  $\Gamma(\text{hadrons})$  and  $\alpha_s$  in their extraction procedures, our average has to be taken with caution.

| <u>VALUE</u>                              | <u>DOCUMENT ID</u>      | <u>TECN</u> | <u>COMMENT</u>                           |
|---|-------------------------|-------------|--|
| <b>0.223±0.006 OUR AVERAGE</b>            |                         |             |  |
| 0.218±0.007                               | <sup>1</sup> ABBIENDI   | 04E OPAL    | $E_{\text{cm}}^{ee} = 91.2$ GeV          |
| 0.230±0.010±0.010                         | <sup>2</sup> ACKERSTAFF | 97T OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.243 <sup>+0.036</sup> <sub>-0.026</sub> | <sup>3</sup> ABREU      | 95X DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.243±0.022                               | <sup>4</sup> ADRIANI    | 93 L3       | $E_{\text{cm}}^{ee} = 91.2$ GeV          |

- <sup>1</sup> ABBIENDI 04E select photons with energy  $> 7$  GeV and use  $\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$  MeV and  $\alpha_s = 0.1172 \pm 0.002$  to obtain  $\Gamma_d = 381 \pm 12$  MeV.
- <sup>2</sup> ACKERSTAFF 97T measure  $\Gamma_{d\bar{d},s\bar{s}}/(\Gamma_{d\bar{d}}+\Gamma_{u\bar{u}}+\Gamma_{s\bar{s}}) = 0.371 \pm 0.016 \pm 0.016$ . To obtain this branching ratio authors use  $R_c+R_b = 0.380 \pm 0.010$ . This measurement is fully negatively correlated with the measurement of  $\Gamma_{u\bar{u}}/(\Gamma_{d\bar{d}} + \Gamma_{u\bar{u}} + \Gamma_{s\bar{s}})$  presented in the previous data block.
- <sup>3</sup> ABREU 95X use  $M_Z = 91.187 \pm 0.009$  GeV,  $\Gamma(\text{hadrons}) = 1725 \pm 12$  MeV and  $\alpha_s = 0.123 \pm 0.005$ . To obtain this branching ratio we divide their value of  $C_{1/3} = 1.62^{+0.24}_{-0.17}$  by their value of  $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$ .
- <sup>4</sup> ADRIANI 93 use  $M_Z = 91.181 \pm 0.022$  GeV,  $\Gamma(\text{hadrons}) = 1742 \pm 19$  MeV and  $\alpha_s = 0.125 \pm 0.009$ . To obtain this branching ratio we divide their value of  $C_{1/3} = 1.63 \pm 0.15$  by their value of  $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$ .

## $R_c = \Gamma(c\bar{c})/\Gamma(\text{hadrons})$

$\Gamma_{11}/\Gamma_8$

OUR FIT is obtained by a simultaneous fit to several  $c$ - and  $b$ -quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

The Standard Model predicts  $R_c = 0.1723$  for  $m_t = 174.3$  GeV and  $M_H = 150$  GeV.

| VALUE   | DOCUMENT ID             | TECN     | COMMENT                 |
|---|-------------------------|----------|-------------------------|
| <b>0.1721±0.0030 OUR FIT</b>  |                         |          |                         |
| 0.1744±0.0031±0.0021  | <sup>1</sup> ABE        | 05F SLD  | $E_{cm}^{ee}=91.28$ GeV |
| 0.1665±0.0051±0.0081  | <sup>2</sup> ABREU      | 00 DLPH  | $E_{cm}^{ee}=88-94$ GeV |
| 0.1698±0.0069   | <sup>3</sup> BARATE     | 00B ALEP | $E_{cm}^{ee}=88-94$ GeV |
| 0.180 ±0.011 ±0.013   | <sup>4</sup> ACKERSTAFF | 98E OPAL | $E_{cm}^{ee}=88-94$ GeV |
| 0.167 ±0.011 ±0.012   | <sup>5</sup> ALEXANDER  | 96R OPAL | $E_{cm}^{ee}=88-94$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |                         |          |                         |
| 0.1623±0.0085±0.0209  | <sup>6</sup> ABREU      | 95D DLPH | $E_{cm}^{ee}=88-94$ GeV |

- <sup>1</sup> ABE 05F use hadronic Z decays collected during 1996–98 to obtain an enriched sample of  $c\bar{c}$  events using a double tag method. The single  $c$ -tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere). A multitag approach is used, defining 4 regions of the output value of the neural network and  $R_c$  is extracted from a simultaneous fit to the count rates of the 4 different tags. The quoted systematic error includes an uncertainty of  $\pm 0.0006$  due to the uncertainty on  $R_b$ .
- <sup>2</sup> ABREU 00 obtain this result properly combining the measurement from the  $D^{*+}$  production rate ( $R_c = 0.1610 \pm 0.0104 \pm 0.0077 \pm 0.0043$  (BR)) with that from the overall charm counting ( $R_c = 0.1692 \pm 0.0047 \pm 0.0063 \pm 0.0074$  (BR)) in  $c\bar{c}$  events. The systematic error includes an uncertainty of  $\pm 0.0054$  due to the uncertainty on the charmed hadron branching fractions.
- <sup>3</sup> BARATE 00B use exclusive decay modes to independently determine the quantities  $R_c \times f(c \rightarrow X)$ ,  $X=D^0, D^+, D_s^+$ , and  $\Lambda_c$ . Estimating  $R_c \times f(c \rightarrow \Xi_c/\Omega_c) = 0.0034$ , they simply sum over all the charm decays to obtain  $R_c = 0.1738 \pm 0.0047 \pm 0.0088 \pm 0.0075$ (BR). This is combined with all previous ALEPH measurements (BARATE 98T and BUSKULIC 94G,  $R_c = 0.1681 \pm 0.0054 \pm 0.0062$ ) to obtain the quoted value.
- <sup>4</sup> ACKERSTAFF 98E use an inclusive/exclusive double tag. In one jet  $D^{*\pm}$  mesons are exclusively reconstructed in several decay channels and in the opposite jet a slow pion (opposite charge inclusive  $D^{*\pm}$ ) tag is used. The  $b$  content of this sample is measured by the simultaneous detection of a lepton in one jet and an inclusively reconstructed  $D^{*\pm}$  meson in the opposite jet. The systematic error includes an uncertainty of  $\pm 0.006$  due to the external branching ratios.

- <sup>5</sup> ALEXANDER 96R obtain this value via direct charm counting, summing the partial contributions from  $D^0$ ,  $D^+$ ,  $D_s^+$ , and  $\Lambda_c^+$ , and assuming that strange-charmed baryons account for the 15% of the  $\Lambda_c^+$  production. An uncertainty of  $\pm 0.005$  due to the uncertainties in the charm hadron branching ratios is included in the overall systematics.
- <sup>6</sup> ABREU 95D perform a maximum likelihood fit to the combined  $p$  and  $p_T$  distributions of single and dilepton samples. The second error includes an uncertainty of  $\pm 0.0124$  due to models and branching ratios.

$$R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons}) \qquad \Gamma_{12}/\Gamma_8$$

OUR FIT is obtained by a simultaneous fit to several  $c$ - and  $b$ -quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

The Standard Model predicts  $R_b=0.21581$  for  $m_t=174.3$  GeV and  $M_H=150$  GeV.

| <u>VALUE</u>  | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                         |
|---|-----------------------|-------------|--|
| <b>0.21629<math>\pm</math>0.00066 OUR FIT</b>                                 |                       |             |  |
| 0.21594 $\pm$ 0.00094 $\pm$ 0.00075   | <sup>1</sup> ABE      | 05F SLD     | $E_{\text{cm}}^{ee}=91.28$ GeV         |
| 0.2174 $\pm$ 0.0015 $\pm$ 0.0028  | <sup>2</sup> ACCIARRI | 00 L3       | $E_{\text{cm}}^{ee}=89\text{--}93$ GeV |
| 0.2178 $\pm$ 0.0011 $\pm$ 0.0013  | <sup>3</sup> ABBIENDI | 99B OPAL    | $E_{\text{cm}}^{ee}=88\text{--}94$ GeV |
| 0.21634 $\pm$ 0.00067 $\pm$ 0.00060   | <sup>4</sup> ABREU    | 99B DLPH    | $E_{\text{cm}}^{ee}=88\text{--}94$ GeV |
| 0.2159 $\pm$ 0.0009 $\pm$ 0.0011  | <sup>5</sup> BARATE   | 97F ALEP    | $E_{\text{cm}}^{ee}=88\text{--}94$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |                       |             |  |
| 0.2145 $\pm$ 0.0089 $\pm$ 0.0067  | <sup>6</sup> ABREU    | 95D DLPH    | $E_{\text{cm}}^{ee}=88\text{--}94$ GeV |
| 0.219 $\pm$ 0.006 $\pm$ 0.005   | <sup>7</sup> BUSKULIC | 94G ALEP    | $E_{\text{cm}}^{ee}=88\text{--}94$ GeV |
| 0.251 $\pm$ 0.049 $\pm$ 0.030   | <sup>8</sup> JACOBSEN | 91 MRK2     | $E_{\text{cm}}^{ee}=91$ GeV            |

- <sup>1</sup> ABE 05F use hadronic  $Z$  decays collected during 1996–98 to obtain an enriched sample of  $b\bar{b}$  events using a double tag method. The single  $b$ -tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere; the key tag is obtained requiring the secondary vertex corrected mass to be above the  $D$ -meson mass). ABE 05F obtain  $R_b=0.21604 \pm 0.00098 \pm 0.00074$  where the systematic error includes an uncertainty of  $\pm 0.00012$  due to the uncertainty on  $R_c$ . The value reported here is obtained properly combining with ABE 98D. The quoted systematic error includes an uncertainty of  $\pm 0.00012$  due to the uncertainty on  $R_c$ .
- <sup>2</sup> ACCIARRI 00 obtain this result using a double-tagging technique, with a high  $p_T$  lepton tag and an impact parameter tag in opposite hemispheres.
- <sup>3</sup> ABBIENDI 99B tag  $Z \rightarrow b\bar{b}$  decays using leptons and/or separated decay vertices. The  $b$ -tagging efficiency is measured directly from the data using a double-tagging technique.
- <sup>4</sup> ABREU 99B obtain this result combining in a multivariate analysis several tagging methods (impact parameter and secondary vertex reconstruction, complemented by event shape variables). For  $R_c$  different from its Standard Model value of 0.172,  $R_b$  varies as  $-0.024 \times (R_c - 0.172)$ .
- <sup>5</sup> BARATE 97F combine the lifetime-mass hemisphere tag (BARATE 97E) with event shape information and lepton tag to identify  $Z \rightarrow b\bar{b}$  candidates. They further use  $c$ - and  $uds$ -selection tags to identify the background. For  $R_c$  different from its Standard Model value of 0.172,  $R_b$  varies as  $-0.019 \times (R_c - 0.172)$ .
- <sup>6</sup> ABREU 95D perform a maximum likelihood fit to the combined  $p$  and  $p_T$  distributions of single and dilepton samples. The second error includes an uncertainty of  $\pm 0.0023$  due to models and branching ratios.
- <sup>7</sup> BUSKULIC 94G perform a simultaneous fit to the  $p$  and  $p_T$  spectra of both single and dilepton events.
- <sup>8</sup> JACOBSEN 91 tagged  $b\bar{b}$  events by requiring coincidence of  $\geq 3$  tracks with significant impact parameters using vertex detector. Systematic error includes lifetime and decay uncertainties ( $\pm 0.014$ ).

### $\Gamma(b\bar{b}b\bar{b})/\Gamma(\text{hadrons})$

$\Gamma_{13}/\Gamma_8$

| VALUE (units $10^{-4}$ )                    | DOCUMENT ID           | TECN     | COMMENT                                  |
|---|-----------------------|----------|--|
| <b><math>5.2 \pm 1.9</math></b> OUR AVERAGE |                       |          |  |
| $3.6 \pm 1.7 \pm 2.7$                       | <sup>1</sup> ABBIENDI | 01G OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $6.0 \pm 1.9 \pm 1.4$                       | <sup>2</sup> ABREU    | 99U DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ABBIENDI 01G use a sample of four-jet events from hadronic Z decays. To enhance the  $b\bar{b}b\bar{b}$  signal, at least three of the four jets are required to have a significantly detached secondary vertex.

<sup>2</sup> ABREU 99U force hadronic Z decays into 3jets to use all the available phase space and require a  $b$  tag for every jet. This decay mode includes primary and secondary  $4b$  production, e.g. from gluon splitting to  $b\bar{b}$ .

### $\Gamma(ggg)/\Gamma(\text{hadrons})$

$\Gamma_{14}/\Gamma_8$

| VALUE                                      | CL% | DOCUMENT ID        | TECN     | COMMENT                                  |
|--|-----|--------------------|----------|--|
| <b><math>&lt;1.6 \times 10^{-2}</math></b> | 95  | <sup>1</sup> ABREU | 96S DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> This branching ratio is slightly dependent on the jet-finder algorithm. The value we quote is obtained using the JADE algorithm, while using the DURHAM algorithm ABREU 96S obtain an upper limit of  $1.5 \times 10^{-2}$ .

### $\Gamma(\pi^0\gamma)/\Gamma_{\text{total}}$

$\Gamma_{15}/\Gamma$

| VALUE                                       | CL% | DOCUMENT ID           | TECN     | COMMENT                                  |
|---|-----|-----------------------|----------|--|
| <b><math>&lt;2.01 \times 10^{-5}</math></b> | 95  | AALTONEN              | 14E CDF  | $E_{\text{cm}}^{p\bar{p}} = 1.96$ TeV    |
| $<5.2 \times 10^{-5}$                       | 95  | <sup>1</sup> ACCIARRI | 95G L3   | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<5.5 \times 10^{-5}$                       | 95  | ABREU                 | 94B DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<2.1 \times 10^{-4}$                       | 95  | DECAMP                | 92 ALEP  | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<1.4 \times 10^{-4}$                       | 95  | AKRAWY                | 91F OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> This limit is for both decay modes  $Z \rightarrow \pi^0\gamma/\gamma\gamma$  which are indistinguishable in ACCIARRI 95G.

### $\Gamma(\eta\gamma)/\Gamma_{\text{total}}$

$\Gamma_{16}/\Gamma$

| VALUE                                      | CL% | DOCUMENT ID | TECN     | COMMENT                                  |
|--|-----|-------------|----------|--|
| $<7.6 \times 10^{-5}$                      | 95  | ACCIARRI    | 95G L3   | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<8.0 \times 10^{-5}$                      | 95  | ABREU       | 94B DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| <b><math>&lt;5.1 \times 10^{-5}</math></b> | 95  | DECAMP      | 92 ALEP  | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<2.0 \times 10^{-4}$                      | 95  | AKRAWY      | 91F OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

### $\Gamma(\rho^0\gamma)/\Gamma_{\text{total}}$

$\Gamma_{17}/\Gamma$

| VALUE                                      | CL% | EVTS  | DOCUMENT ID         | TECN      | COMMENT                             |
|--|-----|-------|---------------------|-----------|-------------------------------------|
| <b><math>&lt;2.5 \times 10^{-5}</math></b> | 95  | 12.5k | <sup>1</sup> AABOUD | 18AU ATLS | $E_{\text{cm}}^{p\bar{p}} = 13$ TeV |

<sup>1</sup> AABOUD 18AU search for the  $Z \rightarrow \rho\gamma$  decay mode where the  $\rho$  is identified through its decay  $\rho \rightarrow \pi^+\pi^-$ . In the data corresponding to  $32.3 \text{ fb}^{-1}$ , 12,583 events are selected for  $635 < m(\pi^+\pi^-) < 915$  MeV.

### $\Gamma(\omega\gamma)/\Gamma_{\text{total}}$

$\Gamma_{18}/\Gamma$

| VALUE                                      | CL% | DOCUMENT ID | TECN     | COMMENT                                  |
|--|-----|-------------|----------|--|
| <b><math>&lt;6.5 \times 10^{-4}</math></b> | 95  | ABREU       | 94B DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

$\Gamma(\eta'(958)\gamma)/\Gamma_{\text{total}}$   $\Gamma_{19}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID | TECN    | COMMENT                                  |
|-----------------------|-----|-------------|---------|--|
| $<4.2 \times 10^{-5}$ | 95  | DECAMP      | 92 ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

$\Gamma(\phi\gamma)/\Gamma_{\text{total}}$   $\Gamma_{20}/\Gamma$

| VALUE               | CL% | EVTS | DOCUMENT ID         | TECN      | COMMENT                       |
|---------------------|-----|------|---------------------|-----------|-------------------------------|
| $<9 \times 10^{-7}$ | 95  | 3.3k | <sup>1</sup> AABOUD | 18AU ATLS | $E_{\text{cm}}^{pp} = 13$ TeV |

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

|                       |    |      |                     |          |                               |
|-----------------------|----|------|---------------------|----------|-------------------------------|
| $<8.3 \times 10^{-6}$ | 95 | 1.0k | <sup>2</sup> AABOUD | 16K ATLS | $E_{\text{cm}}^{pp} = 13$ TeV |
|-----------------------|----|------|---------------------|----------|-------------------------------|

<sup>1</sup> AABOUD 18AU search for the  $Z \rightarrow \phi\gamma$  decay mode where the  $\phi$  is identified through its decay  $\phi \rightarrow K^+K^-$ . In the data corresponding to  $32.3 \text{ fb}^{-1}$ , 3,364 events are selected for  $1012 < m(K^+K^-) < 1028$  MeV.

<sup>2</sup> AABOUD 16K search for the  $Z \rightarrow \phi\gamma$  decay mode where the  $\phi$  is identified through its decay into  $K^+K^-$ . In the data corresponding to a total luminosity of  $2.7 \text{ fb}^{-1}$ , 1065 events are selected and their  $K^+K^-\gamma$  invariant mass spectrum is analyzed.

$\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_{21}/\Gamma$

This decay would violate the Landau-Yang theorem.

| VALUE                  | CL% | DOCUMENT ID           | TECN     | COMMENT                                  |
|------------------------|-----|-----------------------|----------|--|
| $<1.46 \times 10^{-5}$ | 95  | AALTONEN              | 14E CDF  | $E_{\text{cm}}^{pp} = 1.96$ TeV          |
| $<5.2 \times 10^{-5}$  | 95  | <sup>1</sup> ACCIARRI | 95G L3   | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<5.5 \times 10^{-5}$  | 95  | ABREU                 | 94B DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<1.4 \times 10^{-4}$  | 95  | AKRAWY                | 91F OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> This limit is for both decay modes  $Z \rightarrow \pi^0\gamma/\gamma\gamma$  which are indistinguishable in ACCIARRI 95G.

$\Gamma(\pi^0\pi^0)/\Gamma_{\text{total}}$   $\Gamma_{22}/\Gamma$

| VALUE                  | CL% | DOCUMENT ID | TECN    | COMMENT                         |
|------------------------|-----|-------------|---------|---------------------------------|
| $<1.52 \times 10^{-5}$ | 95  | AALTONEN    | 14E CDF | $E_{\text{cm}}^{pp} = 1.96$ TeV |

$\Gamma(\gamma\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_{23}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID | TECN     | COMMENT                      |
|-----------------------|-----|-------------|----------|------------------------------|
| $<2.2 \times 10^{-6}$ | 95  | AAD         | 16L ATLS | $E_{\text{cm}}^{pp} = 8$ TeV |

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

|                       |    |                       |          |  |
|-----------------------|----|-----------------------|----------|--|
| $<1.0 \times 10^{-5}$ | 95 | <sup>1</sup> ACCIARRI | 95C L3   | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<1.7 \times 10^{-5}$ | 95 | <sup>1</sup> ABREU    | 94B DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| $<6.6 \times 10^{-5}$ | 95 | AKRAWY                | 91F OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> Limit derived in the context of composite  $Z$  model.

$\Gamma(\pi^\pm W^\mp)/\Gamma_{\text{total}}$   $\Gamma_{24}/\Gamma$

The value is for the sum of the charge states indicated.

| VALUE               | CL% | DOCUMENT ID | TECN    | COMMENT                                  |
|---------------------|-----|-------------|---------|--|
| $<7 \times 10^{-5}$ | 95  | DECAMP      | 92 ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

$\Gamma(\rho^\pm W^\mp)/\Gamma_{\text{total}}$   $\Gamma_{25}/\Gamma$

The value is for the sum of the charge states indicated.

| VALUE                 | CL% | DOCUMENT ID | TECN    | COMMENT                                  |
|-----------------------|-----|-------------|---------|--|
| $<8.3 \times 10^{-5}$ | 95  | DECAMP      | 92 ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

$\Gamma(J/\psi(1S)X)/\Gamma_{\text{total}}$   $\Gamma_{26}/\Gamma$

| VALUE (units $10^{-3}$ ) | EVTS | DOCUMENT ID | TECN | COMMENT |
|--------------------------|------|-------------|------|---------|
|--------------------------|------|-------------|------|---------|

**3.51<sup>+0.23</sup><sub>-0.25</sub> OUR AVERAGE** Error includes scale factor of 1.1.

3.21 ± 0.21<sup>+0.19</sup><sub>-0.28</sub> 553 <sup>1</sup> ACCIARRI 99F L3  $E_{\text{cm}}^{ee} = 88\text{--}94$  GeV

3.9 ± 0.2 ± 0.3 511 <sup>2</sup> ALEXANDER 96B OPAL  $E_{\text{cm}}^{ee} = 88\text{--}94$  GeV

3.73 ± 0.39 ± 0.36 153 <sup>3</sup> ABREU 94P DLPH  $E_{\text{cm}}^{ee} = 88\text{--}94$  GeV

<sup>1</sup> ACCIARRI 99F combine  $\mu^+ \mu^-$  and  $e^+ e^- J/\psi(1S)$  decay channels. The branching ratio for prompt  $J/\psi(1S)$  production is measured to be  $(2.1 \pm 0.6 \pm 0.4^{+0.4}_{-0.2}(\text{theor.})) \times 10^{-4}$ .

<sup>2</sup> ALEXANDER 96B identify  $J/\psi(1S)$  from the decays into lepton pairs.  $(4.8 \pm 2.4)\%$  of this branching ratio is due to prompt  $J/\psi(1S)$  production (ALEXANDER 96N).

<sup>3</sup> Combining  $\mu^+ \mu^-$  and  $e^+ e^-$  channels and taking into account the common systematic errors.  $(7.7^{+6.3}_{-5.4})\%$  of this branching ratio is due to prompt  $J/\psi(1S)$  production.

$\Gamma(J/\psi(1S)\gamma)/\Gamma_{\text{total}}$   $\Gamma_{27}/\Gamma$

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|-------|-----|-------------|------|---------|
|-------|-----|-------------|------|---------|

$<2.3 \times 10^{-6}$  95 <sup>1</sup> AABOUD 18BL ATLS  $E_{\text{cm}}^{pp} = 13$  TeV

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

$<2.6 \times 10^{-6}$  95 <sup>2</sup> AAD 15l ATLS  $E_{\text{cm}}^{pp} = 8$  TeV

<sup>1</sup> AABOUD 18BL study  $Z \rightarrow J/\psi \gamma$  in 13 TeV  $pp$  interactions. Two triggers were used: isolated photon of  $p_T > 35(25)$  GeV and a muon with  $p_T > 18(24)$  GeV. The  $J/\psi$  is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the  $J/\psi$  in the plane transverse to the beam direction is  $> \pi/2$ . The number of observed/expected background events is  $92/89 \pm 6$  in the dimuon mass range 2.9–3.3 GeV leading to the quoted 95% C.L. limit.

<sup>2</sup> AAD 15l use events with the highest  $p_T$  muon in the pair required to have  $p_T > 20$  GeV, the dimuon mass required to be within 0.2 GeV of the  $J/\psi(1S)$  mass and it's transverse momentum required to be  $> 36$  GeV. The photon is also required to have it's  $p_T > 36$  GeV.

$\Gamma(\psi(2S)X)/\Gamma_{\text{total}}$   $\Gamma_{28}/\Gamma$

| VALUE (units $10^{-3}$ ) | EVTS | DOCUMENT ID | TECN | COMMENT |
|--------------------------|------|-------------|------|---------|
|--------------------------|------|-------------|------|---------|

**1.60 ± 0.29 OUR AVERAGE**

1.6 ± 0.5 ± 0.3 39 <sup>1</sup> ACCIARRI 97J L3  $E_{\text{cm}}^{ee} = 88\text{--}94$  GeV

1.6 ± 0.3 ± 0.2 46.9 <sup>2</sup> ALEXANDER 96B OPAL  $E_{\text{cm}}^{ee} = 88\text{--}94$  GeV

1.60 ± 0.73 ± 0.33 5.4 <sup>3</sup> ABREU 94P DLPH  $E_{\text{cm}}^{ee} = 88\text{--}94$  GeV

<sup>1</sup> ACCIARRI 97J measure this branching ratio via the decay channel  $\psi(2S) \rightarrow \ell^+ \ell^-$  ( $\ell = \mu, e$ ).

<sup>2</sup> ALEXANDER 96B measure this branching ratio via the decay channel  $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ , with  $J/\psi \rightarrow \ell^+ \ell^-$ .

<sup>3</sup> ABREU 94P measure this branching ratio via decay channel  $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ , with  $J/\psi \rightarrow \mu^+ \mu^-$ .

$\Gamma(\psi(2S)\gamma)/\Gamma_{\text{total}}$   $\Gamma_{29}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID         | TECN      | COMMENT                               |
|-----------------------|-----|---------------------|-----------|---------------------------------------|
| $<4.5 \times 10^{-6}$ | 95  | <sup>1</sup> AABOUD | 18BL ATLS | $E_{\text{cm}}^{pp} = 13 \text{ TeV}$ |

<sup>1</sup> AABOUD 18BL study  $Z \rightarrow \psi(2S)\gamma$  in 13 TeV  $pp$  interactions. Two triggers were used: isolated photon of  $p_T > 35(25) \text{ GeV}$  and a muon with  $p_T > 18(24) \text{ GeV}$ . The  $\psi(2S)$  is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the  $\psi(2S)$  in the plane transverse to the beam direction is  $> \pi/2$ . The number of observed/expected background events is  $43/42 \pm 5$  in the dimuon mass range 3.5–3.9 GeV leading to the quoted 95% C.L. limit.

$\Gamma(J/\psi(1S)\ell^+\ell^-)/\Gamma(\mu^+\mu^-\mu^+\mu^-)$   $\Gamma_{30}/\Gamma_5$

| VALUE                    | DOCUMENT ID           | TECN     | COMMENT        |
|--------------------------|-----------------------|----------|----------------|
| $0.67 \pm 0.18 \pm 0.05$ | <sup>1</sup> SIRUNYAN | 18DZ CMS | $pp$ at 13 TeV |

<sup>1</sup> SIRUNYAN 18DZ observe the decay  $Z \rightarrow \Psi \ell^+ \ell^-$  in  $pp$  collisions at  $\sqrt{s} = 13 \text{ TeV}$ , where  $\Psi$  includes  $J/\psi$  as well as  $\psi(2S) \rightarrow J/\psi X$ , and  $\ell^+ \ell^-$  represents an electron or muon pair while the  $J/\psi$  is detected via its  $\mu^+ \mu^-$  decay channel. To reduce systematic errors they determine the ratio of the branching fraction of this decay to that of  $Z \rightarrow \mu^+ \mu^- \mu^+ \mu^-$  within phase-space cuts imposed on lepton transverse momentum and pseudo rapidity, dilepton invariant mass, and  $J/\psi$  transverse momentum. The number of selected  $\Psi \mu^+ \mu^-$  ( $\Psi e^+ e^-$ ) candidate events is 29 (18). Analyzing the  $\mu^+ \mu^-$  and  $\mu^+ \mu^- \ell^+ \ell^-$  invariant mass distributions, a yield of  $13.0 \pm 3.9$  ( $11.2 \pm 3.4$ ) events for the  $\Psi \mu^+ \mu^-$  ( $\Psi e^+ e^-$ ) mode is obtained. The ratio of the branching fractions is determined as  $0.67 \pm 0.18 \pm 0.05$  within the selected phase-space cuts. Assuming extrapolation to full phase space cancels in the ratio, and using their measured value of  $B(Z \rightarrow \mu^+ \mu^- \mu^+ \mu^-) = (1.20 \pm 0.08) \times 10^{-6}$ , they estimate  $B(Z \rightarrow J/\psi \ell^+ \ell^-) = 8 \times 10^{-7}$ .

$\Gamma(\chi_{c1}(1P)X)/\Gamma_{\text{total}}$   $\Gamma_{31}/\Gamma$

| VALUE (units $10^{-3}$ )                    | EVTS | DOCUMENT ID           | TECN     | COMMENT  |
|---|------|-----------------------|----------|--|
| <b><math>2.9 \pm 0.7</math> OUR AVERAGE</b> |      |                       |          |  |
| $2.7 \pm 0.6 \pm 0.5$                       | 33   | <sup>1</sup> ACCIARRI | 97J L3   | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $5.0 \pm 2.1^{+1.5}_{-0.9}$                 | 6.4  | <sup>2</sup> ABREU    | 94P DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> ACCIARRI 97J measure this branching ratio via the decay channel  $\chi_{c1} \rightarrow J/\psi + \gamma$ , with  $J/\psi \rightarrow \ell^+ \ell^-$  ( $\ell = \mu, e$ ). The  $M(\ell^+ \ell^- \gamma) - M(\ell^+ \ell^-)$  mass difference spectrum is fitted with two gaussian shapes for  $\chi_{c1}$  and  $\chi_{c2}$ .

<sup>2</sup> This branching ratio is measured via the decay channel  $\chi_{c1} \rightarrow J/\psi + \gamma$ , with  $J/\psi \rightarrow \mu^+ \mu^-$ .

$\Gamma(\chi_{c2}(1P)X)/\Gamma_{\text{total}}$   $\Gamma_{32}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID           | TECN   | COMMENT  |
|-----------------------|-----|-----------------------|--------|--|
| $<3.2 \times 10^{-3}$ | 90  | <sup>1</sup> ACCIARRI | 97J L3 | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> ACCIARRI 97J derive this limit via the decay channel  $\chi_{c2} \rightarrow J/\psi + \gamma$ , with  $J/\psi \rightarrow \ell^+ \ell^-$  ( $\ell = \mu, e$ ). The  $M(\ell^+ \ell^- \gamma) - M(\ell^+ \ell^-)$  mass difference spectrum is fitted with two gaussian shapes for  $\chi_{c1}$  and  $\chi_{c2}$ .



$\Gamma(\Upsilon(1S)X + \Upsilon(2S)X + \Upsilon(3S)X)/\Gamma_{\text{total}}$        $\Gamma_{33}/\Gamma = (\Gamma_{34} + \Gamma_{36} + \Gamma_{38})/\Gamma$

| VALUE (units $10^{-4}$ )                 | EVTS | DOCUMENT ID                | TECN | COMMENT                                  |
|--|------|----------------------------|------|--|
| <b><math>1.0 \pm 0.4 \pm 0.22</math></b> | 6.4  | <sup>1</sup> ALEXANDER 96F | OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ALEXANDER 96F identify the  $\Upsilon$  (which refers to any of the three lowest bound states) through its decay into  $e^+e^-$  and  $\mu^+\mu^-$ . The systematic error includes an uncertainty of  $\pm 0.2$  due to the production mechanism.

$\Gamma(\Upsilon(1S)X)/\Gamma_{\text{total}}$        $\Gamma_{34}/\Gamma$

| VALUE                                       | CL% | DOCUMENT ID          | TECN | COMMENT                      |
|---|-----|----------------------|------|------------------------------|
| <b><math>&lt; 3.4 \times 10^{-6}</math></b> | 95  | <sup>1</sup> AAD 15I | ATLS | $E_{\text{cm}}^{pp} = 8$ TeV |

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

|                        |    |                           |    |  |
|------------------------|----|---------------------------|----|--|
| $< 4.4 \times 10^{-5}$ | 95 | <sup>2</sup> ACCIARRI 99F | L3 | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
|------------------------|----|---------------------------|----|--|

<sup>1</sup> AAD 15I use events with the highest  $p_T$  muon in the pair required to have  $p_T > 20$  GeV, the dimuon mass required to be in the range 8–12 GeV and it's transverse momentum required to be  $> 36$  GeV. The photon is also required to have it's  $p_T > 36$  GeV.

<sup>2</sup> ACCIARRI 99F search for  $\Upsilon(1S)$  through its decay into  $\ell^+\ell^-$  ( $\ell = e$  or  $\mu$ ).

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{\text{total}}$        $\Gamma_{35}/\Gamma$

| VALUE                                       | CL% | DOCUMENT ID              | TECN | COMMENT                       |
|---|-----|--------------------------|------|-------------------------------|
| <b><math>&lt; 2.8 \times 10^{-6}</math></b> | 95  | <sup>1</sup> AABOUD 18BL | ATLS | $E_{\text{cm}}^{pp} = 13$ TeV |

<sup>1</sup> AABOUD 18BL study  $Z \rightarrow \Upsilon(1S)\gamma$  in 13 TeV  $pp$  interactions. Two triggers were used: isolated photon of  $p_T > 35(25)$  GeV and a muon with  $p_T > 18(24)$  GeV. The  $\Upsilon(1S)$  is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the  $\Upsilon(1S)$  in the plane transverse to the beam direction is  $> \pi/2$ . The number of observed/expected background events is  $115/126 \pm 8$  in the dimuon mass range 9.0–10.0 GeV leading to the quoted 95% C.L. limit.

$\Gamma(\Upsilon(2S)X)/\Gamma_{\text{total}}$        $\Gamma_{36}/\Gamma$

| VALUE                                       | CL% | DOCUMENT ID          | TECN | COMMENT                      |
|---|-----|----------------------|------|------------------------------|
| <b><math>&lt; 6.5 \times 10^{-6}</math></b> | 95  | <sup>1</sup> AAD 15I | ATLS | $E_{\text{cm}}^{pp} = 8$ TeV |

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

|                         |    |                           |    |  |
|-------------------------|----|---------------------------|----|--|
| $< 13.9 \times 10^{-5}$ | 95 | <sup>2</sup> ACCIARRI 97R | L3 | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
|-------------------------|----|---------------------------|----|--|

<sup>1</sup> AAD 15I use events with the highest  $p_T$  muon in the pair required to have  $p_T > 20$  GeV, the dimuon mass required to be in the range 8–12 GeV and it's transverse momentum required to be  $> 36$  GeV. The photon is also required to have it's  $p_T > 36$  GeV.

<sup>2</sup> ACCIARRI 97R search for  $\Upsilon(2S)$  through its decay into  $\ell^+\ell^-$  ( $\ell = e$  or  $\mu$ ).

$\Gamma(\Upsilon(2S)\gamma)/\Gamma_{\text{total}}$        $\Gamma_{37}/\Gamma$

| VALUE                                       | CL% | DOCUMENT ID              | TECN | COMMENT                       |
|---|-----|--------------------------|------|-------------------------------|
| <b><math>&lt; 1.7 \times 10^{-6}</math></b> | 95  | <sup>1</sup> AABOUD 18BL | ATLS | $E_{\text{cm}}^{pp} = 13$ TeV |

<sup>1</sup> AABOUD 18BL study  $Z \rightarrow \Upsilon(2S)\gamma$  in 13 TeV  $pp$  interactions. Two triggers were used: isolated photon of  $p_T > 35(25)$  GeV and a muon with  $p_T > 18(24)$  GeV. The  $\Upsilon(2S)$  is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the  $\Upsilon(2S)$  in the plane transverse to the beam direction is  $> \pi/2$ . The number of observed/expected background events is  $106/121 \pm 8$  in the dimuon mass range 9.5–10.5 GeV leading to the quoted 95% C.L. limit.

$\Gamma(\Upsilon(3S)X)/\Gamma_{\text{total}}$   $\Gamma_{38}/\Gamma$

| <u>VALUE</u>  | <u>CL%</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                                   |
|---|------------|-----------------------|-------------|--|
| $<5.4 \times 10^{-6}$   | 95         | <sup>1</sup> AAD      | 15I ATLS    | $E_{\text{cm}}^{pp} = 8 \text{ TeV}$             |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |            |                       |             |  |
| $<9.4 \times 10^{-5}$   | 95         | <sup>2</sup> ACCIARRI | 97R L3      | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> AAD 15I use events with the highest  $p_T$  muon in the pair required to have  $p_T > 20 \text{ GeV}$ , the dimuon mass required to be in the range 8–12 GeV and it's transverse momentum required to be  $> 36 \text{ GeV}$ . The photon is also required to have it's  $p_T > 36 \text{ GeV}$ .

<sup>2</sup> ACCIARRI 97R search for  $\Upsilon(3S)$  through its decay into  $\ell^+ \ell^-$  ( $\ell = e$  or  $\mu$ ).

$\Gamma(\Upsilon(3S)\gamma)/\Gamma_{\text{total}}$   $\Gamma_{39}/\Gamma$

| <u>VALUE</u>          | <u>CL%</u> | <u>DOCUMENT ID</u>  | <u>TECN</u> | <u>COMMENT</u>                        |
|-----------------------|------------|---------------------|-------------|---------------------------------------|
| $<4.8 \times 10^{-6}$ | 95         | <sup>1</sup> AABOUD | 18BL ATLS   | $E_{\text{cm}}^{pp} = 13 \text{ TeV}$ |

<sup>1</sup> AABOUD 18BL study  $Z \rightarrow \Upsilon(3S)\gamma$  in 13 TeV  $pp$  interactions. Two triggers were used: isolated photon of  $p_T > 35(25) \text{ GeV}$  and a muon with  $p_T > 18(24) \text{ GeV}$ . The  $\Upsilon(3S)$  is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the  $\Upsilon(3S)$  in the plane transverse to the beam direction is  $> \pi/2$ . The number of observed/expected background events is  $112/113 \pm 8$  in the dimuon mass range 10.0–11.0 GeV leading to the quoted 95% C.L. limit.

$\Gamma((D^0/\bar{D}^0)X)/\Gamma(\text{hadrons})$   $\Gamma_{40}/\Gamma_8$

| <u>VALUE</u>                | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                                   |
|-----------------------------|-------------|--------------------|-------------|--|
| $0.296 \pm 0.019 \pm 0.021$ | 369         | <sup>1</sup> ABREU | 93I DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> The  $(D^0/\bar{D}^0)$  states in ABREU 93I are detected by the  $K\pi$  decay mode. This is a corrected result (see the erratum of ABREU 93I).

$\Gamma(D^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{41}/\Gamma_8$

| <u>VALUE</u>                | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                                   |
|-----------------------------|-------------|--------------------|-------------|--|
| $0.174 \pm 0.016 \pm 0.018$ | 539         | <sup>1</sup> ABREU | 93I DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> The  $D^\pm$  states in ABREU 93I are detected by the  $K\pi\pi$  decay mode. This is a corrected result (see the erratum of ABREU 93I).

$\Gamma(D^*(2010)^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{42}/\Gamma_8$

The value is for the sum of the charge states indicated.

| <u>VALUE</u>                  | <u>EVTS</u> | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>                                   |
|-------------------------------|-------------|-------------------------------------|-------------|--|
| $0.163 \pm 0.019$ OUR AVERAGE |             | Error includes scale factor of 1.3. |             |  |
| $0.155 \pm 0.010 \pm 0.013$   | 358         | <sup>1</sup> ABREU                  | 93I DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $0.21 \pm 0.04$               | 362         | <sup>2</sup> DECAMP                 | 91J ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup>  $D^*(2010)^\pm$  in ABREU 93I are reconstructed from  $D^0\pi^\pm$ , with  $D^0 \rightarrow K^-\pi^+$ . The new CLEO II measurement of  $B(D^{*\pm} \rightarrow D^0\pi^\pm) = (68.1 \pm 1.6) \%$  is used. This is a corrected result (see the erratum of ABREU 93I).

<sup>2</sup> DECAMP 91J report  $B(D^*(2010)^+ \rightarrow D^0\pi^+) B(D^0 \rightarrow K^-\pi^+) \Gamma(D^*(2010)^\pm X) / \Gamma(\text{hadrons}) = (5.11 \pm 0.34) \times 10^{-3}$ . They obtained the above number assuming  $B(D^0 \rightarrow K^-\pi^+) = (3.62 \pm 0.34 \pm 0.44) \%$  and  $B(D^*(2010)^+ \rightarrow D^0\pi^+) = (55 \pm 4) \%$ . We have rescaled their original result of  $0.26 \pm 0.05$  taking into account the new CLEO II branching ratio  $B(D^*(2010)^+ \rightarrow D^0\pi^+) = (68.1 \pm 1.6) \%$ .

$\Gamma(D_{s1}(2536)^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{43}/\Gamma_8$

$D_{s1}(2536)^\pm$  is an expected orbitally-excited state of the  $D_s$  meson.

| VALUE (%)             | EVTS | DOCUMENT ID          | TECN     | COMMENT                                  |
|-----------------------|------|----------------------|----------|--|
| <b>0.52±0.09±0.06</b> | 92   | <sup>1</sup> HEISTER | 02B ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> HEISTER 02B reconstruct this meson in the decay modes  $D_{s1}(2536)^\pm \rightarrow D^{*\pm} K^0$  and  $D_{s1}(2536)^\pm \rightarrow D^{*0} K^\pm$ . The quoted branching ratio assumes that the decay width of the  $D_{s1}(2536)$  is saturated by the two measured decay modes.

$\Gamma(D_{sJ}(2573)^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{44}/\Gamma_8$

$D_{sJ}(2573)^\pm$  is an expected orbitally-excited state of the  $D_s$  meson.

| VALUE (%)  | EVTS | DOCUMENT ID          | TECN     | COMMENT                                  |
|--|------|----------------------|----------|--|
| <b>0.83±0.29<sup>+0.07</sup><sub>-0.13</sub></b> | 64   | <sup>1</sup> HEISTER | 02B ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> HEISTER 02B reconstruct this meson in the decay mode  $D_{s2}^*(2573)^\pm \rightarrow D^0 K^\pm$ . The quoted branching ratio assumes that the detected decay mode represents 45% of the full decay width.

$\Gamma(D^{*'}(2629)^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{45}/\Gamma_8$

$D^{*'}(2629)^\pm$  is a predicted radial excitation of the  $D^*(2010)^\pm$  meson.

| VALUE               | DOCUMENT ID           | TECN     | COMMENT                                  |
|---------------------|-----------------------|----------|--|
| <b>searched for</b> | <sup>1</sup> ABBIENDI | 01N OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ABBIENDI 01N searched for the decay mode  $D^{*'}(2629)^\pm \rightarrow D^{*\pm} \pi^+ \pi^-$  with  $D^{*+} \rightarrow D^0 \pi^+$ , and  $D^0 \rightarrow K^- \pi^+$ . They quote a 95% CL limit for  $Z \rightarrow D^{*'}(2629)^\pm \times \text{B}(D^{*'}(2629)^+ \rightarrow D^{*+} \pi^+ \pi^-) < 3.1 \times 10^{-3}$ .

$\Gamma(B^* X)/[\Gamma(BX) + \Gamma(B^* X)]$   $\Gamma_{47}/(\Gamma_{46} + \Gamma_{47})$

As the experiments assume different values of the  $b$ -baryon contribution, our average should be taken with caution.

| VALUE                         | EVTS | DOCUMENT ID             | TECN     | COMMENT                                  |
|-------------------------------|------|-------------------------|----------|--|
| <b>0.75 ±0.04 OUR AVERAGE</b> |      |                         |          |  |
| 0.760±0.036±0.083             |      | <sup>1</sup> ACKERSTAFF | 97M OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.771±0.026±0.070             |      | <sup>2</sup> BUSKULIC   | 96D ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.72 ±0.03 ±0.06              |      | <sup>3</sup> ABREU      | 95R DLPH | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| 0.76 ±0.08 ±0.06              | 1378 | <sup>4</sup> ACCIARRI   | 95B L3   | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ACKERSTAFF 97M use an inclusive  $B$  reconstruction method and assume a  $(13.2 \pm 4.1)\%$   $b$ -baryon contribution. The value refers to a  $b$ -flavored meson mixture of  $B_u$ ,  $B_d$ , and  $B_s$ .

<sup>2</sup> BUSKULIC 96D use an inclusive reconstruction of  $B$  hadrons and assume a  $(12.2 \pm 4.3)\%$   $b$ -baryon contribution. The value refers to a  $b$ -flavored mixture of  $B_u$ ,  $B_d$ , and  $B_s$ .

<sup>3</sup> ABREU 95R use an inclusive  $B$ -reconstruction method and assume a  $(10 \pm 4)\%$   $b$ -baryon contribution. The value refers to a  $b$ -flavored meson mixture of  $B_u$ ,  $B_d$ , and  $B_s$ .

<sup>4</sup> ACCIARRI 95B assume a 9.4%  $b$ -baryon contribution. The value refers to a  $b$ -flavored mixture of  $B_u$ ,  $B_d$ , and  $B_s$ .

### $\Gamma(B^+X)/\Gamma(\text{hadrons})$

$\Gamma_{48}/\Gamma_8$

“OUR EVALUATION” is obtained using our current values for  $f(\bar{b} \rightarrow B^+)$  and  $R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons})$ . We calculate  $\Gamma(B^+X)/\Gamma(\text{hadrons}) = R_b \times f(\bar{b} \rightarrow B^+)$ .

The decay fraction  $f(\bar{b} \rightarrow B^+)$  was provided by the Heavy Flavor Averaging Group (HFLAV, <http://www.slac.stanford.edu/xorg/hflav/osc/PDG.2009/#FRACZ>).

| <u>VALUE</u>                          | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                           |
|---------------------------------------|-----------------------|-------------|--|
| <b>0.0869 ± 0.0019 OUR EVALUATION</b> |                       |             |  |
| <b>0.0887 ± 0.0030</b>                | <sup>1</sup> ABDALLAH | 03K DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ABDALLAH 03K measure the production fraction of  $B^+$  mesons in hadronic Z decays  $f(B^+) = (40.99 \pm 0.82 \pm 1.11)\%$ . The value quoted here is obtained multiplying this production fraction by our value of  $R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons})$ .

### $\Gamma(B_s^0X)/\Gamma(\text{hadrons})$

$\Gamma_{49}/\Gamma_8$

“OUR EVALUATION” is obtained using our current values for  $f(\bar{b} \rightarrow B_s^0)$  and  $R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons})$ . We calculate  $\Gamma(B_s^0X)/\Gamma(\text{hadrons}) = R_b \times f(\bar{b} \rightarrow B_s^0)$ . The decay

fraction  $f(\bar{b} \rightarrow B_s^0)$  was provided by the Heavy Flavor Averaging Group (HFLAV, <http://www.slac.stanford.edu/xorg/hflav/osc/PDG.2009/#FRACZ>).

| <u>VALUE</u>                          | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                           |
|---------------------------------------|-----------------------|-------------|--|
| <b>0.0227 ± 0.0019 OUR EVALUATION</b> |                       |             |  |
| seen                                  | <sup>1</sup> ABREU    | 92M DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| seen                                  | <sup>2</sup> ACTON    | 92N OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| seen                                  | <sup>3</sup> BUSKULIC | 92E ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ABREU 92M reported value is  $\Gamma(B_s^0X) \times B(B_s^0 \rightarrow D_s \mu \nu_\mu X) \times B(D_s \rightarrow \phi \pi)/\Gamma(\text{hadrons}) = (18 \pm 8) \times 10^{-5}$ .

<sup>2</sup> ACTON 92N find evidence for  $B_s^0$  production using  $D_s$ - $\ell$  correlations, with  $D_s^+ \rightarrow \phi \pi^+$  and  $K^*(892)K^+$ . Assuming  $R_b$  from the Standard Model and averaging over the  $e$  and  $\mu$  channels, authors measure the product branching fraction to be  $f(\bar{b} \rightarrow B_s^0) \times B(B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell X) \times B(D_s^- \rightarrow \phi \pi^-) = (3.9 \pm 1.1 \pm 0.8) \times 10^{-4}$ .

<sup>3</sup> BUSKULIC 92E find evidence for  $B_s^0$  production using  $D_s$ - $\ell$  correlations, with  $D_s^+ \rightarrow \phi \pi^+$  and  $K^*(892)K^+$ . Using  $B(D_s^+ \rightarrow \phi \pi^+) = (2.7 \pm 0.7)\%$  and summing up the  $e$  and  $\mu$  channels, the weighted average product branching fraction is measured to be  $B(\bar{b} \rightarrow B_s^0) \times B(B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell X) = 0.040 \pm 0.011_{-0.012}^{+0.010}$ .

### $\Gamma(B_c^+X)/\Gamma(\text{hadrons})$

$\Gamma_{50}/\Gamma_8$

| <u>VALUE</u> | <u>DOCUMENT ID</u>      | <u>TECN</u> | <u>COMMENT</u>                           |
|--------------|-------------------------|-------------|--|
| searched for | <sup>1</sup> ACKERSTAFF | 98O OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| searched for | <sup>2</sup> ABREU      | 97E DLPH    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |
| searched for | <sup>3</sup> BARATE     | 97H ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ACKERSTAFF 98O searched for the decay modes  $B_c \rightarrow J/\psi \pi^+$ ,  $J/\psi a_1^+$ , and  $J/\psi \ell^+ \nu_\ell$ , with  $J/\psi \rightarrow \ell^+ \ell^-$ ,  $\ell = e, \mu$ . The number of candidates (background) for the three decay modes is 2 ( $0.63 \pm 0.2$ ), 0 ( $1.10 \pm 0.22$ ), and 1 ( $0.82 \pm 0.19$ ) respectively. Interpreting the 2  $B_c \rightarrow J/\psi \pi^+$  candidates as signal, they report  $\Gamma(B_c^+X) \times B(B_c \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) = (3.8_{-2.4}^{+5.0} \pm 0.5) \times 10^{-5}$ . Interpreted as background, the 90% CL bounds are  $\Gamma(B_c^+X) \times B(B_c \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) < 1.06 \times 10^{-4}$ ,  $\Gamma(B_c^+X) \times B(B_c \rightarrow$

$$J/\psi a_1^+)/\Gamma(\text{hadrons}) < 5.29 \times 10^{-4}, \Gamma(B_c^+ X) * B(B_c \rightarrow J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 6.96 \times 10^{-5}.$$

<sup>2</sup> ABREU 97E searched for the decay modes  $B_c \rightarrow J/\psi \pi^+$ ,  $J/\psi \ell^+ \nu_\ell$ , and  $J/\psi (3\pi)^+$ , with  $J/\psi \rightarrow \ell^+ \ell^-$ ,  $\ell = e, \mu$ . The number of candidates (background) for the three decay modes is 1 (1.7), 0 (0.3), and 1 (2.3) respectively. They report the following 90% CL limits:  $\Gamma(B_c^+ X) * B(B_c \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}$ ,  $\Gamma(B_c^+ X) * B(B_c \rightarrow J/\psi \ell \nu_\ell)/\Gamma(\text{hadrons}) < (5.8-5.0) \times 10^{-5}$ ,  $\Gamma(B_c^+ X) * B(B_c \rightarrow J/\psi (3\pi)^+)/\Gamma(\text{hadrons}) < 1.75 \times 10^{-4}$ , where the ranges are due to the predicted  $B_c$  lifetime (0.4–1.4) ps.

<sup>3</sup> BARATE 97H searched for the decay modes  $B_c \rightarrow J/\psi \pi^+$  and  $J/\psi \ell^+ \nu_\ell$  with  $J/\psi \rightarrow \ell^+ \ell^-$ ,  $\ell = e, \mu$ . The number of candidates (background) for the two decay modes is 0 (0.44) and 2 (0.81) respectively. They report the following 90% CL limits:  $\Gamma(B_c^+ X) * B(B_c \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) < 3.6 \times 10^{-5}$  and  $\Gamma(B_c^+ X) * B(B_c \rightarrow J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 5.2 \times 10^{-5}$ .

### $\Gamma(\Lambda_c^+ X)/\Gamma(\text{hadrons})$

$\Gamma_{51}/\Gamma_8$

| VALUE                            | DOCUMENT ID                | TECN | COMMENT                          |
|----------------------------------|----------------------------|------|----------------------------------|
| <b>0.022 ± 0.005 OUR AVERAGE</b> |                            |      |                                  |
| 0.024 ± 0.005 ± 0.006            | <sup>1</sup> ALEXANDER 96R | OPAL | $E_{\text{cm}}^{ee} = 88-94$ GeV |
| 0.021 ± 0.003 ± 0.005            | <sup>2</sup> BUSKULIC 96Y  | ALEP | $E_{\text{cm}}^{ee} = 88-94$ GeV |

<sup>1</sup> ALEXANDER 96R measure  $R_b \times f(b \rightarrow \Lambda_c^+ X) \times B(\Lambda_c^+ \rightarrow p K^- \pi^+) = (0.122 \pm 0.023 \pm 0.010)\%$  in hadronic  $Z$  decays; the value quoted here is obtained using our best value  $B(\Lambda_c^+ \rightarrow p K^- \pi^+) = (5.0 \pm 1.3)\%$ . The first error is the total experiment's error and the second error is the systematic error due to the branching fraction uncertainty.

<sup>2</sup> BUSKULIC 96Y obtain the production fraction of  $\Lambda_c^+$  baryons in hadronic  $Z$  decays  $f(b \rightarrow \Lambda_c^+ X) = 0.110 \pm 0.014 \pm 0.006$  using  $B(\Lambda_c^+ \rightarrow p K^- \pi^+) = (4.4 \pm 0.6)\%$ ; we have rescaled using our best value  $B(\Lambda_c^+ \rightarrow p K^- \pi^+) = (5.0 \pm 1.3)\%$  obtaining  $f(b \rightarrow \Lambda_c^+ X) = 0.097 \pm 0.013 \pm 0.025$  where the first error is their total experiment's error and the second error is the systematic error due to the branching fraction uncertainty. The value quoted here is obtained multiplying this production fraction by our value of  $R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons})$ .

### $\Gamma(\Xi_c^0 X)/\Gamma(\text{hadrons})$

$\Gamma_{52}/\Gamma_8$

| VALUE | DOCUMENT ID | TECN | COMMENT |
|-------|-------------|------|---------|
|-------|-------------|------|---------|

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

seen <sup>1</sup> ABDALLAH 05C DLPH  $E_{\text{cm}}^{ee} = 88-94$  GeV  
<sup>1</sup> ABDALLAH 05C searched for the charmed strange baryon  $\Xi_c^0$  in the decay channel  $\Xi_c^0 \rightarrow \Xi^- \pi^+$  ( $\Xi^- \rightarrow \Lambda \pi^-$ ). The production rate is measured to be  $f_{\Xi_c^0} \times B(\Xi_c^0 \rightarrow \Xi^- \pi^+) = (4.7 \pm 1.4 \pm 1.1) \times 10^{-4}$  per hadronic  $Z$  decay.

### $\Gamma(\Xi_b X)/\Gamma(\text{hadrons})$

$\Gamma_{53}/\Gamma_8$

Here  $\Xi_b$  is used as a notation for the strange  $b$ -baryon states  $\Xi_b^-$  and  $\Xi_b^0$ .

| VALUE | DOCUMENT ID | TECN | COMMENT |
|-------|-------------|------|---------|
|-------|-------------|------|---------|

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

seen <sup>1</sup> ABDALLAH 05C DLPH  $E_{\text{cm}}^{ee} = 88-94$  GeV  
 seen <sup>2</sup> BUSKULIC 96T ALEP  $E_{\text{cm}}^{ee} = 88-94$  GeV  
 seen <sup>3</sup> ABREU 95V DLPH  $E_{\text{cm}}^{ee} = 88-94$  GeV

<sup>1</sup> ABDALLAH 05C searched for the beauty strange baryon  $\Xi_b$  in the inclusive semileptonic decay channel  $\Xi_b \rightarrow \Xi^- \ell^- \bar{\nu}_\ell X$ . Evidence for the  $\Xi_b$  production is seen from the observation of  $\Xi^\mp$  production accompanied by a lepton of the same sign. From the excess of “right-sign” pairs  $\Xi^\mp \ell^\mp$  compared to “wrong-sign” pairs  $\Xi^\mp \ell^\pm$  the production rate is measured to be  $B(b \rightarrow \Xi_b) \times B(\Xi_b \rightarrow \Xi^- \ell^- X) = (3.0 \pm 1.0 \pm 0.3) \times 10^{-4}$  per lepton species, averaged over electrons and muons.

<sup>2</sup> BUSKULIC 96T investigate  $\Xi$ -lepton correlations and find a significant excess of “right-sign” pairs  $\Xi^\mp \ell^\mp$  compared to “wrong-sign” pairs  $\Xi^\mp \ell^\pm$ . This excess is interpreted as evidence for  $\Xi_b$  semileptonic decay. The measured product branching ratio is  $B(b \rightarrow \Xi_b) \times B(\Xi_b \rightarrow X_c X \ell^- \bar{\nu}_\ell) \times B(X_c \rightarrow \Xi^- X') = (5.4 \pm 1.1 \pm 0.8) \times 10^{-4}$  per lepton species, averaged over electrons and muons, with  $X_c$  a charmed baryon.

<sup>3</sup> ABREU 95V observe an excess of “right-sign” pairs  $\Xi^\mp \ell^\mp$  compared to “wrong-sign” pairs  $\Xi^\mp \ell^\pm$  in jets: this excess is interpreted as evidence for the beauty strange baryon  $\Xi_b$  production, with  $\Xi_b \rightarrow \Xi^- \ell^- \bar{\nu}_\ell X$ . They find that the probability for this signal to come from non  $b$ -baryon decays is less than  $5 \times 10^{-4}$  and that  $\Lambda_b$  decays can account for less than 10% of these events. The  $\Xi_b$  production rate is then measured to be  $B(b \rightarrow \Xi_b) \times B(\Xi_b \rightarrow \Xi^- \ell^- X) = (5.9 \pm 2.1 \pm 1.0) \times 10^{-4}$  per lepton species, averaged over electrons and muons.

### $\Gamma(b\text{-baryon } X)/\Gamma(\text{hadrons})$

$\Gamma_{54}/\Gamma_8$

“OUR EVALUATION” is obtained using our current values for  $f(b \rightarrow b\text{-baryon})$  and  $R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons})$ . We calculate  $\Gamma(b\text{-baryon } X)/\Gamma(\text{hadrons}) = R_b \times f(b \rightarrow b\text{-baryon})$ . The decay fraction  $f(b \rightarrow b\text{-baryon})$  was provided by the Heavy Flavor Averaging Group (HFLAV, [http://www.slac.stanford.edu/xorg/hflav/osc/PDG\\_2009](http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009)).

| VALUE                                 | DOCUMENT ID         | TECN     | COMMENT                                  |
|---------------------------------------|---------------------|----------|--|
| <b>0.0197 ± 0.0032 OUR EVALUATION</b> |                     |          |  |
| <b>0.0221 ± 0.0015 ± 0.0058</b>       | <sup>1</sup> BARATE | 98V ALEP | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> BARATE 98V use the overall number of identified protons in  $b$ -hadron decays to measure  $f(b \rightarrow b\text{-baryon}) = 0.102 \pm 0.007 \pm 0.027$ . They assume  $\text{BR}(b\text{-baryon} \rightarrow pX) = (58 \pm 6)\%$  and  $\text{BR}(B_s^0 \rightarrow pX) = (8.0 \pm 4.0)\%$ . The value quoted here is obtained multiplying this production fraction by our value of  $R_b = \Gamma(b\bar{b})/\Gamma(\text{hadrons})$ .

### $\Gamma(\text{anomalous } \gamma + \text{hadrons})/\Gamma_{\text{total}}$

$\Gamma_{55}/\Gamma$

Limits on additional sources of prompt photons beyond expectations for final-state bremsstrahlung.

| VALUE                             | CL% | DOCUMENT ID         | TECN     | COMMENT                                  |
|-----------------------------------|-----|---------------------|----------|--|
| <b>&lt; 3.2 × 10<sup>-3</sup></b> | 95  | <sup>1</sup> AKRAWY | 90J OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> AKRAWY 90J report  $\Gamma(\gamma X) < 8.2$  MeV at 95%CL. They assume a three-body  $\gamma q\bar{q}$  distribution and use  $E(\gamma) > 10$  GeV.

### $\Gamma(e^+ e^- \gamma)/\Gamma_{\text{total}}$

$\Gamma_{56}/\Gamma$

| VALUE                             | CL% | DOCUMENT ID        | TECN     | COMMENT                         |
|-----------------------------------|-----|--------------------|----------|---------------------------------|
| <b>&lt; 5.2 × 10<sup>-4</sup></b> | 95  | <sup>1</sup> ACTON | 91B OPAL | $E_{\text{cm}}^{ee} = 91.2$ GeV |

<sup>1</sup> ACTON 91B looked for isolated photons with  $E > 2\%$  of beam energy ( $> 0.9$  GeV).

### $\Gamma(\mu^+ \mu^- \gamma)/\Gamma_{\text{total}}$

$\Gamma_{57}/\Gamma$

| VALUE                             | CL% | DOCUMENT ID        | TECN     | COMMENT                         |
|-----------------------------------|-----|--------------------|----------|---------------------------------|
| <b>&lt; 5.6 × 10<sup>-4</sup></b> | 95  | <sup>1</sup> ACTON | 91B OPAL | $E_{\text{cm}}^{ee} = 91.2$ GeV |

<sup>1</sup> ACTON 91B looked for isolated photons with  $E > 2\%$  of beam energy ( $> 0.9$  GeV).

$\Gamma(\tau^+ \tau^- \gamma)/\Gamma_{\text{total}}$   $\Gamma_{58}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID        | TECN     | COMMENT                                 |
|-----------------------|-----|--------------------|----------|---|
| $<7.3 \times 10^{-4}$ | 95  | <sup>1</sup> ACTON | 91B OPAL | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup> ACTON 91B looked for isolated photons with  $E > 2\%$  of beam energy ( $> 0.9 \text{ GeV}$ ).

$\Gamma(\ell^+ \ell^- \gamma \gamma)/\Gamma_{\text{total}}$   $\Gamma_{59}/\Gamma$

The value is the sum over  $\ell = e, \mu, \tau$ .

| VALUE                 | CL% | DOCUMENT ID        | TECN     | COMMENT  |
|-----------------------|-----|--------------------|----------|--|
| $<6.8 \times 10^{-6}$ | 95  | <sup>1</sup> ACTON | 93E OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> For  $m_{\gamma\gamma} = 60 \pm 5 \text{ GeV}$ .

$\Gamma(q\bar{q}\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_{60}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID        | TECN     | COMMENT  |
|-----------------------|-----|--------------------|----------|--|
| $<5.5 \times 10^{-6}$ | 95  | <sup>1</sup> ACTON | 93E OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> For  $m_{\gamma\gamma} = 60 \pm 5 \text{ GeV}$ .

$\Gamma(\nu\bar{\nu}\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_{61}/\Gamma$

| VALUE                 | CL% | DOCUMENT ID        | TECN     | COMMENT  |
|-----------------------|-----|--------------------|----------|--|
| $<3.1 \times 10^{-6}$ | 95  | <sup>1</sup> ACTON | 93E OPAL | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> For  $m_{\gamma\gamma} = 60 \pm 5 \text{ GeV}$ .

$\Gamma(e^\pm \mu^\mp)/\Gamma_{\text{total}}$   $\Gamma_{62}/\Gamma$

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

| VALUE                 | CL% | DOCUMENT ID | TECN      | COMMENT  |
|-----------------------|-----|-------------|-----------|--|
| $<7.5 \times 10^{-7}$ | 95  | AAD         | 14AU ATLS | $E_{\text{cm}}^{pp} = 8 \text{ TeV}$             |
| $<2.5 \times 10^{-6}$ | 95  | ABREU       | 97C DLPH  | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $<1.7 \times 10^{-6}$ | 95  | AKERS       | 95W OPAL  | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $<0.6 \times 10^{-5}$ | 95  | ADRIANI     | 93I L3    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $<2.6 \times 10^{-5}$ | 95  | DECAMP      | 92 ALEP   | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

$\Gamma(e^\pm \mu^\mp)/\Gamma(e^+ e^-)$   $\Gamma_{62}/\Gamma_1$

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

| VALUE   | CL% | DOCUMENT ID | TECN   | COMMENT  |
|---------|-----|-------------|--------|--|
| $<0.07$ | 90  | ALBAJAR     | 89 UA1 | $E_{\text{cm}}^{p\bar{p}} = 546,630 \text{ GeV}$ |

$\Gamma(e^\pm \tau^\mp)/\Gamma_{\text{total}}$   $\Gamma_{63}/\Gamma$

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

| VALUE                 | CL% | DOCUMENT ID | TECN      | COMMENT  |
|-----------------------|-----|-------------|-----------|--|
| $<5.8 \times 10^{-5}$ | 95  | AABOUD      | 18CN ATLS | $E_{\text{cm}}^{pp} = 13 \text{ TeV}$            |
| $<2.2 \times 10^{-5}$ | 95  | ABREU       | 97C DLPH  | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $<9.8 \times 10^{-6}$ | 95  | AKERS       | 95W OPAL  | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $<1.3 \times 10^{-5}$ | 95  | ADRIANI     | 93I L3    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $<1.2 \times 10^{-4}$ | 95  | DECAMP      | 92 ALEP   | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |

$\Gamma(\mu^\pm \tau^\mp)/\Gamma_{\text{total}}$   $\Gamma_{64}/\Gamma$

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

| VALUE                                      | CL% | DOCUMENT ID | TECN      | COMMENT                                  |
|--|-----|-------------|-----------|--|
| $<1.3 \times 10^{-5}$                      | 95  | AABOUD      | 18CN ATLS | $E_{\text{cm}}^{pp} = 8, 13 \text{ TeV}$ |
| <b><math>&lt;1.2 \times 10^{-5}</math></b> | 95  | ABREU       | 97C DLPH  | $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |
| $<1.7 \times 10^{-5}$                      | 95  | AKERS       | 95W OPAL  | $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |
| $<1.9 \times 10^{-5}$                      | 95  | ADRIANI     | 93I L3    | $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |
| $<1.0 \times 10^{-4}$                      | 95  | DECAMP      | 92 ALEP   | $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |

$\Gamma(pe)/\Gamma_{\text{total}}$   $\Gamma_{65}/\Gamma$

Test of baryon number and lepton number conservations. Charge conjugate states are implied.

| VALUE                                      | CL% | DOCUMENT ID           | TECN     | COMMENT                                  |
|--|-----|-----------------------|----------|--|
| <b><math>&lt;1.8 \times 10^{-6}</math></b> | 95  | <sup>1</sup> ABBIENDI | 99I OPAL | $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |

<sup>1</sup> ABBIENDI 99I give the 95%CL limit on the partial width  $\Gamma(Z^0 \rightarrow pe) < 4.6 \text{ KeV}$  and we have transformed it into a branching ratio.

$\Gamma(p\mu)/\Gamma_{\text{total}}$   $\Gamma_{66}/\Gamma$

Test of baryon number and lepton number conservations. Charge conjugate states are implied.

| VALUE                                      | CL% | DOCUMENT ID           | TECN     | COMMENT                                  |
|--|-----|-----------------------|----------|--|
| <b><math>&lt;1.8 \times 10^{-6}</math></b> | 95  | <sup>1</sup> ABBIENDI | 99I OPAL | $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |

<sup>1</sup> ABBIENDI 99I give the 95%CL limit on the partial width  $\Gamma(Z^0 \rightarrow p\mu) < 4.4 \text{ KeV}$  and we have transformed it into a branching ratio.

## AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC Z DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_\gamma \rangle$

| VALUE                                       | DOCUMENT ID    | TECN | COMMENT                                 |
|---|----------------|------|---|
| <b><math>20.97 \pm 0.02 \pm 1.15</math></b> | ACKERSTAFF 98A | OPAL | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

$\langle N_{\pi^\pm} \rangle$

| VALUE  | DOCUMENT ID | TECN     | COMMENT                                 |
|--|-------------|----------|---|
| <b><math>17.03 \pm 0.16</math> OUR AVERAGE</b> |             |          |   |
| $17.007 \pm 0.209$                             | ABE         | 04C SLD  | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $17.26 \pm 0.10 \pm 0.88$                      | ABREU       | 98L DLPH | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $17.04 \pm 0.31$                               | BARATE      | 98V ALEP | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $17.05 \pm 0.43$                               | AKERS       | 94P OPAL | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

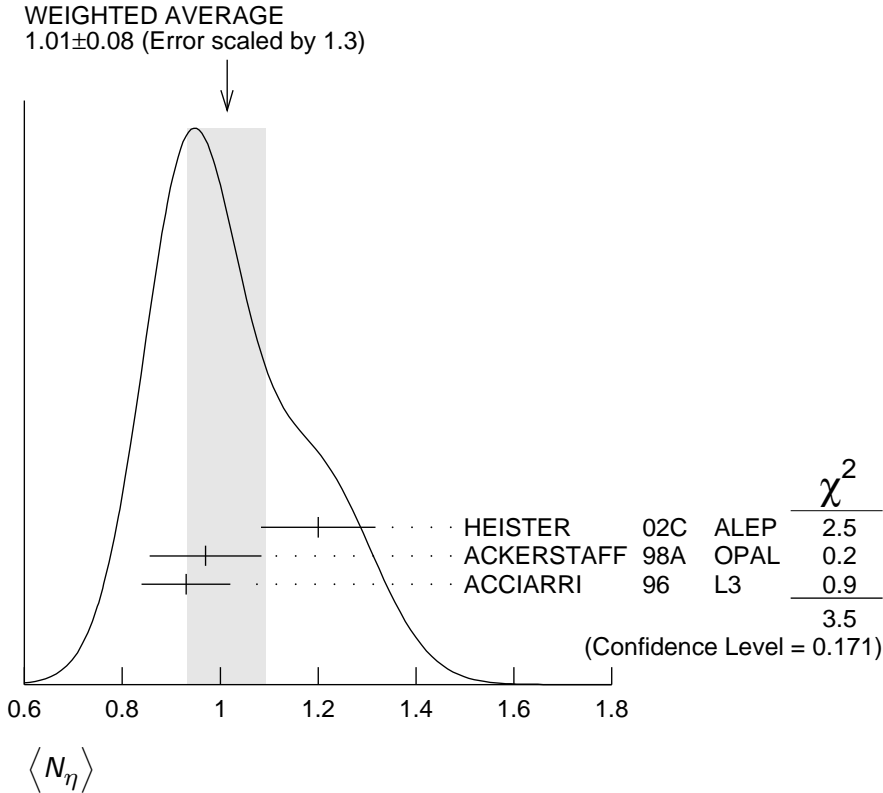
$\langle N_{\pi^0} \rangle$

| VALUE   | DOCUMENT ID    | TECN     | COMMENT                                 |
|---|----------------|----------|---|
| <b><math>9.76 \pm 0.26</math> OUR AVERAGE</b> |                |          |   |
| $9.55 \pm 0.06 \pm 0.75$                      | ACKERSTAFF 98A | OPAL     | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $9.63 \pm 0.13 \pm 0.63$                      | BARATE         | 97J ALEP | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $9.90 \pm 0.02 \pm 0.33$                      | ACCIARRI       | 96 L3    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $9.2 \pm 0.2 \pm 1.0$                         | ADAM           | 96 DLPH  | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |



### $\langle N_\eta \rangle$

| <u>VALUE</u>                   | <u>DOCUMENT ID</u>  | <u>TECN</u> | <u>COMMENT</u>                |
|--------------------------------|---|-------------|-------------------------------|
| <b>1.01 ± 0.08 OUR AVERAGE</b> | Error includes scale factor of 1.3. See the ideogram below. |             |                               |
| 1.20 ± 0.04 ± 0.11             | HEISTER   | 02C         | ALEP $E_{cm}^{ee} = 91.2$ GeV |
| 0.97 ± 0.03 ± 0.11             | ACKERSTAFF  | 98A         | OPAL $E_{cm}^{ee} = 91.2$ GeV |
| 0.93 ± 0.01 ± 0.09             | ACCIARRI  | 96          | L3 $E_{cm}^{ee} = 91.2$ GeV   |



### $\langle N_{\rho^\pm} \rangle$

| <u>VALUE</u>                   | <u>DOCUMENT ID</u>   | <u>TECN</u> | <u>COMMENT</u>                          |
|--------------------------------|----------------------|-------------|---|
| <b>2.57 ± 0.15 OUR AVERAGE</b> |                      |             |   |
| 2.59 ± 0.03 ± 0.16             | <sup>1</sup> BEDDALL | 09          | ALEPH archive, $E_{cm}^{ee} = 91.2$ GeV |
| 2.40 ± 0.06 ± 0.43             | ACKERSTAFF           | 98A         | OPAL $E_{cm}^{ee} = 91.2$ GeV           |

<sup>1</sup> BEDDALL 09 analyse 3.2 million hadronic Z decays as archived by ALEPH collaboration and report a value of  $2.59 \pm 0.03 \pm 0.15 \pm 0.04$ . The first error is statistical, the second systematic, and the third arises from extrapolation to full phase space. We combine the systematic errors in quadrature.

### $\langle N_{\rho^0} \rangle$

| <u>VALUE</u>                   | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>                |
|--------------------------------|-------------------------------------|-------------|-------------------------------|
| <b>1.24 ± 0.10 OUR AVERAGE</b> | Error includes scale factor of 1.1. |             |                               |
| 1.19 ± 0.10                    | ABREU                               | 99J         | DLPH $E_{cm}^{ee} = 91.2$ GeV |
| 1.45 ± 0.06 ± 0.20             | BUSKULIC                            | 96H         | ALEP $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_\omega \rangle$ 

| <u>VALUE</u>                   | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                          |
|--------------------------------|--------------------|-------------|---|
| <b>1.02 ± 0.06 OUR AVERAGE</b> |                    |             |   |
| 1.00 ± 0.03 ± 0.06             | HEISTER            | 02C ALEP    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 1.04 ± 0.04 ± 0.14             | ACKERSTAFF         | 98A OPAL    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 1.17 ± 0.09 ± 0.15             | ACCIARRI           | 97D L3      | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{\eta'} \rangle$ 

| <u>VALUE</u>   | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>                          |
|--|-------------------------------------|-------------|---|
| <b>0.17 ± 0.05 OUR AVERAGE</b>   | Error includes scale factor of 2.4. |             |   |
| 0.14 ± 0.01 ± 0.02   | ACKERSTAFF                          | 98A OPAL    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 0.25 ± 0.04  | <sup>1</sup> ACCIARRI               | 97D L3      | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • •  |                                     |             |   |
| 0.068 ± 0.018 ± 0.016  | <sup>2</sup> BUSKULIC               | 92D ALEP    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| <sup>1</sup> ACCIARRI 97D obtain this value averaging over the two decay channels $\eta' \rightarrow \pi^+ \pi^- \eta$ and $\eta' \rightarrow \rho^0 \gamma$ . |                                     |             |   |
| <sup>2</sup> BUSKULIC 92D obtain this value for $x > 0.1$ .  |                                     |             |   |

 $\langle N_{f_0(980)} \rangle$ 

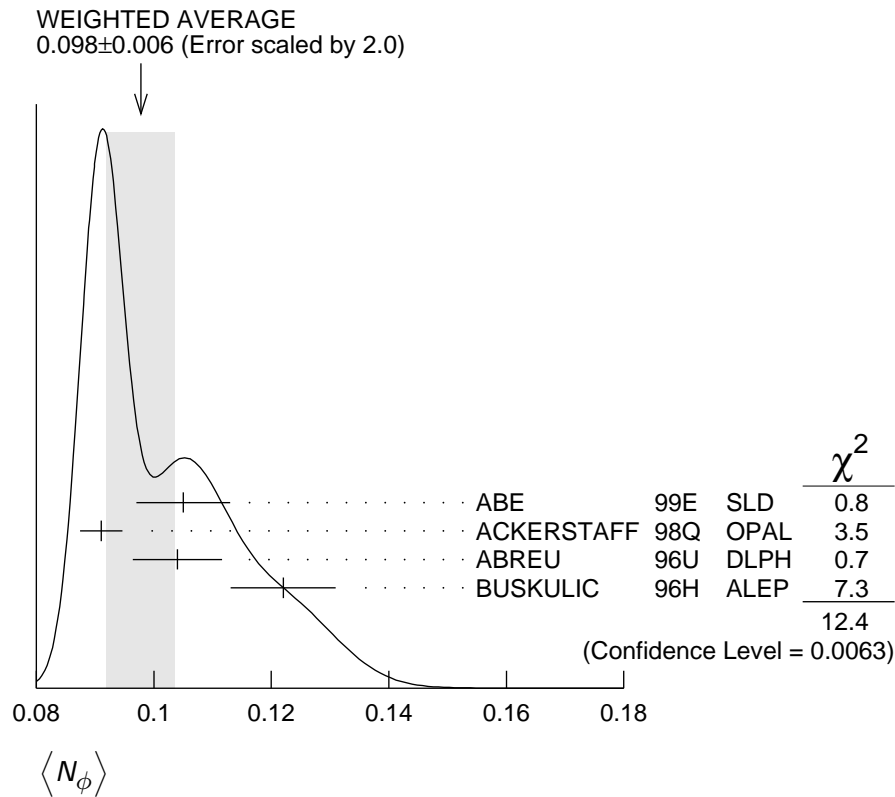
| <u>VALUE</u>                     | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                          |
|----------------------------------|--------------------|-------------|---|
| <b>0.147 ± 0.011 OUR AVERAGE</b> |                    |             |   |
| 0.164 ± 0.021                    | ABREU              | 99J DLPH    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 0.141 ± 0.007 ± 0.011            | ACKERSTAFF         | 98Q OPAL    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{a_0(980)^\pm} \rangle$ 

| <u>VALUE</u>              | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                          |
|---------------------------|--------------------|-------------|---|
| <b>0.27 ± 0.04 ± 0.10</b> | ACKERSTAFF         | 98A OPAL    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_\phi \rangle$ 

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>  | <u>TECN</u> | <u>COMMENT</u>                          |
|----------------------------------|---|-------------|---|
| <b>0.098 ± 0.006 OUR AVERAGE</b> | Error includes scale factor of 2.0. See the ideogram below. |             |   |
| 0.105 ± 0.008                    | ABE   | 99E SLD     | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 0.091 ± 0.002 ± 0.003            | ACKERSTAFF  | 98Q OPAL    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 0.104 ± 0.003 ± 0.007            | ABREU   | 96U DLPH    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| 0.122 ± 0.004 ± 0.008            | BUSKULIC  | 96H ALEP    | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |



$\langle N_{f_2(1270)} \rangle$

| VALUE   | DOCUMENT ID                         | TECN | COMMENT                       |
|---|-------------------------------------|------|-------------------------------|
| <b><math>0.169 \pm 0.025</math> OUR AVERAGE</b> | Error includes scale factor of 1.4. |      |                               |
| $0.214 \pm 0.038$                               | ABREU                               | 99J  | DLPH $E_{cm}^{ee} = 91.2$ GeV |
| $0.155 \pm 0.011 \pm 0.018$                     | ACKERSTAFF                          | 98Q  | OPAL $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_{f_1(1285)} \rangle$

| VALUE                               | DOCUMENT ID           | TECN | COMMENT                       |
|-------------------------------------|-----------------------|------|-------------------------------|
| <b><math>0.165 \pm 0.051</math></b> | <sup>1</sup> ABDALLAH | 03H  | DLPH $E_{cm}^{ee} = 91.2$ GeV |

<sup>1</sup> ABDALLAH 03H assume a  $K\bar{K}\pi$  branching ratio of  $(9.0 \pm 0.4)\%$ .

$\langle N_{f_1(1420)} \rangle$

| VALUE                               | DOCUMENT ID           | TECN | COMMENT                       |
|-------------------------------------|-----------------------|------|-------------------------------|
| <b><math>0.056 \pm 0.012</math></b> | <sup>1</sup> ABDALLAH | 03H  | DLPH $E_{cm}^{ee} = 91.2$ GeV |

<sup>1</sup> ABDALLAH 03H assume a  $K\bar{K}\pi$  branching ratio of 100%.

$\langle N_{f_2'(1525)} \rangle$

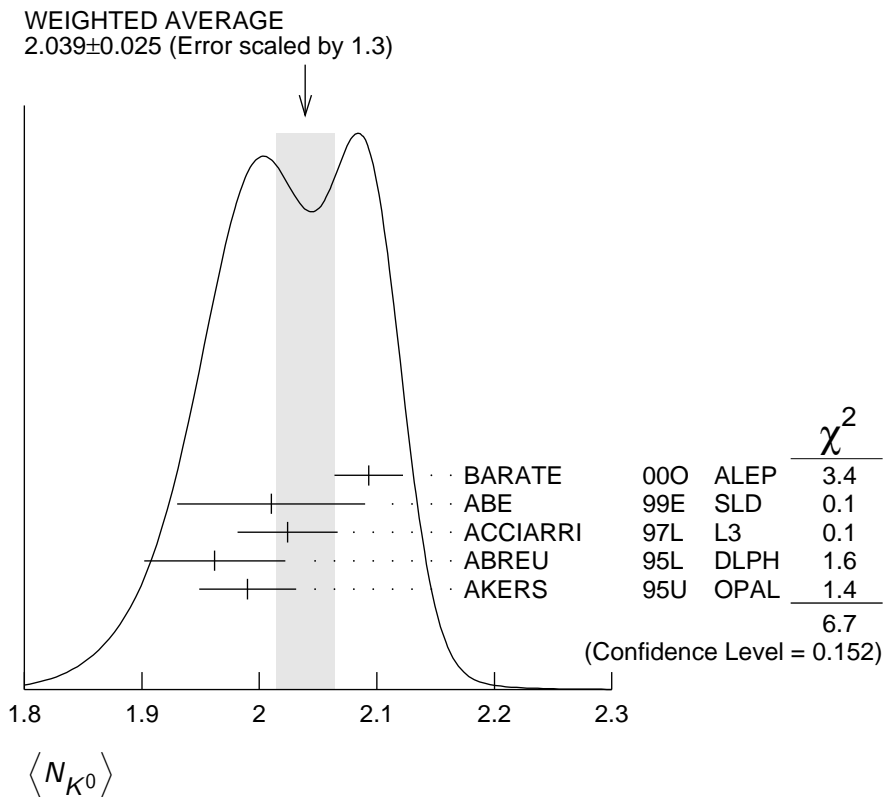
| VALUE                               | DOCUMENT ID | TECN | COMMENT                       |
|-------------------------------------|-------------|------|-------------------------------|
| <b><math>0.012 \pm 0.006</math></b> | ABREU       | 99J  | DLPH $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_{K^\pm} \rangle$

| VALUE                          | DOCUMENT ID | TECN     | COMMENT                  |
|--------------------------------|-------------|----------|--------------------------|
| <b>2.24 ± 0.04 OUR AVERAGE</b> |             |          |                          |
| 2.203 ± 0.071                  | ABE         | 04C SLD  | $E_{cm}^{ee} = 91.2$ GeV |
| 2.21 ± 0.05 ± 0.05             | ABREU       | 98L DLPH | $E_{cm}^{ee} = 91.2$ GeV |
| 2.26 ± 0.12                    | BARATE      | 98V ALEP | $E_{cm}^{ee} = 91.2$ GeV |
| 2.42 ± 0.13                    | AKERS       | 94P OPAL | $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_{K^0} \rangle$

| VALUE                            | DOCUMENT ID   | TECN     | COMMENT                  |
|----------------------------------|---|----------|--------------------------|
| <b>2.039 ± 0.025 OUR AVERAGE</b> | Error includes scale factor of 1.3. See the ideogram below. |          |                          |
| 2.093 ± 0.004 ± 0.029            | BARATE  | 000 ALEP | $E_{cm}^{ee} = 91.2$ GeV |
| 2.01 ± 0.08                      | ABE   | 99E SLD  | $E_{cm}^{ee} = 91.2$ GeV |
| 2.024 ± 0.006 ± 0.042            | ACCIARRI  | 97L L3   | $E_{cm}^{ee} = 91.2$ GeV |
| 1.962 ± 0.022 ± 0.056            | ABREU   | 95L DLPH | $E_{cm}^{ee} = 91.2$ GeV |
| 1.99 ± 0.01 ± 0.04               | AKERS   | 95U OPAL | $E_{cm}^{ee} = 91.2$ GeV |



$\langle N_{K^*(892)^\pm} \rangle$

| VALUE                          | DOCUMENT ID | TECN     | COMMENT                  |
|--------------------------------|-------------|----------|--------------------------|
| <b>0.72 ± 0.05 OUR AVERAGE</b> |             |          |                          |
| 0.712 ± 0.031 ± 0.059          | ABREU       | 95L DLPH | $E_{cm}^{ee} = 91.2$ GeV |
| 0.72 ± 0.02 ± 0.08             | ACTON       | 93 OPAL  | $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_{K^*(892)^0} \rangle$

| <u>VALUE</u>                   | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                |
|--------------------------------|--------------------|-------------|-------------------------------|
| <b>0.739±0.022 OUR AVERAGE</b> |                    |             |                               |
| 0.707±0.041                    | ABE                | 99E         | SLD $E_{cm}^{ee} = 91.2$ GeV  |
| 0.74 ±0.02 ±0.02               | ACKERSTAFF         | 97S         | OPAL $E_{cm}^{ee} = 91.2$ GeV |
| 0.77 ±0.02 ±0.07               | ABREU              | 96U         | DLPH $E_{cm}^{ee} = 91.2$ GeV |
| 0.83 ±0.01 ±0.09               | BUSKULIC           | 96H         | ALEP $E_{cm}^{ee} = 91.2$ GeV |
| 0.97 ±0.18 ±0.31               | ABREU              | 93          | DLPH $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_{K_2^*(1430)} \rangle$

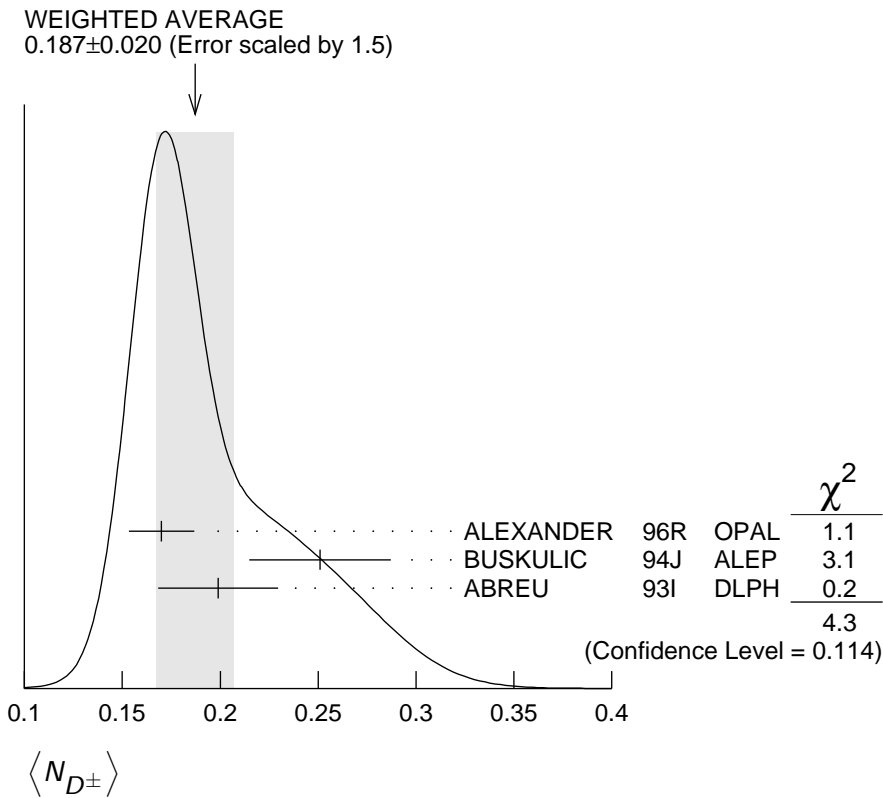
| <u>VALUE</u>  | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                |
|---|--------------------|-------------|-------------------------------|
| <b>0.073±0.023</b>  | ABREU              | 99J         | DLPH $E_{cm}^{ee} = 91.2$ GeV |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |                    |             |                               |
| 0.19 ±0.04 ±0.06  | <sup>1</sup> AKERS | 95X         | OPAL $E_{cm}^{ee} = 91.2$ GeV |

<sup>1</sup> AKERS 95X obtain this value for  $x < 0.3$ .

$\langle N_{D^\pm} \rangle$

| <u>VALUE</u>                   | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>                |
|--------------------------------|-------------------------------------|-------------|-------------------------------|
| <b>0.187±0.020 OUR AVERAGE</b> | Error includes scale factor of 1.5. |             | See the ideogram below.       |
| 0.170±0.009±0.014              | ALEXANDER                           | 96R         | OPAL $E_{cm}^{ee} = 91.2$ GeV |
| 0.251±0.026±0.025              | BUSKULIC                            | 94J         | ALEP $E_{cm}^{ee} = 91.2$ GeV |
| 0.199±0.019±0.024              | <sup>1</sup> ABREU                  | 93I         | DLPH $E_{cm}^{ee} = 91.2$ GeV |

<sup>1</sup> See ABREU 95 (erratum).



$\langle N_{D^0} \rangle$ 

| <u>VALUE</u>                                    | <u>DOCUMENT ID</u>     | <u>TECN</u> | <u>COMMENT</u>                          |
|---|------------------------|-------------|---|
| <b><math>0.462 \pm 0.026</math> OUR AVERAGE</b> |                        |             |   |
| $0.465 \pm 0.017 \pm 0.027$                     | ALEXANDER 96R          | OPAL        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $0.518 \pm 0.052 \pm 0.035$                     | BUSKULIC 94J           | ALEP        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $0.403 \pm 0.038 \pm 0.044$                     | <sup>1</sup> ABREU 93I | DLPH        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup> See ABREU 95 (erratum). $\langle N_{D_s^\pm} \rangle$ 

| <u>VALUE</u>                                  | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                          |
|---|--------------------|-------------|---|
| <b><math>0.131 \pm 0.010 \pm 0.018</math></b> | ALEXANDER 96R      | OPAL        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{D^*(2010)^\pm} \rangle$ 

| <u>VALUE</u>                                    | <u>DOCUMENT ID</u>          | <u>TECN</u> | <u>COMMENT</u>                          |
|---|-----------------------------|-------------|---|
| <b><math>0.183 \pm 0.008</math> OUR AVERAGE</b> |                             |             |   |
| $0.1854 \pm 0.0041 \pm 0.0091$                  | <sup>1</sup> ACKERSTAFF 98E | OPAL        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $0.187 \pm 0.015 \pm 0.013$                     | BUSKULIC 94J                | ALEP        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| $0.171 \pm 0.012 \pm 0.016$                     | <sup>2</sup> ABREU 93I      | DLPH        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup> ACKERSTAFF 98E systematic error includes an uncertainty of  $\pm 0.0069$  due to the branching ratios  $B(D^{*+} \rightarrow D^0 \pi^+) = 0.683 \pm 0.014$  and  $B(D^0 \rightarrow K^- \pi^+) = 0.0383 \pm 0.0012$ .<sup>2</sup> See ABREU 95 (erratum). $\langle N_{D_{s1}(2536)^+} \rangle$ 

| <u>VALUE (units <math>10^{-3}</math>)</u>  | <u>DOCUMENT ID</u>          | <u>TECN</u> | <u>COMMENT</u>                          |
|--|-----------------------------|-------------|---|
| <b>• • • We do not use the following data for averages, fits, limits, etc. • • •</b> |                             |             |   |
| $2.9^{+0.7}_{-0.6} \pm 0.2$  | <sup>1</sup> ACKERSTAFF 97W | OPAL        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup> ACKERSTAFF 97W obtain this value for  $x > 0.6$  and with the assumption that its decay width is saturated by the  $D^* K$  final states. $\langle N_{B^*} \rangle$ 

| <u>VALUE</u>                               | <u>DOCUMENT ID</u>     | <u>TECN</u> | <u>COMMENT</u>                          |
|--|------------------------|-------------|---|
| <b><math>0.28 \pm 0.01 \pm 0.03</math></b> | <sup>1</sup> ABREU 95R | DLPH        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup> ABREU 95R quote this value for a flavor-averaged excited state. $\langle N_{J/\psi(1S)} \rangle$ 

| <u>VALUE</u>                                     | <u>DOCUMENT ID</u>         | <u>TECN</u> | <u>COMMENT</u>                          |
|--|----------------------------|-------------|---|
| <b><math>0.0056 \pm 0.0003 \pm 0.0004</math></b> | <sup>1</sup> ALEXANDER 96B | OPAL        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup> ALEXANDER 96B identify  $J/\psi(1S)$  from the decays into lepton pairs. $\langle N_{\psi(2S)} \rangle$ 

| <u>VALUE</u>                                     | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                          |
|--|--------------------|-------------|---|
| <b><math>0.0023 \pm 0.0004 \pm 0.0003</math></b> | ALEXANDER 96B      | OPAL        | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |

$\langle N_p \rangle$

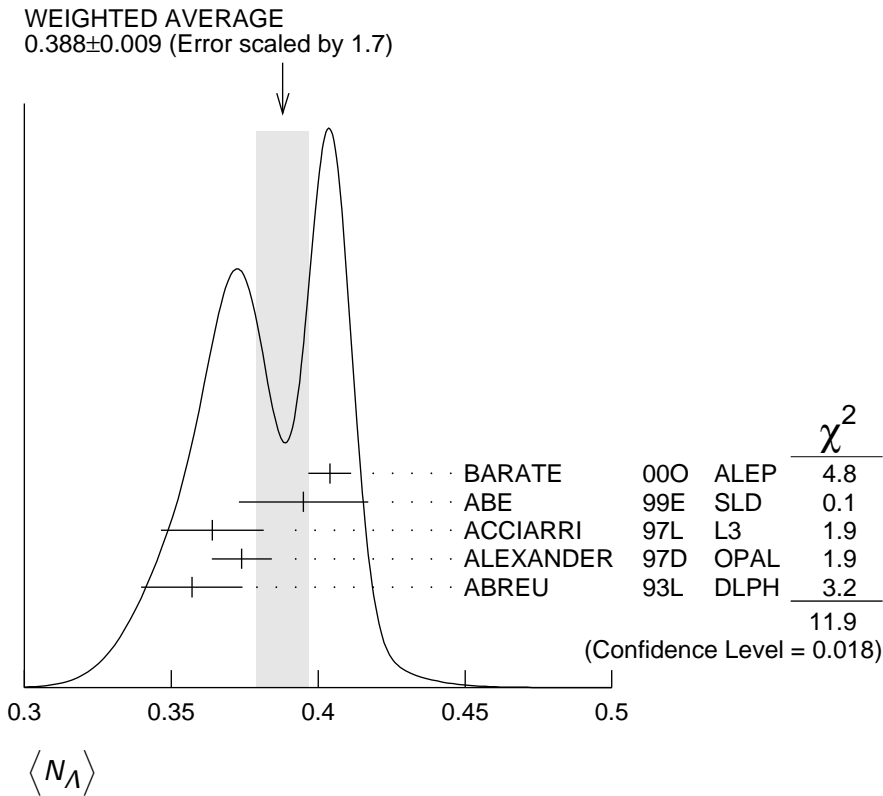
| <u>VALUE</u>                     | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                |
|----------------------------------|--------------------|-------------|-------------------------------|
| <b>1.046 ± 0.026 OUR AVERAGE</b> |                    |             |                               |
| 1.054 ± 0.035                    | ABE                | 04C         | SLD $E_{cm}^{ee} = 91.2$ GeV  |
| 1.08 ± 0.04 ± 0.03               | ABREU              | 98L         | DLPH $E_{cm}^{ee} = 91.2$ GeV |
| 1.00 ± 0.07                      | BARATE             | 98V         | ALEP $E_{cm}^{ee} = 91.2$ GeV |
| 0.92 ± 0.11                      | AKERS              | 94P         | OPAL $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_{\Delta(1232)^{++}} \rangle$

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>                |
|----------------------------------|-------------------------------------|-------------|-------------------------------|
| <b>0.087 ± 0.033 OUR AVERAGE</b> | Error includes scale factor of 2.4. |             |                               |
| 0.079 ± 0.009 ± 0.011            | ABREU                               | 95W         | DLPH $E_{cm}^{ee} = 91.2$ GeV |
| 0.22 ± 0.04 ± 0.04               | ALEXANDER                           | 95D         | OPAL $E_{cm}^{ee} = 91.2$ GeV |

$\langle N_\Lambda \rangle$

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>  | <u>TECN</u> | <u>COMMENT</u>                |
|----------------------------------|---|-------------|-------------------------------|
| <b>0.388 ± 0.009 OUR AVERAGE</b> | Error includes scale factor of 1.7. See the ideogram below. |             |                               |
| 0.404 ± 0.002 ± 0.007            | BARATE  | 00O         | ALEP $E_{cm}^{ee} = 91.2$ GeV |
| 0.395 ± 0.022                    | ABE   | 99E         | SLD $E_{cm}^{ee} = 91.2$ GeV  |
| 0.364 ± 0.004 ± 0.017            | ACCIARRI  | 97L         | L3 $E_{cm}^{ee} = 91.2$ GeV   |
| 0.374 ± 0.002 ± 0.010            | ALEXANDER   | 97D         | OPAL $E_{cm}^{ee} = 91.2$ GeV |
| 0.357 ± 0.003 ± 0.017            | ABREU   | 93L         | DLPH $E_{cm}^{ee} = 91.2$ GeV |



$\langle N_{\Lambda(1520)} \rangle$ 

| <u>VALUE</u>                       | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|------------------------------------|--------------------|-------------|----------------------------------|
| <b>0.0224 ± 0.0027 OUR AVERAGE</b> |                    |             |                                  |
| 0.029 ± 0.005 ± 0.005              | ABREU              | 00P DLPH    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.0213 ± 0.0021 ± 0.0019           | ALEXANDER          | 97D OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{\Sigma^+} \rangle$ 

| <u>VALUE</u>                     | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|----------------------------------|--------------------|-------------|----------------------------------|
| <b>0.107 ± 0.010 OUR AVERAGE</b> |                    |             |                                  |
| 0.114 ± 0.011 ± 0.009            | ACCIARRI           | 00J L3      | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.099 ± 0.008 ± 0.013            | ALEXANDER          | 97E OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{\Sigma^-} \rangle$ 

| <u>VALUE</u>                     | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|----------------------------------|--------------------|-------------|----------------------------------|
| <b>0.082 ± 0.007 OUR AVERAGE</b> |                    |             |                                  |
| 0.081 ± 0.002 ± 0.010            | ABREU              | 00P DLPH    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.083 ± 0.006 ± 0.009            | ALEXANDER          | 97E OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{\Sigma^{++}\Sigma^-} \rangle$ 

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>     | <u>TECN</u> | <u>COMMENT</u>                   |
|----------------------------------|------------------------|-------------|----------------------------------|
| <b>0.181 ± 0.018 OUR AVERAGE</b> |                        |             |                                  |
| 0.182 ± 0.010 ± 0.016            | <sup>1</sup> ALEXANDER | 97E OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.170 ± 0.014 ± 0.061            | ABREU                  | 95O DLPH    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

<sup>1</sup>We have combined the values of  $\langle N_{\Sigma^+} \rangle$  and  $\langle N_{\Sigma^-} \rangle$  from ALEXANDER 97E adding the statistical and systematic errors of the two final states separately in quadrature. If isospin symmetry is assumed this value becomes  $0.174 \pm 0.010 \pm 0.015$ .

 $\langle N_{\Sigma^0} \rangle$ 

| <u>VALUE</u>                     | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|----------------------------------|--------------------|-------------|----------------------------------|
| <b>0.076 ± 0.010 OUR AVERAGE</b> |                    |             |                                  |
| 0.095 ± 0.015 ± 0.013            | ACCIARRI           | 00J L3      | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.071 ± 0.012 ± 0.013            | ALEXANDER          | 97E OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.070 ± 0.010 ± 0.010            | ADAM               | 96B DLPH    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{(\Sigma^+\Sigma^-\Sigma^0)/3} \rangle$ 

| <u>VALUE</u>                 | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|------------------------------|--------------------|-------------|----------------------------------|
| <b>0.084 ± 0.005 ± 0.008</b> | ALEXANDER          | 97E OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{\Sigma(1385)^+} \rangle$ 

| <u>VALUE</u>                    | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|---------------------------------|--------------------|-------------|----------------------------------|
| <b>0.0239 ± 0.0009 ± 0.0012</b> | ALEXANDER          | 97D OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

 $\langle N_{\Sigma(1385)^-} \rangle$ 

| <u>VALUE</u>                    | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|---------------------------------|--------------------|-------------|----------------------------------|
| <b>0.0240 ± 0.0010 ± 0.0014</b> | ALEXANDER          | 97D OPAL    | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |



$\langle N_{\Sigma(1385)^{++}\Sigma(1385)^{-}} \rangle$ 

| <u>VALUE</u>                     | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>           |
|----------------------------------|-------------------------------------|-------------|--------------------------|
| <b>0.046 ± 0.004 OUR AVERAGE</b> | Error includes scale factor of 1.6. |             |                          |
| 0.0479 ± 0.0013 ± 0.0026         | ALEXANDER                           | 97D OPAL    | $E_{cm}^{ee} = 91.2$ GeV |
| 0.0382 ± 0.0028 ± 0.0045         | ABREU                               | 95O DLPH    | $E_{cm}^{ee} = 91.2$ GeV |

 $\langle N_{\Xi^{-}} \rangle$ 

| <u>VALUE</u>                       | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>           |
|------------------------------------|--------------------|-------------|--------------------------|
| <b>0.0258 ± 0.0009 OUR AVERAGE</b> |                    |             |                          |
| 0.0247 ± 0.0009 ± 0.0025           | ABDALLAH           | 06E DLPH    | $E_{cm}^{ee} = 91.2$ GeV |
| 0.0259 ± 0.0004 ± 0.0009           | ALEXANDER          | 97D OPAL    | $E_{cm}^{ee} = 91.2$ GeV |

 $\langle N_{\Xi(1530)^0} \rangle$ 

| <u>VALUE</u>                       | <u>DOCUMENT ID</u>                  | <u>TECN</u> | <u>COMMENT</u>           |
|------------------------------------|-------------------------------------|-------------|--------------------------|
| <b>0.0059 ± 0.0011 OUR AVERAGE</b> | Error includes scale factor of 2.3. |             |                          |
| 0.0045 ± 0.0005 ± 0.0006           | ABDALLAH                            | 05C DLPH    | $E_{cm}^{ee} = 91.2$ GeV |
| 0.0068 ± 0.0005 ± 0.0004           | ALEXANDER                           | 97D OPAL    | $E_{cm}^{ee} = 91.2$ GeV |

 $\langle N_{\Omega^{-}} \rangle$ 

| <u>VALUE</u>                         | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>           |
|--------------------------------------|--------------------|-------------|--------------------------|
| <b>0.00164 ± 0.00028 OUR AVERAGE</b> |                    |             |                          |
| 0.0018 ± 0.0003 ± 0.0002             | ALEXANDER          | 97D OPAL    | $E_{cm}^{ee} = 91.2$ GeV |
| 0.0014 ± 0.0002 ± 0.0004             | ADAM               | 96B DLPH    | $E_{cm}^{ee} = 91.2$ GeV |

 $\langle N_{\Lambda_c^+} \rangle$ 

| <u>VALUE</u>                 | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>           |
|------------------------------|--------------------|-------------|--------------------------|
| <b>0.078 ± 0.012 ± 0.012</b> | ALEXANDER          | 96R OPAL    | $E_{cm}^{ee} = 91.2$ GeV |

 $\langle N_{\bar{D}} \rangle$ 

| <u>VALUE (units <math>10^{-6}</math>)</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|--------------------|-------------|----------------|
|---|--------------------|-------------|----------------|

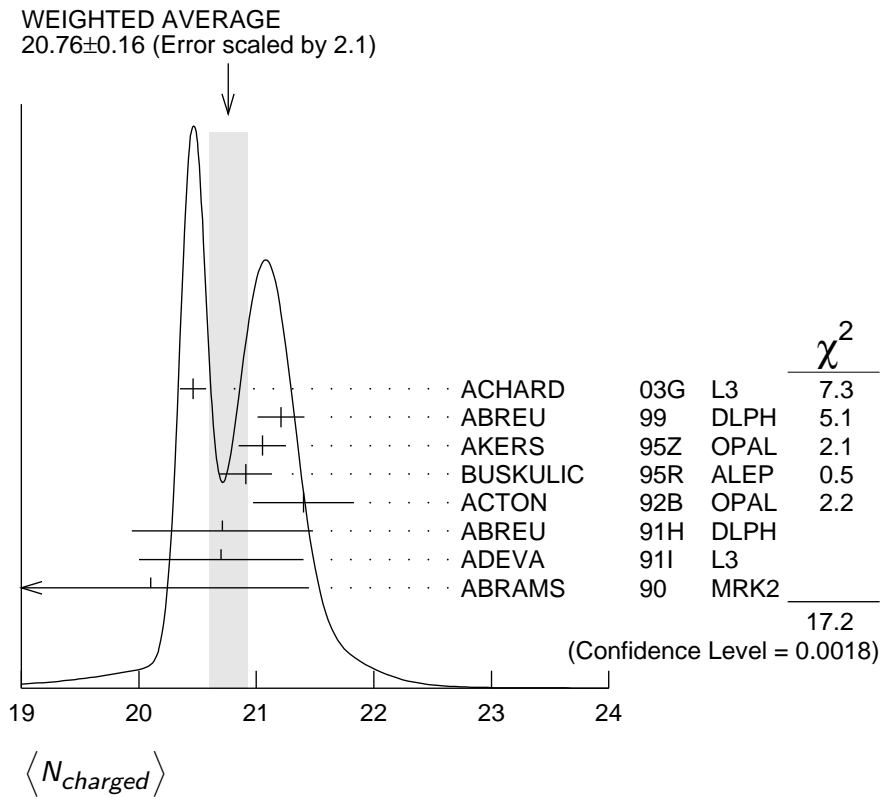
• • • We do not use the following data for averages, fits, limits, etc. • • •

5.9 ± 1.8 ± 0.5 <sup>1</sup>SCHAEL 06A ALEP  $E_{cm}^{ee} = 91.2$  GeV

<sup>1</sup>SCHAEL 06A obtain this anti-deuteron production rate per hadronic Z decay in the anti-deuteron momentum range from 0.62 to 1.03 GeV/c.

 $\langle N_{charged} \rangle$ 

| <u>VALUE</u>                    | <u>DOCUMENT ID</u>  | <u>TECN</u> | <u>COMMENT</u>           |
|---------------------------------|---|-------------|--------------------------|
| <b>20.76 ± 0.16 OUR AVERAGE</b> | Error includes scale factor of 2.1. See the ideogram below. |             |                          |
| 20.46 ± 0.01 ± 0.11             | ACHARD  | 03G L3      | $E_{cm}^{ee} = 91.2$ GeV |
| 21.21 ± 0.01 ± 0.20             | ABREU   | 99 DLPH     | $E_{cm}^{ee} = 91.2$ GeV |
| 21.05 ± 0.20                    | AKERS   | 95Z OPAL    | $E_{cm}^{ee} = 91.2$ GeV |
| 20.91 ± 0.03 ± 0.22             | BUSKULIC  | 95R ALEP    | $E_{cm}^{ee} = 91.2$ GeV |
| 21.40 ± 0.43                    | ACTON   | 92B OPAL    | $E_{cm}^{ee} = 91.2$ GeV |
| 20.71 ± 0.04 ± 0.77             | ABREU   | 91H DLPH    | $E_{cm}^{ee} = 91.2$ GeV |
| 20.7 ± 0.7                      | ADEVA   | 91I L3      | $E_{cm}^{ee} = 91.2$ GeV |
| 20.1 ± 1.0 ± 0.9                | ABRAMS  | 90 MRK2     | $E_{cm}^{ee} = 91.1$ GeV |



## Z HADRONIC POLE CROSS SECTION

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06). This quantity is defined as

$$\sigma_h^0 = \frac{12\pi}{M_Z^2} \frac{\Gamma(e^+e^-)\Gamma(\text{hadrons})}{\Gamma_Z^2}$$

It is one of the parameters used in the Z lineshape fit.

| VALUE (nb)  | EVTS  | DOCUMENT ID           | TECN     | COMMENT                               |
|---|-------|-----------------------|----------|---------------------------------------|
| <b><math>41.541 \pm 0.037</math> OUR FIT</b>                                  |       |                       |          |                                       |
| $41.501 \pm 0.055$  | 4.10M | <sup>1</sup> ABBIENDI | 01A OPAL | $E_{cm}^{ee} = 88\text{--}94$ GeV     |
| $41.578 \pm 0.069$  | 3.70M | ABREU                 | 00F DLPH | $E_{cm}^{ee} = 88\text{--}94$ GeV     |
| $41.535 \pm 0.055$  | 3.54M | ACCIARRI              | 00C L3   | $E_{cm}^{ee} = 88\text{--}94$ GeV     |
| $41.559 \pm 0.058$  | 4.07M | <sup>2</sup> BARATE   | 00C ALEP | $E_{cm}^{ee} = 88\text{--}94$ GeV     |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |       |                       |          |                                       |
| 42 ± 4  | 450   | ABRAMS                | 89B MRK2 | $E_{cm}^{ee} = 89.2\text{--}93.0$ GeV |

<sup>1</sup> ABBIENDI 01A error includes approximately 0.031 due to statistics, 0.033 due to event selection systematics, 0.029 due to uncertainty in luminosity measurement, and 0.011 due to LEP energy uncertainty.

<sup>2</sup> BARATE 00C error includes approximately 0.030 due to statistics, 0.026 due to experimental systematics, and 0.025 due to uncertainty in luminosity measurement.

## Z VECTOR COUPLINGS

These quantities are the effective vector couplings of the  $Z$  to charged leptons and quarks. Their magnitude is derived from a measurement of the  $Z$  lineshape and the forward-backward lepton asymmetries as a function of energy around the  $Z$  mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the  $Z$  asymmetry parameters,  $A_e$ ,  $A_\mu$ , and  $A_\tau$ . By convention the sign of  $g_A^e$  is fixed to be negative (and opposite to that of  $g_V^e$  obtained using  $\nu_e$  scattering measurements). For the light quarks, the sign of the couplings is assigned consistently with this assumption. The LEP/SLD-based fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and  $A_e$ ,  $A_\mu$ , and  $A_\tau$  measurements. See the note “The  $Z$  boson” and ref. LEP-SLC 06 for details. Where  $p\bar{p}$  and  $e\bar{p}$  data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

### $g_V^e$

| <u>VALUE</u>                      | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                    |
|-----------------------------------|-------------|-----------------------|-------------|-----------------------------------|
| <b>−0.03817 ± 0.00047 OUR FIT</b> |             |                       |             |                                   |
| −0.058 ± 0.016 ± 0.007            | 5026        | <sup>1</sup> ACOSTA   | 05M CDF     | $E_{cm}^{p\bar{p}} = 1.96$ TeV    |
| −0.0346 ± 0.0023                  | 137.0K      | <sup>2</sup> ABBIENDI | 01O OPAL    | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.0412 ± 0.0027                  | 124.4k      | <sup>3</sup> ACCIARRI | 00C L3      | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.0400 ± 0.0037                  |             | BARATE                | 00C ALEP    | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.0414 ± 0.0020                  |             | <sup>4</sup> ABE      | 95J SLD     | $E_{cm}^{ee} = 91.31$ GeV         |

<sup>1</sup> ACOSTA 05M determine the forward–backward asymmetry of  $e^+e^-$  pairs produced via  $q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$  in 15 M( $e^+e^-$ ) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial–vector couplings of the  $Z$  to  $e^+e^-$ , assuming the quark couplings are as predicted by the standard model. Higher order radiative corrections have not been taken into account.

<sup>2</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>3</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

<sup>4</sup> ABE 95J obtain this result combining polarized Bhabha results with the  $A_{LR}$  measurement of ABE 94C. The Bhabha results alone give  $-0.0507 \pm 0.0096 \pm 0.0020$ .

### $g_V^\mu$

| <u>VALUE</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                    |
|---|-------------|-----------------------|-------------|-----------------------------------|
| <b>−0.0367 ± 0.0023 OUR FIT</b>   |             |                       |             |                                   |
| −0.0388 $^{+0.0060}_{-0.0064}$  | 182.8K      | <sup>1</sup> ABBIENDI | 01O OPAL    | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.0386 ± 0.0073  | 113.4k      | <sup>2</sup> ACCIARRI | 00C L3      | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.0362 ± 0.0061  |             | BARATE                | 00C ALEP    | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |             |                       |             |                                   |
| −0.0413 ± 0.0060  | 66143       | <sup>3</sup> ABBIENDI | 01K OPAL    | $E_{cm}^{ee} = 89\text{--}93$ GeV |

- <sup>1</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.  
<sup>2</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.  
<sup>3</sup> ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

### $g_V^\tau$

| VALUE                           | EVTS   | DOCUMENT ID               | TECN | COMMENT                   |
|---------------------------------|--------|---------------------------|------|---------------------------|
| <b>-0.0366 ± 0.0010 OUR FIT</b> |        |                           |      |                           |
| -0.0365 ± 0.0023                | 151.5K | <sup>1</sup> ABBIENDI 010 | OPAL | $E_{cm}^{ee} = 88-94$ GeV |
| -0.0384 ± 0.0026                | 103.0k | <sup>2</sup> ACCIARRI 00C | L3   | $E_{cm}^{ee} = 88-94$ GeV |
| -0.0361 ± 0.0068                |        | BARATE 00C                | ALEP | $E_{cm}^{ee} = 88-94$ GeV |

- <sup>1</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.  
<sup>2</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

### $g_V^l$

| VALUE                             | EVTS   | DOCUMENT ID               | TECN | COMMENT                   |
|-----------------------------------|--------|---------------------------|------|---------------------------|
| <b>-0.03783 ± 0.00041 OUR FIT</b> |        |                           |      |                           |
| -0.0358 ± 0.0014                  | 471.3K | <sup>1</sup> ABBIENDI 010 | OPAL | $E_{cm}^{ee} = 88-94$ GeV |
| -0.0397 ± 0.0020                  | 379.4k | <sup>2</sup> ABREU 00F    | DLPH | $E_{cm}^{ee} = 88-94$ GeV |
| -0.0397 ± 0.0017                  | 340.8k | <sup>3</sup> ACCIARRI 00C | L3   | $E_{cm}^{ee} = 88-94$ GeV |
| -0.0383 ± 0.0018                  | 500k   | BARATE 00C                | ALEP | $E_{cm}^{ee} = 88-94$ GeV |

- <sup>1</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.  
<sup>2</sup> Using forward-backward lepton asymmetries.  
<sup>3</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

### $g_V^u$

| VALUE   | EVTS | DOCUMENT ID                | TECN | COMMENT  |
|---|------|----------------------------|------|--|
| <b>0.266 ± 0.034 OUR AVERAGE</b>  |      |                            |      |  |
| 0.270 ± 0.037   |      | <sup>1</sup> ANDREEV 18A   | H1   | $e^\pm p$  |
| 0.201 ± 0.112   | 156k | <sup>2</sup> ABAZOV 11D    | D0   | $E_{cm}^{p\bar{p}} = 1.97$ TeV   |
| 0.24 $^{+0.28}_{-0.11}$   |      | <sup>3</sup> LEP-SLC 06    |      | $E_{cm}^{ee} = 88-94$ GeV  |
| 0.399 $^{+0.152}_{-0.188} \pm 0.066$  | 5026 | <sup>4</sup> ACOSTA 05M    | CDF  | $E_{cm}^{p\bar{p}} = 1.96$ TeV   |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |      |                            |      |  |
| 0.14 $^{+0.09}_{-0.09}$   |      | <sup>5</sup> ABRAMOWICZ16A | ZEUS |  |
| 0.144 $^{+0.066}_{-0.058}$  |      | <sup>6</sup> ABT 16        |      |  |
| 0.27 ± 0.13   | 1500 | <sup>7</sup> AKTAS 06      | H1   | $e^\pm p \rightarrow \bar{\nu}_e(\nu_e)X,$<br>$\sqrt{s} \approx 300$ GeV |

- <sup>1</sup> ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic  $e^+p$  and  $e^-p$  neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.
- <sup>2</sup> ABAZOV 11D study  $p\bar{p} \rightarrow Z/\gamma^* e^+e^-$  events using  $5\text{ fb}^{-1}$  data at  $\sqrt{s} = 1.96\text{ TeV}$ . The candidate events are selected by requiring two isolated electromagnetic showers with  $E_T > 25\text{ GeV}$ , at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the  $u$ - and  $d$ - quarks and the value of  $\sin^2\theta_{eff}^{\ell} = 0.2309 \pm 0.0008(\text{stat}) \pm 0.0006(\text{syst})$ .
- <sup>3</sup> LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging.  $s$ - and  $d$ -quark couplings are assumed to be identical.
- <sup>4</sup> ACOSTA 05M determine the forward-backward asymmetry of  $e^+e^-$  pairs produced via  $q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$  in 15  $M(e^+e^-)$  effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the  $Z$  to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.
- <sup>5</sup> ABRAMOWICZ 16A determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.
- <sup>6</sup> ABT 16 determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.
- <sup>7</sup> AKTAS 06 fit the neutral current ( $1.5 \leq Q^2 \leq 30,000\text{ GeV}^2$ ) and charged current ( $1.5 \leq Q^2 \leq 15,000\text{ GeV}^2$ ) differential cross sections. In the determination of the  $u$ -quark couplings the electron and  $d$ -quark couplings are fixed to their standard model values.

$g_V^d$

| VALUE   | EVTS | DOCUMENT ID                | TECN | COMMENT  |
|---|------|----------------------------|------|--|
| <b><math>-0.38^{+0.04}_{-0.05}</math></b>                                     |      |                            |      | <b>OUR AVERAGE</b>   |
| $-0.488 \pm 0.092$  |      | <sup>1</sup> ANDREEV 18A   | H1   | $e^{\pm}p$   |
| $-0.351 \pm 0.251$  | 156k | <sup>2</sup> ABAZOV 11D    | D0   | $E_{\text{cm}}^{p\bar{p}} = 1.97\text{ TeV}$                                     |
| $-0.33^{+0.05}_{-0.07}$   |      | <sup>3</sup> LEP-SLC 06    |      | $E_{\text{cm}}^{ee} = 88\text{--}94\text{ GeV}$                                  |
| $-0.226^{+0.635}_{-0.290} \pm 0.090$  | 5026 | <sup>4</sup> ACOSTA 05M    | CDF  | $E_{\text{cm}}^{p\bar{p}} = 1.96\text{ TeV}$                                     |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |      |                            |      |  |
| $-0.41^{+0.25}_{-0.20}$   |      | <sup>5</sup> ABRAMOWICZ16A | ZEUS |  |
| $-0.503^{+0.171}_{-0.103}$  |      | <sup>6</sup> ABT 16        |      |  |
| $-0.33 \pm 0.33$  | 1500 | <sup>7</sup> AKTAS 06      | H1   | $e^{\pm}p \rightarrow \bar{\nu}_e(\nu_e)X,$<br>$\sqrt{s} \approx 300\text{ GeV}$ |

- <sup>1</sup> ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic  $e^+p$  and  $e^-p$  neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.
- <sup>2</sup> ABAZOV 11D study  $p\bar{p} \rightarrow Z/\gamma^* e^+e^-$  events using  $5\text{ fb}^{-1}$  data at  $\sqrt{s} = 1.96\text{ TeV}$ . The candidate events are selected by requiring two isolated electromagnetic showers with  $E_T > 25\text{ GeV}$ , at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the  $u$ - and  $d$ - quarks and the value of  $\sin^2\theta_{eff}^{\ell} = 0.2309 \pm 0.0008(\text{stat}) \pm 0.0006(\text{syst})$ .

- <sup>3</sup> LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging.  $s$ - and  $d$ -quark couplings are assumed to be identical.
- <sup>4</sup> ACOSTA 05M determine the forward-backward asymmetry of  $e^+e^-$  pairs produced via  $q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$  in 15  $M(e^+e^-)$  effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the  $Z$  to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.
- <sup>5</sup> ABRAMOWICZ 16A determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.
- <sup>6</sup> ABT 16 determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.
- <sup>7</sup> AKTAS 06 fit the neutral current ( $1.5 \leq Q^2 \leq 30,000 \text{ GeV}^2$ ) and charged current ( $1.5 \leq Q^2 \leq 15,000 \text{ GeV}^2$ ) differential cross sections. In the determination of the  $d$ -quark couplings the electron and  $u$ -quark couplings are fixed to their standard model values.

## Z AXIAL-VECTOR COUPLINGS

These quantities are the effective axial-vector couplings of the  $Z$  to charged leptons and quarks. Their magnitude is derived from a measurement of the  $Z$  lineshape and the forward-backward lepton asymmetries as a function of energy around the  $Z$  mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the  $Z$  asymmetry parameters,  $A_e$ ,  $A_\mu$ , and  $A_\tau$ . By convention the sign of  $g_A^e$  is fixed to be negative (and opposite to that of  $g^{\nu e}$  obtained using  $\nu_e$  scattering measurements). For the light quarks, the sign of the couplings is assigned consistently with this assumption. The LEP/SLD-based fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and  $A_e$ ,  $A_\mu$ , and  $A_\tau$  measurements. See the note “The  $Z$  boson” and ref. LEP-SLC 06 for details. Where  $p\bar{p}$  and  $e p$  data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

$g_A^e$

| <u>VALUE</u>                                     | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                                   |
|--|-------------|-----------------------|-------------|--|
| <b><math>-0.50111 \pm 0.00035</math> OUR FIT</b> |             |                       |             |  |
| $-0.528 \pm 0.123 \pm 0.059$                     | 5026        | <sup>1</sup> ACOSTA   | 05M CDF     | $E_{\text{cm}}^{p\bar{p}} = 1.96 \text{ TeV}$    |
| $-0.50062 \pm 0.00062$                           | 137.0K      | <sup>2</sup> ABBIENDI | 010 OPAL    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $-0.5015 \pm 0.0007$                             | 124.4k      | <sup>3</sup> ACCIARRI | 00C L3      | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $-0.50166 \pm 0.00057$                           |             | BARATE                | 00C ALEP    | $E_{\text{cm}}^{ee} = 88\text{--}94 \text{ GeV}$ |
| $-0.4977 \pm 0.0045$                             |             | <sup>4</sup> ABE      | 95J SLD     | $E_{\text{cm}}^{ee} = 91.31 \text{ GeV}$         |

- <sup>1</sup> ACOSTA 05M determine the forward-backward asymmetry of  $e^+e^-$  pairs produced via  $q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$  in 15  $M(e^+e^-)$  effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the  $Z$  to  $e^+e^-$ , assuming the quark couplings are as predicted by the standard model. Higher order radiative corrections have not been taken into account.
- <sup>2</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.
- <sup>3</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.
- <sup>4</sup> ABE 95J obtain this result combining polarized Bhabha results with the  $A_{LR}$  measurement of ABE 94C. The Bhabha results alone give  $-0.4968 \pm 0.0039 \pm 0.0027$ .

$g_A^\mu$ 

| VALUE                           | EVTS   | DOCUMENT ID           | TECN     | COMMENT                           |
|---------------------------------|--------|-----------------------|----------|-----------------------------------|
| <b>−0.50120±0.00054 OUR FIT</b> |        |                       |          |                                   |
| −0.50117±0.00099                | 182.8K | <sup>1</sup> ABBIENDI | 01O OPAL | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.5009 ±0.0014                 | 113.4k | <sup>2</sup> ACCIARRI | 00C L3   | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.50046±0.00093                |        | BARATE                | 00C ALEP | $E_{cm}^{ee} = 88\text{--}94$ GeV |

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

|               |       |                       |          |                                   |
|---------------|-------|-----------------------|----------|-----------------------------------|
| −0.520 ±0.015 | 66143 | <sup>3</sup> ABBIENDI | 01K OPAL | $E_{cm}^{ee} = 89\text{--}93$ GeV |
|---------------|-------|-----------------------|----------|-----------------------------------|

<sup>1</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>2</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

<sup>3</sup> ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

 $g_A^\tau$ 

| VALUE                           | EVTS   | DOCUMENT ID           | TECN     | COMMENT                           |
|---------------------------------|--------|-----------------------|----------|-----------------------------------|
| <b>−0.50204±0.00064 OUR FIT</b> |        |                       |          |                                   |
| −0.50165±0.00124                | 151.5K | <sup>1</sup> ABBIENDI | 01O OPAL | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.5023 ±0.0017                 | 103.0k | <sup>2</sup> ACCIARRI | 00C L3   | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.50216±0.00100                |        | BARATE                | 00C ALEP | $E_{cm}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>2</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

 $g_A^l$ 

| VALUE                           | EVTS   | DOCUMENT ID           | TECN     | COMMENT                           |
|---------------------------------|--------|-----------------------|----------|-----------------------------------|
| <b>−0.50123±0.00026 OUR FIT</b> |        |                       |          |                                   |
| −0.50089±0.00045                | 471.3K | <sup>1</sup> ABBIENDI | 01O OPAL | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.5007 ±0.0005                 | 379.4k | ABREU                 | 00F DLPH | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.50153±0.00053                | 340.8k | <sup>2</sup> ACCIARRI | 00C L3   | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| −0.50150±0.00046                | 500k   | BARATE                | 00C ALEP | $E_{cm}^{ee} = 88\text{--}94$ GeV |

<sup>1</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>2</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

 $g_A^u$ 

| VALUE  | EVTS | DOCUMENT ID          | TECN    | COMMENT                           |
|--|------|----------------------|---------|-----------------------------------|
| <b>0.519<sup>+0.028</sup><sub>−0.033</sub> OUR AVERAGE</b> |      |                      |         |                                   |
| 0.548±0.036  |      | <sup>1</sup> ANDREEV | 18A H1  | $e^\pm p$                         |
| 0.501±0.110  | 156k | <sup>2</sup> ABAZOV  | 11D D0  | $E_{cm}^{p\bar{p}} = 1.97$ TeV    |
| 0.47 <sup>+0.05</sup> <sub>−0.33</sub>                     |      | <sup>3</sup> LEP-SLC | 06      | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| 0.441 <sup>+0.207</sup> <sub>−0.173</sub> ±0.067           | 5026 | <sup>4</sup> ACOSTA  | 05M CDF | $E_{cm}^{p\bar{p}} = 1.96$ TeV    |

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

|       |                      |      |                            |       |   |
|-------|----------------------|------|----------------------------|-------|---|
| 0.50  | $+0.12$<br>$-0.05$   |      | <sup>5</sup> ABRAMOWICZ16A | ZEUS  |   |
| 0.532 | $+0.107$<br>$-0.063$ |      | <sup>6</sup> ABT           | 16    |   |
| 0.57  | $\pm 0.08$           | 1500 | <sup>7</sup> AKTAS         | 06 H1 | $e^\pm p \rightarrow \bar{\nu}_e(\nu_e)X$ ,<br>$\sqrt{s} \approx 300$ GeV |

<sup>1</sup> ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic  $e^+p$  and  $e^-p$  neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

<sup>2</sup> ABAZOV 11D study  $p\bar{p} \rightarrow Z/\gamma^* e^+ e^-$  events using  $5 \text{ fb}^{-1}$  data at  $\sqrt{s} = 1.96$  TeV. The candidate events are selected by requiring two isolated electromagnetic showers with  $E_T > 25$  GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the  $u$ - and  $d$ - quarks and the value of  $\sin^2\theta_{eff}^e = 0.2309 \pm 0.0008(\text{stat}) \pm 0.0006(\text{syst})$ .

<sup>3</sup> LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging.  $s$ - and  $d$ -quark couplings are assumed to be identical.

<sup>4</sup> ACOSTA 05M determine the forward-backward asymmetry of  $e^+e^-$  pairs produced via  $q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$  in 15  $M(e^+e^-)$  effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the  $Z$  to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

<sup>5</sup> ABRAMOWICZ 16A determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.

<sup>6</sup> ABT 16 determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.

<sup>7</sup> AKTAS 06 fit the neutral current ( $1.5 \leq Q^2 \leq 30,000 \text{ GeV}^2$ ) and charged current ( $1.5 \leq Q^2 \leq 15,000 \text{ GeV}^2$ ) differential cross sections. In the determination of the  $u$ -quark couplings the electron and  $d$ -quark couplings are fixed to their standard model values.

**$g_A^d$**

| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
|-------|------|-------------|------|---------|
|-------|------|-------------|------|---------|

**$-0.527^{+0.040}_{-0.028}$  OUR AVERAGE**

|                                  |                  |                      |         |                                   |
|----------------------------------|------------------|----------------------|---------|-----------------------------------|
| $-0.619 \pm 0.108$               |                  | <sup>1</sup> ANDREEV | 18A H1  | $e^\pm p$                         |
| $-0.497 \pm 0.165$               | 156k             | <sup>2</sup> ABAZOV  | 11D D0  | $E_{cm}^{p\bar{p}} = 1.97$ TeV    |
| $-0.52$<br>$+0.05$<br>$-0.03$    |                  | <sup>3</sup> LEP-SLC | 06      | $E_{cm}^{ee} = 88\text{--}94$ GeV |
| $-0.016$<br>$+0.346$<br>$-0.536$ | $\pm 0.091$ 5026 | <sup>4</sup> ACOSTA  | 05M CDF | $E_{cm}^{p\bar{p}} = 1.96$ TeV    |

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

|                                  |      |                            |       |   |
|----------------------------------|------|----------------------------|-------|---|
| $-0.56$<br>$+0.41$<br>$-0.15$    |      | <sup>5</sup> ABRAMOWICZ16A | ZEUS  |   |
| $-0.409$<br>$+0.373$<br>$-0.213$ |      | <sup>6</sup> ABT           | 16    |   |
| $-0.80 \pm 0.24$                 | 1500 | <sup>7</sup> AKTAS         | 06 H1 | $e^\pm p \rightarrow \bar{\nu}_e(\nu_e)X$ ,<br>$\sqrt{s} \approx 300$ GeV |



- <sup>1</sup> ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic  $e^+p$  and  $e^-p$  neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.
- <sup>2</sup> ABZOV 11D study  $p\bar{p} \rightarrow Z/\gamma^* e^+ e^-$  events using  $5 \text{ fb}^{-1}$  data at  $\sqrt{s} = 1.96 \text{ TeV}$ . The candidate events are selected by requiring two isolated electromagnetic showers with  $E_T > 25 \text{ GeV}$ , at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the  $u$ - and  $d$ - quarks and the value of  $\sin^2\theta_{eff}^l = 0.2309 \pm 0.0008(\text{stat}) \pm 0.0006(\text{sys})$ .
- <sup>3</sup> LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging.  $s$ - and  $d$ -quark couplings are assumed to be identical.
- <sup>4</sup> ACOSTA 05M determine the forward-backward asymmetry of  $e^+e^-$  pairs produced via  $q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$  in 15  $M(e^+e^-)$  effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the  $Z$  to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.
- <sup>5</sup> ABRAMOWICZ 16A determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.
- <sup>6</sup> ABT 16 determine the  $Z^0$  couplings to  $u$ - and  $d$ -quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.
- <sup>7</sup> AKTAS 06 fit the neutral current ( $1.5 \leq Q^2 \leq 30,000 \text{ GeV}^2$ ) and charged current ( $1.5 \leq Q^2 \leq 15,000 \text{ GeV}^2$ ) differential cross sections. In the determination of the  $d$ -quark couplings the electron and  $u$ -quark couplings are fixed to their standard model values.

## Z COUPLINGS TO NEUTRAL LEPTONS

Averaging over neutrino species, the invisible  $Z$  decay width determines the effective neutrino coupling  $g^{\nu\ell}$ . For  $g^{\nu e}$  and  $g^{\nu\mu}$ ,  $\nu_e e$  and  $\nu_\mu e$  scattering results are combined with  $g_A^e$  and  $g_V^e$  measurements at the  $Z$  mass to obtain  $g^{\nu e}$  and  $g^{\nu\mu}$  following NOVIKOV 93C.

### $g^{\nu\ell}$

| VALUE                    | DOCUMENT ID          | TECN | COMMENT                                   |
|--------------------------|----------------------|------|---|
| <b>0.50076 ± 0.00076</b> | <sup>1</sup> LEP-SLC | 06   | $E_{cm}^{ee} = 88\text{--}94 \text{ GeV}$ |

<sup>1</sup> From invisible  $Z$ -decay width.

### $g^{\nu e}$

| VALUE                | DOCUMENT ID         | TECN | COMMENT  |
|----------------------|---------------------|------|--|
| <b>0.528 ± 0.085</b> | <sup>1</sup> VILAIN | 94   | CHM2 From $\nu_\mu e$ and $\nu_e e$ scattering |

<sup>1</sup> VILAIN 94 derive this value from their value of  $g^{\nu\mu}$  and their ratio  $g^{\nu e}/g^{\nu\mu} = 1.05^{+0.15}_{-0.18}$ .

### $g^{\nu\mu}$

| VALUE                | DOCUMENT ID         | TECN | COMMENT                          |
|----------------------|---------------------|------|----------------------------------|
| <b>0.502 ± 0.017</b> | <sup>1</sup> VILAIN | 94   | CHM2 From $\nu_\mu e$ scattering |

<sup>1</sup> VILAIN 94 derive this value from their measurement of the couplings  $g_A^{e\nu\mu} = -0.503 \pm 0.017$  and  $g_V^{e\nu\mu} = -0.035 \pm 0.017$  obtained from  $\nu_\mu e$  scattering. We have re-evaluated this value using the current PDG values for  $g_A^e$  and  $g_V^e$ .

## Z ASYMMETRY PARAMETERS

For each fermion-antifermion pair coupling to the  $Z$  these quantities are defined as

$$A_f = \frac{2g_V^f g_A^f}{(g_V^f)^2 + (g_A^f)^2}$$

where  $g_V^f$  and  $g_A^f$  are the effective vector and axial-vector couplings. For their relation to the various lepton asymmetries see the note “The  $Z$  boson” and ref. LEP-SLC 06.

### $A_e$

Using polarized beams, this quantity can also be measured as  $(\sigma_L - \sigma_R) / (\sigma_L + \sigma_R)$ , where  $\sigma_L$  and  $\sigma_R$  are the  $e^+ e^-$  production cross sections for  $Z$  bosons produced with left-handed and right-handed electrons respectively.

| <u>VALUE</u>                       | <u>EVTs</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>            |
|------------------------------------|-------------|-----------------------|-------------|---------------------------|
| <b>0.1515 ± 0.0019 OUR AVERAGE</b> |             |                       |             |                           |
| 0.1454 ± 0.0108 ± 0.0036           | 144810      | <sup>1</sup> ABBIENDI | 010 OPAL    | $E_{cm}^{ee} = 88-94$ GeV |
| 0.1516 ± 0.0021                    | 559000      | <sup>2</sup> ABE      | 01B SLD     | $E_{cm}^{ee} = 91.24$ GeV |
| 0.1504 ± 0.0068 ± 0.0008           |             | <sup>3</sup> HEISTER  | 01 ALEP     | $E_{cm}^{ee} = 88-94$ GeV |
| 0.1382 ± 0.0116 ± 0.0005           | 105000      | <sup>4</sup> ABREU    | 00E DLPH    | $E_{cm}^{ee} = 88-94$ GeV |
| 0.1678 ± 0.0127 ± 0.0030           | 137092      | <sup>5</sup> ACCIARRI | 98H L3      | $E_{cm}^{ee} = 88-94$ GeV |
| 0.162 ± 0.041 ± 0.014              | 89838       | <sup>6</sup> ABE      | 97 SLD      | $E_{cm}^{ee} = 91.27$ GeV |
| 0.202 ± 0.038 ± 0.008              |             | <sup>7</sup> ABE      | 95J SLD     | $E_{cm}^{ee} = 91.31$ GeV |

<sup>1</sup> ABBIENDI 010 fit for  $A_e$  and  $A_\tau$  from measurements of the  $\tau$  polarization at varying  $\tau$  production angles. The correlation between  $A_e$  and  $A_\tau$  is less than 0.03.

<sup>2</sup> ABE 01B use the left-right production and left-right forward-backward decay asymmetries in leptonic  $Z$  decays to obtain a value of  $0.1544 \pm 0.0060$ . This is combined with left-right production asymmetry measurement using hadronic  $Z$  decays (ABE 00B) to obtain the quoted value.

<sup>3</sup> HEISTER 01 obtain this result fitting the  $\tau$  polarization as a function of the polar production angle of the  $\tau$ .

<sup>4</sup> ABREU 00E obtain this result fitting the  $\tau$  polarization as a function of the polar  $\tau$  production angle. This measurement is a combination of different analyses (exclusive  $\tau$  decay modes, inclusive hadronic 1-prong reconstruction, and a neural network analysis).

<sup>5</sup> Derived from the measurement of forward-backward  $\tau$  polarization asymmetry.

<sup>6</sup> ABE 97 obtain this result from a measurement of the observed left-right charge asymmetry,  $A_Q^{\text{obs}} = 0.225 \pm 0.056 \pm 0.019$ , in hadronic  $Z$  decays. If they combine this value of  $A_Q^{\text{obs}}$  with their earlier measurement of  $A_{LR}^{\text{obs}}$  they determine  $A_e$  to be  $0.1574 \pm 0.0197 \pm 0.0067$  independent of the beam polarization.

<sup>7</sup> ABE 95J obtain this result from polarized Bhabha scattering.

**$A_\mu$** 

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in  $\mu^+\mu^-$  production at SLC using a polarized electron beam. This double asymmetry eliminates the dependence on the  $Z$ - $e$ - $e$  coupling parameter  $A_e$ .

| <u>VALUE</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|---|-------------|--------------------|-------------|----------------------------------|
| <b>0.142±0.015</b>  | 16844       | <sup>1</sup> ABE   | 01B SLD     | $E_{\text{cm}}^{ee} = 91.24$ GeV |
| ••• We do not use the following data for averages, fits, limits, etc. ••• |             |                    |             |                                  |
| 0.153±0.012   | 1.7M        | <sup>2</sup> AAD   | 15BT ATLS   | $E_{\text{cm}}^{pp} = 7$ TeV     |

<sup>1</sup> ABE 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in  $\mu^+\mu^-$  decays of the  $Z$  boson obtained with a polarized electron beam.

<sup>2</sup> AAD 15BT study  $pp \rightarrow Z \rightarrow \ell^+\ell^-$  events where  $\ell$  is an electron or a muon in the dilepton mass region 70–1000 GeV. The background in the  $Z$  peak region is estimated to be < 1% for the muon channel. The muon asymmetry parameter is derived from the measured forward-backward asymmetry assuming the value of the quark asymmetry parameter from the SM. For this reason it is not used in the average.

 **$A_\tau$** 

The LEP Collaborations derive this quantity from the measurement of the  $\tau$  polarization in  $Z \rightarrow \tau^+\tau^-$ . The SLD Collaboration directly extracts this quantity from its measured left-right forward-backward asymmetry in  $Z \rightarrow \tau^+\tau^-$  produced using a polarized  $e^-$  beam. This double asymmetry eliminates the dependence on the  $Z$ - $e$ - $e$  coupling parameter  $A_e$ .

| <u>VALUE</u>                    | <u>EVTS</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                    |
|---------------------------------|-------------|-----------------------|-------------|-----------------------------------|
| <b>0.143 ±0.004 OUR AVERAGE</b> |             |                       |             |                                   |
| 0.1456±0.0076±0.0057            | 144810      | <sup>1</sup> ABBIENDI | 010 OPAL    | $E_{\text{cm}}^{ee} = 88$ –94 GeV |
| 0.136 ±0.015                    | 16083       | <sup>2</sup> ABE      | 01B SLD     | $E_{\text{cm}}^{ee} = 91.24$ GeV  |
| 0.1451±0.0052±0.0029            |             | <sup>3</sup> HEISTER  | 01 ALEP     | $E_{\text{cm}}^{ee} = 88$ –94 GeV |
| 0.1359±0.0079±0.0055            | 105000      | <sup>4</sup> ABREU    | 00E DLPH    | $E_{\text{cm}}^{ee} = 88$ –94 GeV |
| 0.1476±0.0088±0.0062            | 137092      | ACCIARRI              | 98H L3      | $E_{\text{cm}}^{ee} = 88$ –94 GeV |

<sup>1</sup> ABBIENDI 010 fit for  $A_e$  and  $A_\tau$  from measurements of the  $\tau$  polarization at varying  $\tau$  production angles. The correlation between  $A_e$  and  $A_\tau$  is less than 0.03.

<sup>2</sup> ABE 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in  $\tau^+\tau^-$  decays of the  $Z$  boson obtained with a polarized electron beam.

<sup>3</sup> HEISTER 01 obtain this result fitting the  $\tau$  polarization as a function of the polar production angle of the  $\tau$ .

<sup>4</sup> ABREU 00E obtain this result fitting the  $\tau$  polarization as a function of the polar  $\tau$  production angle. This measurement is a combination of different analyses (exclusive  $\tau$  decay modes, inclusive hadronic 1-prong reconstruction, and a neural network analysis).

 **$A_s$** 

The SLD Collaboration directly extracts this quantity by a simultaneous fit to four measured  $s$ -quark polar angle distributions corresponding to two states of  $e^-$  polarization (positive and negative) and to the  $K^+K^-$  and  $K^\pm K_S^0$  strange particle tagging modes in the hadronic final states.

| <u>VALUE</u>             | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                  |
|--------------------------|-------------|--------------------|-------------|---------------------------------|
| <b>0.895±0.066±0.062</b> | 2870        | <sup>1</sup> ABE   | 00D SLD     | $E_{\text{cm}}^{ee} = 91.2$ GeV |

<sup>1</sup> ABE 00D tag  $Z \rightarrow s\bar{s}$  events by an absence of  $B$  or  $D$  hadrons and the presence in each hemisphere of a high momentum  $K^\pm$  or  $K_S^0$ .

**$A_c$** 

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in  $c\bar{c}$  production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the  $Z$ - $e$ - $e$  coupling parameter  $A_e$ . OUR FIT is obtained by a simultaneous fit to several  $c$ - and  $b$ -quark measurements as explained in the note “The  $Z$  boson” and ref. LEP-SLC 06.

| <u>VALUE</u>  | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|---|--------------------|-------------|----------------------------------|
| <b>0.670 ± 0.027 OUR FIT</b>  |                    |             |                                  |
| 0.6712 ± 0.0224 ± 0.0157  | <sup>1</sup> ABE   | 05 SLD      | $E_{\text{cm}}^{ee} = 91.24$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |                    |             |                                  |
| 0.583 ± 0.055 ± 0.055   | <sup>2</sup> ABE   | 02G SLD     | $E_{\text{cm}}^{ee} = 91.24$ GeV |
| 0.688 ± 0.041   | <sup>3</sup> ABE   | 01C SLD     | $E_{\text{cm}}^{ee} = 91.25$ GeV |

<sup>1</sup> ABE 05 use hadronic  $Z$  decays collected during 1996–98 to obtain an enriched sample of  $c\bar{c}$  events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying  $c$ -quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (9970 events)  $A_c = 0.6747 \pm 0.0290 \pm 0.0233$ . Taking into account all correlations with earlier results reported in ABE 02G and ABE 01C, they obtain the quoted overall SLD result.

<sup>2</sup> ABE 02G tag  $b$  and  $c$  quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously  $A_b$  and  $A_c$ .

<sup>3</sup> ABE 01C tag  $Z \rightarrow c\bar{c}$  events using two techniques: exclusive reconstruction of  $D^{*+}$ ,  $D^+$  and  $D^0$  mesons and the soft pion tag for  $D^{*+} \rightarrow D^0 \pi^+$ . The large background from  $D$  mesons produced in  $b\bar{b}$  events is separated efficiently from the signal using precision vertex information. When combining the  $A_c$  values from these two samples, care is taken to avoid double counting of events common to the two samples, and common systematic errors are properly taken into account.

 **$A_b$** 

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in  $b\bar{b}$  production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the  $Z$ - $e$ - $e$  coupling parameter  $A_e$ . OUR FIT is obtained by a simultaneous fit to several  $c$ - and  $b$ -quark measurements as explained in the note “The  $Z$  boson” and ref. LEP-SLC 06.

| <u>VALUE</u>  | <u>EVTS</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                   |
|---|-------------|--------------------|-------------|----------------------------------|
| <b>0.923 ± 0.020 OUR FIT</b>  |             |                    |             |                                  |
| 0.9170 ± 0.0147 ± 0.0145  |             | <sup>1</sup> ABE   | 05 SLD      | $E_{\text{cm}}^{ee} = 91.24$ GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |             |                    |             |                                  |
| 0.907 ± 0.020 ± 0.024   | 48028       | <sup>2</sup> ABE   | 03F SLD     | $E_{\text{cm}}^{ee} = 91.24$ GeV |
| 0.919 ± 0.030 ± 0.024   |             | <sup>3</sup> ABE   | 02G SLD     | $E_{\text{cm}}^{ee} = 91.24$ GeV |
| 0.855 ± 0.088 ± 0.102   | 7473        | <sup>4</sup> ABE   | 99L SLD     | $E_{\text{cm}}^{ee} = 91.27$ GeV |

<sup>1</sup> ABE 05 use hadronic  $Z$  decays collected during 1996–98 to obtain an enriched sample of  $b\bar{b}$  events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying  $b$ -quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (25917 events)  $A_b = 0.9173 \pm 0.0184 \pm 0.0173$ . Taking into account all correlations with earlier results reported in ABE 03F, ABE 02G and ABE 99L, they obtain the quoted overall SLD result.

<sup>2</sup> ABE 03F obtain an enriched sample of  $b\bar{b}$  events tagging on the invariant mass of a 3-dimensional topologically reconstructed secondary decay. The charge of the underlying  $b$  quark is obtained using a self-calibrating track-charge method. For the 1996–1998 data sample they measure  $A_b = 0.906 \pm 0.022 \pm 0.023$ . The value quoted here is obtained combining the above with the result of ABE 98I (1993–1995 data sample).

- <sup>3</sup> ABE 02G tag  $b$  and  $c$  quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously  $A_b$  and  $A_c$ .
- <sup>4</sup> ABE 99L obtain an enriched sample of  $b\bar{b}$  events tagging with an inclusive vertex mass cut. For distinguishing  $b$  and  $\bar{b}$  quarks they use the charge of identified  $K^\pm$ .

## TRANSVERSE SPIN CORRELATIONS IN $Z \rightarrow \tau^+ \tau^-$

The correlations between the transverse spin components of  $\tau^+ \tau^-$  produced in  $Z$  decays may be expressed in terms of the vector and axial-vector couplings:

$$C_{TT} = \frac{|g_A^\tau|^2 - |g_V^\tau|^2}{|g_A^\tau|^2 + |g_V^\tau|^2}$$

$$C_{TN} = -2 \frac{|g_A^\tau| |g_V^\tau|}{|g_A^\tau|^2 + |g_V^\tau|^2} \sin(\Phi_{g_V^\tau} - \Phi_{g_A^\tau})$$

$C_{TT}$  refers to the transverse-transverse (within the collision plane) spin correlation and  $C_{TN}$  refers to the transverse-normal (to the collision plane) spin correlation.

The longitudinal  $\tau$  polarization  $P_\tau (= -A_\tau)$  is given by:

$$P_\tau = -2 \frac{|g_A^\tau| |g_V^\tau|}{|g_A^\tau|^2 + |g_V^\tau|^2} \cos(\Phi_{g_V^\tau} - \Phi_{g_A^\tau})$$

Here  $\Phi$  is the phase and the phase difference  $\Phi_{g_V^\tau} - \Phi_{g_A^\tau}$  can be obtained using both the measurements of  $C_{TN}$  and  $P_\tau$ .

### $C_{TT}$

| VALUE   | EVTS | DOCUMENT ID | TECN     | COMMENT                         |
|---|------|-------------|----------|---------------------------------|
| <b>1.01 ± 0.12 OUR AVERAGE</b>                |      |             |          |                                 |
| 0.87 ± 0.20 <sup>+0.10</sup> <sub>-0.12</sub> | 9.1k | ABREU       | 97G DLPH | $E_{\text{cm}}^{ee} = 91.2$ GeV |
| 1.06 ± 0.13 ± 0.05                            | 120k | BARATE      | 97D ALEP | $E_{\text{cm}}^{ee} = 91.2$ GeV |

### $C_{TN}$

| VALUE                     | EVTS | DOCUMENT ID         | TECN     | COMMENT                         |
|---------------------------|------|---------------------|----------|---------------------------------|
| <b>0.08 ± 0.13 ± 0.04</b> | 120k | <sup>1</sup> BARATE | 97D ALEP | $E_{\text{cm}}^{ee} = 91.2$ GeV |

<sup>1</sup> BARATE 97D combine their value of  $C_{TN}$  with the world average  $P_\tau = -0.140 \pm 0.007$  to obtain  $\tan(\Phi_{g_V^\tau} - \Phi_{g_A^\tau}) = -0.57 \pm 0.97$ .

## FORWARD-BACKWARD $e^+ e^- \rightarrow f\bar{f}$ CHARGE ASYMMETRIES

These asymmetries are experimentally determined by tagging the respective lepton or quark flavor in  $e^+ e^-$  interactions. Details of heavy flavor ( $c$ - or  $b$ -quark) tagging at LEP are described in the note on "The Z boson" and ref. LEP-SLC 06. The Standard Model predictions for LEP data have been (re)computed using the ZFITTER package (version 6.36) with input parameters  $M_Z = 91.187$  GeV,  $M_{\text{top}} = 174.3$  GeV,  $M_{\text{Higgs}} = 150$  GeV,  $\alpha_s = 0.119$ ,  $\alpha^{(5)}(M_Z) = 1/128.877$  and the Fermi constant  $G_F = 1.16637 \times 10^{-5}$  GeV<sup>-2</sup> (see the note on "The Z boson" for references).

For non-LEP data the Standard Model predictions are as given by the authors of the respective publications.

## ———— $A_{FB}^{(0,e)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow e^+e^-$ ————

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by  $(3/4)A_e^2$  as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

| <u>ASYMMETRY (%)</u>       | <u>STD. MODEL</u> | <u><math>\sqrt{s}</math> (GeV)</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> |
|----------------------------|-------------------|------------------------------------|-----------------------|-------------|
| <b>1.45 ± 0.25 OUR FIT</b> |                   |                                    |                       |             |
| 0.89 ± 0.44                | 1.57              | 91.2                               | <sup>1</sup> ABBIENDI | 01A OPAL    |
| 1.71 ± 0.49                | 1.57              | 91.2                               | ABREU                 | 00F DLPH    |
| 1.06 ± 0.58                | 1.57              | 91.2                               | ACCIARRI              | 00C L3      |
| 1.88 ± 0.34                | 1.57              | 91.2                               | <sup>2</sup> BARATE   | 00C ALEP    |

<sup>1</sup> ABBIENDI 01A error includes approximately 0.38 due to statistics, 0.16 due to event selection systematics, and 0.18 due to the theoretical uncertainty in *t*-channel prediction.

<sup>2</sup> BARATE 00C error includes approximately 0.31 due to statistics, 0.06 due to experimental systematics, and 0.13 due to the theoretical uncertainty in *t*-channel prediction.

## ———— $A_{FB}^{(0,\mu)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow \mu^+\mu^-$ ————

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by  $(3/4)A_e A_\mu$  as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

| <u>ASYMMETRY (%)</u>       | <u>STD. MODEL</u> | <u><math>\sqrt{s}</math> (GeV)</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> |
|----------------------------|-------------------|------------------------------------|-----------------------|-------------|
| <b>1.69 ± 0.13 OUR FIT</b> |                   |                                    |                       |             |
| 1.59 ± 0.23                | 1.57              | 91.2                               | <sup>1</sup> ABBIENDI | 01A OPAL    |
| 1.65 ± 0.25                | 1.57              | 91.2                               | ABREU                 | 00F DLPH    |
| 1.88 ± 0.33                | 1.57              | 91.2                               | ACCIARRI              | 00C L3      |
| 1.71 ± 0.24                | 1.57              | 91.2                               | <sup>2</sup> BARATE   | 00C ALEP    |

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

|   |       |       |                     |          |
|---|-------|-------|---------------------|----------|
| 9 ± 30  | −1.3  | 20    | <sup>3</sup> ABREU  | 95M DLPH |
| 7 ± 26  | −8.3  | 40    | <sup>3</sup> ABREU  | 95M DLPH |
| −11 ± 33                                      | −24.1 | 57    | <sup>3</sup> ABREU  | 95M DLPH |
| −62 ± 17                                      | −44.6 | 69    | <sup>3</sup> ABREU  | 95M DLPH |
| −56 ± 10                                      | −63.5 | 79    | <sup>3</sup> ABREU  | 95M DLPH |
| −13 ± 5                                       | −34.4 | 87.5  | <sup>3</sup> ABREU  | 95M DLPH |
| −29.0 <sup>+</sup> 5.0 <sub>− 4.8</sub> ± 0.5 | −32.1 | 56.9  | <sup>4</sup> ABE    | 90I VNS  |
| − 9.9 ± 1.5 ± 0.5                             | −9.2  | 35    | HEGNER              | 90 JADE  |
| 0.05 ± 0.22                                   | 0.026 | 91.14 | <sup>5</sup> ABRAMS | 89D MRK2 |
| −43.4 ± 17.0                                  | −24.9 | 52.0  | <sup>6</sup> BACALA | 89 AMY   |
| −11.0 ± 16.5                                  | −29.4 | 55.0  | <sup>6</sup> BACALA | 89 AMY   |
| −30.0 ± 12.4                                  | −31.2 | 56.0  | <sup>6</sup> BACALA | 89 AMY   |

|                                 |       |      |                     |     |      |
|---------------------------------|-------|------|---------------------|-----|------|
| -46.2 ± 14.9                    | -33.0 | 57.0 | <sup>6</sup> BACALA | 89  | AMY  |
| -29 ± 13                        | -25.9 | 53.3 | ADACHI              | 88C | TOPZ |
| + 5.3 ± 5.0 ± 0.5               | -1.2  | 14.0 | ADEVA               | 88  | MRKJ |
| -10.4 ± 1.3 ± 0.5               | -8.6  | 34.8 | ADEVA               | 88  | MRKJ |
| -12.3 ± 5.3 ± 0.5               | -10.7 | 38.3 | ADEVA               | 88  | MRKJ |
| -15.6 ± 3.0 ± 0.5               | -14.9 | 43.8 | ADEVA               | 88  | MRKJ |
| - 1.0 ± 6.0                     | -1.2  | 13.9 | BRAUNSCH...         | 88D | TASS |
| - 9.1 ± 2.3 ± 0.5               | -8.6  | 34.5 | BRAUNSCH...         | 88D | TASS |
| -10.6 +<br>- 2.2<br>- 2.3 ± 0.5 | -8.9  | 35.0 | BRAUNSCH...         | 88D | TASS |
| -17.6 +<br>- 4.4<br>- 4.3 ± 0.5 | -15.2 | 43.6 | BRAUNSCH...         | 88D | TASS |
| - 4.8 ± 6.5 ± 1.0               | -11.5 | 39   | BEHREND             | 87C | CELL |
| -18.8 ± 4.5 ± 1.0               | -15.5 | 44   | BEHREND             | 87C | CELL |
| + 2.7 ± 4.9                     | -1.2  | 13.9 | BARTEL              | 86C | JADE |
| -11.1 ± 1.8 ± 1.0               | -8.6  | 34.4 | BARTEL              | 86C | JADE |
| -17.3 ± 4.8 ± 1.0               | -13.7 | 41.5 | BARTEL              | 86C | JADE |
| -22.8 ± 5.1 ± 1.0               | -16.6 | 44.8 | BARTEL              | 86C | JADE |
| - 6.3 ± 0.8 ± 0.2               | -6.3  | 29   | ASH                 | 85  | MAC  |
| - 4.9 ± 1.5 ± 0.5               | -5.9  | 29   | DERRICK             | 85  | HRS  |
| - 7.1 ± 1.7                     | -5.7  | 29   | LEVI                | 83  | MRK2 |
| -16.1 ± 3.2                     | -9.2  | 34.2 | BRANDELIK           | 82C | TASS |

<sup>1</sup> ABBIENDI 01A error is almost entirely on account of statistics.

<sup>2</sup> BARATE 00C error is almost entirely on account of statistics.

<sup>3</sup> ABREU 95M perform this measurement using radiative muon-pair events associated with high-energy isolated photons.

<sup>4</sup> ABE 90I measurements in the range  $50 \leq \sqrt{s} \leq 60.8$  GeV.

<sup>5</sup> ABRAMS 89D asymmetry includes both  $9 \mu^+ \mu^-$  and  $15 \tau^+ \tau^-$  events.

<sup>6</sup> BACALA 89 systematic error is about 5%.

## ———— $A_{FB}^{(0,\tau)}$ CHARGE ASYMMETRY IN $e^+ e^- \rightarrow \tau^+ \tau^-$ ————

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note “The Z boson” and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by  $(3/4)A_e A_\tau$  as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

| ASYMMETRY (%)   | STD.<br>MODEL | $\sqrt{s}$<br>(GeV) | DOCUMENT ID           | TECN     |
|---|---------------|---------------------|-----------------------|----------|
| <b>1.88 ± 0.17 OUR FIT</b>  |               |                     |                       |          |
| 1.45 ± 0.30   | 1.57          | 91.2                | <sup>1</sup> ABBIENDI | 01A OPAL |
| 2.41 ± 0.37   | 1.57          | 91.2                | ABREU                 | 00F DLPH |
| 2.60 ± 0.47   | 1.57          | 91.2                | ACCIARRI              | 00C L3   |
| 1.70 ± 0.28   | 1.57          | 91.2                | <sup>2</sup> BARATE   | 00C ALEP |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |               |                     |                       |          |
| -32.8 +<br>- 6.4<br>- 6.2 ± 1.5   | -32.1         | 56.9                | <sup>3</sup> ABE      | 90I VNS  |
| - 8.1 ± 2.0 ± 0.6   | -9.2          | 35                  | HEGNER                | 90 JADE  |
| -18.4 ± 19.2  | -24.9         | 52.0                | <sup>4</sup> BACALA   | 89 AMY   |
| -17.7 ± 26.1  | -29.4         | 55.0                | <sup>4</sup> BACALA   | 89 AMY   |
| -45.9 ± 16.6  | -31.2         | 56.0                | <sup>4</sup> BACALA   | 89 AMY   |
| -49.5 ± 18.0  | -33.0         | 57.0                | <sup>4</sup> BACALA   | 89 AMY   |

|                   |        |      |           |     |      |
|-------------------|--------|------|-----------|-----|------|
| -20 ± 14          | -25.9  | 53.3 | ADACHI    | 88C | TOPZ |
| -10.6 ± 3.1 ± 1.5 | -8.5   | 34.7 | ADEVA     | 88  | MRKJ |
| - 8.5 ± 6.6 ± 1.5 | -15.4  | 43.8 | ADEVA     | 88  | MRKJ |
| - 6.0 ± 2.5 ± 1.0 | 8.8    | 34.6 | BARTEL    | 85F | JADE |
| -11.8 ± 4.6 ± 1.0 | 14.8   | 43.0 | BARTEL    | 85F | JADE |
| - 5.5 ± 1.2 ± 0.5 | -0.063 | 29.0 | FERNANDEZ | 85  | MAC  |
| - 4.2 ± 2.0       | 0.057  | 29   | LEVI      | 83  | MRK2 |
| -10.3 ± 5.2       | -9.2   | 34.2 | BEHREND   | 82  | CELL |
| - 0.4 ± 6.6       | -9.1   | 34.2 | BRANDELIK | 82C | TASS |

<sup>1</sup> ABBIENDI 01A error includes approximately 0.26 due to statistics and 0.14 due to event selection systematics.

<sup>2</sup> BARATE 00C error includes approximately 0.26 due to statistics and 0.11 due to experimental systematics.

<sup>3</sup> ABE 90I measurements in the range  $50 \leq \sqrt{s} \leq 60.8$  GeV.

<sup>4</sup> BACALA 89 systematic error is about 5%.

### ———— $A_{FB}^{(0,\ell)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow \ell^+\ell^-$ ————

For the  $Z$  peak, we report the pole asymmetry defined by  $(3/4)A_\ell^2$  as determined by the five-parameter fit to cross-section and lepton forward-backward asymmetry data assuming lepton universality. For details see the note “The  $Z$  boson” and ref. LEP-SLC 06.

| <u>ASYMMETRY (%)</u>       | <u>STD. MODEL</u> | <u><math>\sqrt{s}</math> (GeV)</u> | <u>DOCUMENT ID</u>        | <u>TECN</u> |
|----------------------------|-------------------|------------------------------------|---------------------------|-------------|
| <b>1.71 ± 0.10 OUR FIT</b> |                   |                                    |                           |             |
| 1.45 ± 0.17                | 1.57              | 91.2                               | <sup>1</sup> ABBIENDI 01A | OPAL        |
| 1.87 ± 0.19                | 1.57              | 91.2                               | ABREU 00F                 | DLPH        |
| 1.92 ± 0.24                | 1.57              | 91.2                               | ACCIARRI 00C              | L3          |
| 1.73 ± 0.16                | 1.57              | 91.2                               | <sup>2</sup> BARATE 00C   | ALEP        |

<sup>1</sup> ABBIENDI 01A error includes approximately 0.15 due to statistics, 0.06 due to event selection systematics, and 0.03 due to the theoretical uncertainty in  $t$ -channel prediction.

<sup>2</sup> BARATE 00C error includes approximately 0.15 due to statistics, 0.04 due to experimental systematics, and 0.02 due to the theoretical uncertainty in  $t$ -channel prediction.

### ———— $A_{FB}^{(0,u)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow u\bar{u}$ ————

| <u>ASYMMETRY (%)</u>   | <u>STD. MODEL</u> | <u><math>\sqrt{s}</math> (GeV)</u> | <u>DOCUMENT ID</u>          | <u>TECN</u> |
|------------------------|-------------------|------------------------------------|-----------------------------|-------------|
| <b>4.0 ± 6.7 ± 2.8</b> | <b>7.2</b>        | <b>91.2</b>                        | <sup>1</sup> ACKERSTAFF 97T | OPAL        |

<sup>1</sup> ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types.

### ———— $A_{FB}^{(0,s)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow s\bar{s}$ ————

The  $s$ -quark asymmetry is derived from measurements of the forward-backward asymmetry of fast hadrons containing an  $s$  quark.



| <u>ASYMMETRY (%)</u>         | <u>STD. MODEL</u> | <u><math>\sqrt{s}</math> (GeV)</u> | <u>DOCUMENT ID</u>          | <u>TECN</u> |
|------------------------------|-------------------|------------------------------------|-----------------------------|-------------|
| <b>9.8 ± 1.1 OUR AVERAGE</b> |                   |                                    |                             |             |
| 10.08 ± 1.13 ± 0.40          | 10.1              | 91.2                               | <sup>1</sup> ABREU 00B      | DLPH        |
| 6.8 ± 3.5 ± 1.1              | 10.1              | 91.2                               | <sup>2</sup> ACKERSTAFF 97T | OPAL        |

<sup>1</sup> ABREU 00B tag the presence of an *s* quark requiring a high-momentum-identified charged kaon. The *s*-quark pole asymmetry is extracted from the charged-kaon asymmetry taking the expected *d*- and *u*-quark asymmetries from the Standard Model and using the measured values for the *c*- and *b*-quark asymmetries.

<sup>2</sup> ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types. The value reported here corresponds then to the forward-backward asymmetry for “down-type” quarks.

### ———— $A_{FB}^{(0,c)}$ CHARGE ASYMMETRY IN $e^+ e^- \rightarrow c \bar{c}$ ————

OUR FIT, which is obtained by a simultaneous fit to several *c*- and *b*-quark measurements as explained in the note “The Z boson” and ref. LEP-SLC 06, refers to the **Z pole** asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

| <u>ASYMMETRY (%)</u>       | <u>STD. MODEL</u> | <u><math>\sqrt{s}</math> (GeV)</u> | <u>DOCUMENT ID</u>         | <u>TECN</u> |
|----------------------------|-------------------|------------------------------------|----------------------------|-------------|
| <b>7.07 ± 0.35 OUR FIT</b> |                   |                                    |                            |             |
| 6.31 ± 0.93 ± 0.65         | 6.35              | 91.26                              | <sup>1</sup> ABDALLAH 04F  | DLPH        |
| 5.68 ± 0.54 ± 0.39         | 6.3               | 91.25                              | <sup>2</sup> ABBIENDI 03P  | OPAL        |
| 6.45 ± 0.57 ± 0.37         | 6.10              | 91.21                              | <sup>3</sup> HEISTER 02H   | ALEP        |
| 6.59 ± 0.94 ± 0.35         | 6.2               | 91.235                             | <sup>4</sup> ABREU 99Y     | DLPH        |
| 6.3 ± 0.9 ± 0.3            | 6.1               | 91.22                              | <sup>5</sup> BARATE 98O    | ALEP        |
| 6.3 ± 1.2 ± 0.6            | 6.1               | 91.22                              | <sup>6</sup> ALEXANDER 97C | OPAL        |
| 8.3 ± 3.8 ± 2.7            | 6.2               | 91.24                              | <sup>7</sup> ADRIANI 92D   | L3          |

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

|                      |      |        |                            |      |
|----------------------|------|--------|----------------------------|------|
| 3.1 ± 3.5 ± 0.5      | −3.5 | 89.43  | <sup>1</sup> ABDALLAH 04F  | DLPH |
| 11.0 ± 2.8 ± 0.7     | 12.3 | 92.99  | <sup>1</sup> ABDALLAH 04F  | DLPH |
| − 6.8 ± 2.5 ± 0.9    | −3.0 | 89.51  | <sup>2</sup> ABBIENDI 03P  | OPAL |
| 14.6 ± 2.0 ± 0.8     | 12.2 | 92.95  | <sup>2</sup> ABBIENDI 03P  | OPAL |
| −12.4 ± 15.9 ± 2.0   | −9.6 | 88.38  | <sup>3</sup> HEISTER 02H   | ALEP |
| − 2.3 ± 2.6 ± 0.2    | −3.8 | 89.38  | <sup>3</sup> HEISTER 02H   | ALEP |
| − 0.3 ± 8.3 ± 0.6    | 0.9  | 90.21  | <sup>3</sup> HEISTER 02H   | ALEP |
| 10.6 ± 7.7 ± 0.7     | 9.6  | 92.05  | <sup>3</sup> HEISTER 02H   | ALEP |
| 11.9 ± 2.1 ± 0.6     | 12.2 | 92.94  | <sup>3</sup> HEISTER 02H   | ALEP |
| 12.1 ± 11.0 ± 1.0    | 14.2 | 93.90  | <sup>3</sup> HEISTER 02H   | ALEP |
| − 4.96 ± 3.68 ± 0.53 | −3.5 | 89.434 | <sup>4</sup> ABREU 99Y     | DLPH |
| 11.80 ± 3.18 ± 0.62  | 12.3 | 92.990 | <sup>4</sup> ABREU 99Y     | DLPH |
| − 1.0 ± 4.3 ± 1.0    | −3.9 | 89.37  | <sup>5</sup> BARATE 98O    | ALEP |
| 11.0 ± 3.3 ± 0.8     | 12.3 | 92.96  | <sup>5</sup> BARATE 98O    | ALEP |
| 3.9 ± 5.1 ± 0.9      | −3.4 | 89.45  | <sup>6</sup> ALEXANDER 97C | OPAL |
| 15.8 ± 4.1 ± 1.1     | 12.4 | 93.00  | <sup>6</sup> ALEXANDER 97C | OPAL |

|                          |         |    |            |     |      |
|--------------------------|---------|----|------------|-----|------|
| $-12.9 \pm 7.8 \pm 5.5$  | $-13.6$ | 35 | BEHREND    | 90D | CELL |
| $7.7 \pm 13.4 \pm 5.0$   | $-22.1$ | 43 | BEHREND    | 90D | CELL |
| $-12.8 \pm 4.4 \pm 4.1$  | $-13.6$ | 35 | ELSEN      | 90  | JADE |
| $-10.9 \pm 12.9 \pm 4.6$ | $-23.2$ | 44 | ELSEN      | 90  | JADE |
| $-14.9 \pm 6.7$          | $-13.3$ | 35 | OULD-SAADA | 89  | JADE |

<sup>1</sup> ABDALLAH 04F tag  $b$ - and  $c$ -quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of  $c\bar{c}$  and  $b\bar{b}$  events are obtained using lifetime information.

<sup>2</sup> ABBIENDI 03P tag heavy flavors using events with one or two identified leptons. This allows the simultaneous fitting of the  $b$  and  $c$  quark forward-backward asymmetries as well as the average  $B^0-\bar{B}^0$  mixing.

<sup>3</sup> HEISTER 02H measure simultaneously  $b$  and  $c$  quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.

<sup>4</sup> ABREU 99Y tag  $Z \rightarrow b\bar{b}$  and  $Z \rightarrow c\bar{c}$  events by an exclusive reconstruction of several  $D$  meson decay modes ( $D^{*+}$ ,  $D^0$ , and  $D^+$  with their charge-conjugate states).

<sup>5</sup> BARATE 980 tag  $Z \rightarrow c\bar{c}$  events requiring the presence of high-momentum reconstructed  $D^{*+}$ ,  $D^+$ , or  $D^0$  mesons.

<sup>6</sup> ALEXANDER 97C identify the  $b$  and  $c$  events using a  $D/D^*$  tag.

<sup>7</sup> ADRIANI 92D use both electron and muon semileptonic decays.

## ———— $A_{FB}^{(0,b)}$ CHARGE ASYMMETRY IN $e^+e^- \rightarrow b\bar{b}$ ————

OUR FIT, which is obtained by a simultaneous fit to several  $c$ - and  $b$ -quark measurements as explained in the note “The  $Z$  boson” and ref. LEP-SLC 06, refers to the **Z pole** asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

| ASYMMETRY (%)              | STD.<br>MODEL | $\sqrt{s}$<br>(GeV) | DOCUMENT ID                 | TECN |
|----------------------------|---------------|---------------------|-----------------------------|------|
| <b>9.92 ± 0.16 OUR FIT</b> |               |                     |                             |      |
| $9.58 \pm 0.32 \pm 0.14$   | 9.68          | 91.231              | <sup>1</sup> ABDALLAH 05    | DLPH |
| $10.04 \pm 0.56 \pm 0.25$  | 9.69          | 91.26               | <sup>2</sup> ABDALLAH 04F   | DLPH |
| $9.72 \pm 0.42 \pm 0.15$   | 9.67          | 91.25               | <sup>3</sup> ABBIENDI 03P   | OPAL |
| $9.77 \pm 0.36 \pm 0.18$   | 9.69          | 91.26               | <sup>4</sup> ABBIENDI 02I   | OPAL |
| $9.52 \pm 0.41 \pm 0.17$   | 9.59          | 91.21               | <sup>5</sup> HEISTER 02H    | ALEP |
| $10.00 \pm 0.27 \pm 0.11$  | 9.63          | 91.232              | <sup>6</sup> HEISTER 01D    | ALEP |
| $7.62 \pm 1.94 \pm 0.85$   | 9.64          | 91.235              | <sup>7</sup> ABREU 99Y      | DLPH |
| $9.60 \pm 0.66 \pm 0.33$   | 9.69          | 91.26               | <sup>8</sup> ACCIARRI 99D   | L3   |
| $9.31 \pm 1.01 \pm 0.55$   | 9.65          | 91.24               | <sup>9</sup> ACCIARRI 98U   | L3   |
| $9.4 \pm 2.7 \pm 2.2$      | 9.61          | 91.22               | <sup>10</sup> ALEXANDER 97C | OPAL |

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

|                           |      |        |                           |      |
|---------------------------|------|--------|---------------------------|------|
| $6.37 \pm 1.43 \pm 0.17$  | 5.8  | 89.449 | <sup>1</sup> ABDALLAH 05  | DLPH |
| $10.41 \pm 1.15 \pm 0.24$ | 12.1 | 92.990 | <sup>1</sup> ABDALLAH 05  | DLPH |
| $6.7 \pm 2.2 \pm 0.2$     | 5.7  | 89.43  | <sup>2</sup> ABDALLAH 04F | DLPH |
| $11.2 \pm 1.8 \pm 0.2$    | 12.1 | 92.99  | <sup>2</sup> ABDALLAH 04F | DLPH |
| $4.7 \pm 1.8 \pm 0.1$     | 5.9  | 89.51  | <sup>3</sup> ABBIENDI 03P | OPAL |
| $10.3 \pm 1.5 \pm 0.2$    | 12.0 | 92.95  | <sup>3</sup> ABBIENDI 03P | OPAL |
| $5.82 \pm 1.53 \pm 0.12$  | 5.9  | 89.50  | <sup>4</sup> ABBIENDI 02I | OPAL |
| $12.21 \pm 1.23 \pm 0.25$ | 12.0 | 92.91  | <sup>4</sup> ABBIENDI 02I | OPAL |
| $-13.1 \pm 13.5 \pm 1.0$  | 3.2  | 88.38  | <sup>5</sup> HEISTER 02H  | ALEP |

|                           |         |        |                         |     |      |
|---------------------------|---------|--------|-------------------------|-----|------|
| $5.5 \pm 1.9 \pm 0.1$     | 5.6     | 89.38  | <sup>5</sup> HEISTER    | 02H | ALEP |
| $-0.4 \pm 6.7 \pm 0.8$    | 7.5     | 90.21  | <sup>5</sup> HEISTER    | 02H | ALEP |
| $11.1 \pm 6.4 \pm 0.5$    | 11.0    | 92.05  | <sup>5</sup> HEISTER    | 02H | ALEP |
| $10.4 \pm 1.5 \pm 0.3$    | 12.0    | 92.94  | <sup>5</sup> HEISTER    | 02H | ALEP |
| $13.8 \pm 9.3 \pm 1.1$    | 12.9    | 93.90  | <sup>5</sup> HEISTER    | 02H | ALEP |
| $4.36 \pm 1.19 \pm 0.11$  | 5.8     | 89.472 | <sup>6</sup> HEISTER    | 01D | ALEP |
| $11.72 \pm 0.97 \pm 0.11$ | 12.0    | 92.950 | <sup>6</sup> HEISTER    | 01D | ALEP |
| $5.67 \pm 7.56 \pm 1.17$  | 5.7     | 89.434 | <sup>7</sup> ABREU      | 99Y | DLPH |
| $8.82 \pm 6.33 \pm 1.22$  | 12.1    | 92.990 | <sup>7</sup> ABREU      | 99Y | DLPH |
| $6.11 \pm 2.93 \pm 0.43$  | 5.9     | 89.50  | <sup>8</sup> ACCIARRI   | 99D | L3   |
| $13.71 \pm 2.40 \pm 0.44$ | 12.2    | 93.10  | <sup>8</sup> ACCIARRI   | 99D | L3   |
| $4.95 \pm 5.23 \pm 0.40$  | 5.8     | 89.45  | <sup>9</sup> ACCIARRI   | 98U | L3   |
| $11.37 \pm 3.99 \pm 0.65$ | 12.1    | 92.99  | <sup>9</sup> ACCIARRI   | 98U | L3   |
| $-8.6 \pm 10.8 \pm 2.9$   | 5.8     | 89.45  | <sup>10</sup> ALEXANDER | 97C | OPAL |
| $-2.1 \pm 9.0 \pm 2.6$    | 12.1    | 93.00  | <sup>10</sup> ALEXANDER | 97C | OPAL |
| $-71 \pm 34 \pm 7$        | $-58$   | 58.3   | SHIMONAKA               | 91  | TOPZ |
| $-22.2 \pm 7.7 \pm 3.5$   | $-26.0$ | 35     | BEHREND                 | 90D | CELL |
| $-49.1 \pm 16.0 \pm 5.0$  | $-39.7$ | 43     | BEHREND                 | 90D | CELL |
| $-28 \pm 11$              | $-23$   | 35     | BRAUNSCH...             | 90  | TASS |
| $-16.6 \pm 7.7 \pm 4.8$   | $-24.3$ | 35     | ELSEN                   | 90  | JADE |
| $-33.6 \pm 22.2 \pm 5.2$  | $-39.9$ | 44     | ELSEN                   | 90  | JADE |
| $3.4 \pm 7.0 \pm 3.5$     | $-16.0$ | 29.0   | BAND                    | 89  | MAC  |
| $-72 \pm 28 \pm 13$       | $-56$   | 55.2   | SAGAWA                  | 89  | AMY  |

<sup>1</sup> ABDALLAH 05 obtain an enriched samples of  $b\bar{b}$  events using lifetime information. The quark (or antiquark) charge is determined with a neural network using the secondary vertex charge, the jet charge and particle identification.

<sup>2</sup> ABDALLAH 04F tag  $b$ - and  $c$ -quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of  $c\bar{c}$  and  $b\bar{b}$  events are obtained using lifetime information.

<sup>3</sup> ABBIENDI 03P tag heavy flavors using events with one or two identified leptons. This allows the simultaneous fitting of the  $b$  and  $c$  quark forward-backward asymmetries as well as the average  $B^0-\bar{B}^0$  mixing.

<sup>4</sup> ABBIENDI 02I tag  $Z^0 \rightarrow b\bar{b}$  decays using a combination of secondary vertex and lepton tags. The sign of the  $b$ -quark charge is determined using an inclusive tag based on jet, vertex, and kaon charges.

<sup>5</sup> HEISTER 02H measure simultaneously  $b$  and  $c$  quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.

<sup>6</sup> HEISTER 01D tag  $Z \rightarrow b\bar{b}$  events using the impact parameters of charged tracks complemented with information from displaced vertices, event shape variables, and lepton identification. The  $b$ -quark direction and charge is determined using the hemisphere charge method along with information from fast kaon tagging and charge estimators of primary and secondary vertices. The change in the quoted value due to variation of  $A_{FB}^C$  and  $R_b$  is given as  $+0.103 (A_{FB}^C - 0.0651) - 0.440 (R_b - 0.21585)$ .

<sup>7</sup> ABREU 99Y tag  $Z \rightarrow b\bar{b}$  and  $Z \rightarrow c\bar{c}$  events by an exclusive reconstruction of several  $D$  meson decay modes ( $D^{*+}$ ,  $D^0$ , and  $D^+$  with their charge-conjugate states).

<sup>8</sup> ACCIARRI 99D tag  $Z \rightarrow b\bar{b}$  events using high  $p$  and  $p_T$  leptons. The analysis determines simultaneously a mixing parameter  $\chi_b = 0.1192 \pm 0.0068 \pm 0.0051$  which is used to correct the observed asymmetry.

<sup>9</sup> ACCIARRI 98U tag  $Z \rightarrow b\bar{b}$  events using lifetime and measure the jet charge using the hemisphere charge.

<sup>10</sup> ALEXANDER 97C identify the  $b$  and  $c$  events using a  $D/D^*$  tag.

## CHARGE ASYMMETRY IN $e^+e^- \rightarrow q\bar{q}$

Summed over five lighter flavors.

Experimental and Standard Model values are somewhat event-selection dependent. Standard Model expectations contain some assumptions on  $B^0-\bar{B}^0$  mixing and on other electroweak parameters.

| <u>ASYMMETRY (%)</u>  | <u>STD.<br/>MODEL</u> | <u><math>\sqrt{s}</math><br/>(GeV)</u> | <u>DOCUMENT ID</u> | <u>TECN</u> |
|---|-----------------------|--|--------------------|-------------|
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |                       |  |                    |             |
| – $0.76 \pm 0.12 \pm 0.15$  |                       | 91.2                                   | <sup>1</sup> ABREU | 92I DLPH    |
| $4.0 \pm 0.4 \pm 0.63$  | 4.0                   | 91.3                                   | <sup>2</sup> ACTON | 92L OPAL    |
| $9.1 \pm 1.4 \pm 1.6$   | 9.0                   | 57.9                                   | ADACHI             | 91 TOPZ     |
| – $0.84 \pm 0.15 \pm 0.04$  |                       | 91                                     | DECAMP             | 91B ALEP    |
| $8.3 \pm 2.9 \pm 1.9$   | 8.7                   | 56.6                                   | STUART             | 90 AMY      |
| $11.4 \pm 2.2 \pm 2.1$  | 8.7                   | 57.6                                   | ABE                | 89L VNS     |
| $6.0 \pm 1.3$   | 5.0                   | 34.8                                   | GREENSHAW          | 89 JADE     |
| $8.2 \pm 2.9$   | 8.5                   | 43.6                                   | GREENSHAW          | 89 JADE     |

<sup>1</sup> ABREU 92I has 0.14 systematic error due to uncertainty of quark fragmentation.

<sup>2</sup> ACTON 92L use the weight function method on 259k selected  $Z \rightarrow$  hadrons events.

The systematic error includes a contribution of 0.2 due to  $B^0-\bar{B}^0$  mixing effect, 0.4 due to Monte Carlo (MC) fragmentation uncertainties and 0.3 due to MC statistics. ACTON 92L derive a value of  $\sin^2\theta_{W}^{\text{eff}}$  to be  $0.2321 \pm 0.0017 \pm 0.0028$ .

## CHARGE ASYMMETRY IN $p\bar{p} \rightarrow Z \rightarrow e^+e^-$

| <u>ASYMMETRY (%)</u>  | <u>STD.<br/>MODEL</u> | <u><math>\sqrt{s}</math><br/>(GeV)</u> | <u>DOCUMENT ID</u> | <u>TECN</u> |
|---|-----------------------|--|--------------------|-------------|
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |                       |  |                    |             |
| $5.2 \pm 5.9 \pm 0.4$   |                       | 91                                     | ABE                | 91E CDF     |

## ANOMALOUS $ZZ\gamma$ , $Z\gamma\gamma$ , AND $ZZV$ COUPLINGS

See the related review(s):

[Anomalous  \$ZZ\gamma\$ ,  \$Z\gamma\gamma\$ , and  \$ZZV\$  Couplings](#)

$h_i^V$

Combining the LEP-2 results taking into account the correlations, the following 95% CL limits are derived [SCHAEL 13A]:

$$\begin{aligned}
 -0.12 < h_1^Z < +0.11, & & -0.07 < h_2^Z < +0.07, \\
 -0.19 < h_3^Z < +0.06, & & -0.04 < h_4^Z < +0.13, \\
 -0.05 < h_1^\gamma < +0.05, & & -0.04 < h_2^\gamma < +0.02, \\
 -0.05 < h_3^\gamma < +0.00, & & +0.01 < h_4^\gamma < +0.05.
 \end{aligned}$$

Some of the recent results from the Tevatron and LHC experiments individually surpass the combined LEP-2 results in precision (see below).

| VALUE         | DOCUMENT ID   | TECN | COMMENT  |
|---------------|---|------|--|
| • • •         | We do not use the following data for averages, fits, limits, etc. • • • |      |  |
| <sup>1</sup>  | AAD 16Q   | ATLS | $E_{\text{cm}}^{pp} = 8 \text{ TeV}$               |
| <sup>2</sup>  | KHACHATRY...16AE  | CMS  | $E_{\text{cm}}^{pp} = 8 \text{ TeV}$               |
| <sup>3</sup>  | KHACHATRY...15AC  | CMS  | $E_{\text{cm}}^{pp} = 8 \text{ TeV}$               |
| <sup>4</sup>  | CHATRCHYAN 14AB   | CMS  | $E_{\text{cm}}^{pp} = 7 \text{ TeV}$               |
| <sup>5</sup>  | AAD 13AN  | ATLS | $E_{\text{cm}}^{pp} = 7 \text{ TeV}$               |
| <sup>6</sup>  | CHATRCHYAN 13BI   | CMS  | $E_{\text{cm}}^{pp} = 7 \text{ TeV}$               |
| <sup>7</sup>  | ABAZOV 12S  | D0   | $E_{\text{cm}}^{pp} = 1.96 \text{ TeV}$            |
| <sup>8</sup>  | AALTONEN 11S  | CDF  | $E_{\text{cm}}^{pp} = 1.96 \text{ TeV}$            |
| <sup>9</sup>  | CHATRCHYAN 11M  | CMS  | $E_{\text{cm}}^{pp} = 7 \text{ TeV}$               |
| <sup>10</sup> | ABAZOV 09L  | D0   | $E_{\text{cm}}^{pp} = 1.96 \text{ TeV}$            |
| <sup>11</sup> | ABAZOV 07M  | D0   | $E_{\text{cm}}^{pp} = 1.96 \text{ TeV}$            |
| <sup>12</sup> | ABDALLAH 07C  | DLPH | $E_{\text{cm}}^{ee} = 183\text{--}208 \text{ GeV}$ |
| <sup>13</sup> | ACHARD 04H  | L3   | $E_{\text{cm}}^{ee} = 183\text{--}208 \text{ GeV}$ |
| <sup>14</sup> | ABBIENDI,G  | OPAL | $E_{\text{cm}}^{ee} = 189 \text{ GeV}$             |
| <sup>15</sup> | ABBOTT 98M  | D0   | $E_{\text{cm}}^{pp} = 1.8 \text{ TeV}$             |
| <sup>16</sup> | ABREU 98K   | DLPH | $E_{\text{cm}}^{ee} = 161, 172 \text{ GeV}$        |

<sup>1</sup> AAD 16Q study  $Z\gamma$  production in  $pp$  collisions. In events with no additional jets, 10268 (12738)  $Z$  decays to electron (muon) pairs are selected, with an expected background of  $1291 \pm 340$  ( $1537 \pm 408$ ) events, as well as 1039  $Z$  decays to neutrino pairs with an expected background of  $450 \pm 96$  events. Analyzing the photon transverse momentum distribution above 250 GeV (400 GeV) for lepton (neutrino) events, yields the 95% C.L. limits:  $-7.8 \times 10^{-4} < h_3^Z < 8.6 \times 10^{-4}$ ,  $-3.0 \times 10^{-6} < h_4^Z < 2.9 \times 10^{-6}$ ,  $-9.5 \times 10^{-4} < h_3^\gamma < 9.9 \times 10^{-4}$ ,  $-3.2 \times 10^{-6} < h_4^\gamma < 3.2 \times 10^{-6}$ .

<sup>2</sup> KHACHATRYAN 16AE determine the  $Z\gamma \rightarrow \nu\bar{\nu}\gamma$  cross section by selecting events with a photon of  $E_T > 145 \text{ GeV}$  and  $\cancel{E}_T > 140 \text{ GeV}$ . 630 candidate events are observed with an expected SM background of  $269 \pm 26$ . The  $E_T$  spectrum of the photon is used to set 95% C.L. limits as follows:  $-1.5 \times 10^{-3} < h_3^Z < 1.6 \times 10^{-3}$ ,  $-3.9 \times 10^{-6} < h_4^Z < 4.5 \times 10^{-6}$ ,  $-1.1 \times 10^{-3} < h_3^\gamma < 0.9 \times 10^{-3}$ ,  $-3.8 \times 10^{-6} < h_4^\gamma < 4.3 \times 10^{-6}$ .

<sup>3</sup> KHACHATRYAN 15AC study  $Z\gamma$  events in 8 TeV  $pp$  interactions, where the  $Z$  decays into 2 same-flavor, opposite sign leptons ( $e$  or  $\mu$ ) and a photon with  $p_T > 15 \text{ GeV}$ . The  $p_T$  of a lepton is required to be  $> 20 \text{ GeV}/c$ , their effective mass  $> 50 \text{ GeV}$ , and the photon should have a separation  $\Delta R > 0.7$  with each lepton. The observed  $p_T$  distribution of the photons is used to extract the 95% C.L. limits:  $-3.8 \times 10^{-3} < h_3^Z < 3.7 \times 10^{-3}$ ,  $-3.1 \times 10^{-5} < h_4^Z < 3.0 \times 10^{-5}$ ,  $-4.6 \times 10^{-3} < h_3^\gamma < 4.6 \times 10^{-3}$ ,  $-3.6 \times 10^{-5} < h_4^\gamma < 3.5 \times 10^{-5}$ .

<sup>4</sup> CHATRCHYAN 14AB measure  $Z\gamma$  production cross section for  $p_T^\gamma > 15 \text{ GeV}$  and  $R(\ell\gamma) > 0.7$ , which is the separation between the  $\gamma$  and the final state charged lepton ( $e$  or  $\mu$ ) in the azimuthal angle-pseudorapidity ( $\phi - \eta$ ) plane. The di-lepton mass is required to be  $> 50 \text{ GeV}$ . After background subtraction the number of  $ee\gamma$  and  $\mu\mu\gamma$  events is determined to be  $3160 \pm 120$  and  $5030 \pm 233$  respectively, compatible with expectations from the SM. This leads to a 95% CL limits of  $-1 \times 10^{-2} < h_3^\gamma < 1 \times 10^{-2}$ ,

- $-9 \times 10^{-5} < h_4^\gamma < 9 \times 10^{-5}$ ,  $-9 \times 10^{-3} < h_3^Z < 9 \times 10^{-3}$ ,  $-8 \times 10^{-5} < h_4^Z < 8 \times 10^{-5}$ , assuming  $h_1^V$  and  $h_2^V$  have SM values,  $V = \gamma$  or  $Z$ .
- <sup>5</sup> AAD 13AN study  $Z\gamma$  production in  $pp$  collisions. In events with no additional jet, 1417 (2031)  $Z$  decays to electron (muon) pairs are selected, with an expected background of  $156 \pm 54$  ( $244 \pm 64$ ) events, as well as 662  $Z$  decays to neutrino pairs with an expected background of  $302 \pm 42$  events. Analysing the photon  $p_T$  spectrum above 100 GeV yields the 95% C.L. limits:  $-0.013 < h_3^Z < 0.014$ ,  $-8.7 \times 10^{-5} < h_4^Z < 8.7 \times 10^{-5}$ ,  $-0.015 < h_3^\gamma < 0.016$ ,  $-9.4 \times 10^{-5} < h_4^\gamma < 9.2 \times 10^{-5}$ . Supersedes AAD 12BX.
- <sup>6</sup> CHATRCHYAN 13BI determine the  $Z\gamma \rightarrow \nu\bar{\nu}\gamma$  cross section by selecting events with a photon of  $E_T > 145$  GeV and a  $\cancel{E}_T > 130$  GeV. 73 candidate events are observed with an expected SM background of  $30.2 \pm 6.5$ . The  $E_T$  spectrum of the photon is used to set 95% C.L. limits as follows:  $|h_3^Z| < 2.7 \times 10^{-3}$ ,  $|h_4^Z| < 1.3 \times 10^{-5}$ ,  $|h_3^\gamma| < 2.9 \times 10^{-3}$ ,  $|h_4^\gamma| < 1.5 \times 10^{-5}$ .
- <sup>7</sup> ABAZOV 12S study  $Z\gamma$  production in  $p\bar{p}$  collisions at  $\sqrt{s} = 1.96$  TeV using  $6.2 \text{ fb}^{-1}$  of data where the  $Z$  decays to electron (muon) pairs and the photon has at least 10 GeV of transverse momentum. In data, 304 (308) di-electron (di-muon) events are observed with an expected background of  $255 \pm 16$  ( $285 \pm 24$ ) events. Based on the photon  $p_T$  spectrum, and including also earlier data and the  $Z \rightarrow \nu\bar{\nu}$  decay mode (from ABAZOV 09L), the following 95% C.L. limits are reported:  $|h_{03}^Z| < 0.026$ ,  $|h_{04}^Z| < 0.0013$ ,  $|h_{03}^\gamma| < 0.027$ ,  $|h_{04}^\gamma| < 0.0014$  for a form factor scale of  $\Lambda = 1.5$  TeV.
- <sup>8</sup> AALTONEN 11S study  $Z\gamma$  events in  $p\bar{p}$  interactions at  $\sqrt{s} = 1.96$  TeV with integrated luminosity  $5.1 \text{ fb}^{-1}$  for  $Z \rightarrow e^+e^-/\mu^+\mu^-$  and  $4.9 \text{ fb}^{-1}$  for  $Z \rightarrow \nu\bar{\nu}$ . For the charged lepton case, the two leptons must be of the same flavor with the transverse momentum/energy of one  $> 20$  GeV and the other  $> 10$  GeV. The isolated photon must have  $E_T > 50$  GeV. They observe 91 events with  $87.2 \pm 7.8$  events expected from standard model processes. For the  $\nu\bar{\nu}$  case they require solitary photons with  $E_T > 25$  GeV and missing  $E_T > 25$  GeV and observe 85 events with standard model expectation of  $85.9 \pm 5.6$  events. Taking the form factor  $\Lambda = 1.5$  TeV they derive 95% C.L. limits as  $|h_3^{\gamma,Z}| < 0.022$  and  $|h_4^{\gamma,Z}| < 0.0009$ .
- <sup>9</sup> CHATRCHYAN 11M study  $Z\gamma$  production in  $pp$  collisions at  $\sqrt{s} = 7$  TeV using  $36 \text{ pb}^{-1}$   $pp$  data, where the  $Z$  decays to  $e^+e^-$  or  $\mu^+\mu^-$ . The total cross sections are measured for photon transverse energy  $E_T^\gamma > 10$  GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle  $\Delta R(\ell,\gamma) > 0.7$  with the dilepton invariant mass requirement of  $M_{\ell\ell} > 50$  GeV. The number of  $e^+e^-\gamma$  and  $\mu^+\mu^-\gamma$  candidates is 81 and 90 with estimated backgrounds of  $20.5 \pm 2.5$  and  $27.3 \pm 3.2$  events respectively. The 95% CL limits for  $ZZ\gamma$  couplings are  $-0.05 < h_3^Z < 0.06$  and  $-0.0005 < h_4^Z < 0.0005$ , and for  $Z\gamma\gamma$  couplings are  $-0.07 < h_3^\gamma < 0.07$  and  $-0.0005 < h_4^\gamma < 0.0006$ .
- <sup>10</sup> ABAZOV 09L study  $Z\gamma$ ,  $Z \rightarrow \nu\bar{\nu}$  production in  $p\bar{p}$  collisions at 1.96 TeV C.M. energy. They select 51 events with a photon of transverse energy  $E_T$  larger than 90 GeV, with an expected background of 17 events. Based on the photon  $E_T$  spectrum and including also  $Z$  decays to charged leptons (from ABAZOV 07M), the following 95% CL limits are reported:  $|h_{30}^\gamma| < 0.033$ ,  $|h_{40}^\gamma| < 0.0017$ ,  $|h_{30}^Z| < 0.033$ ,  $|h_{40}^Z| < 0.0017$ .
- <sup>11</sup> ABAZOV 07M use 968  $p\bar{p} \rightarrow e^+e^-/\mu^+\mu^-\gamma X$  candidates, at 1.96 TeV center of mass energy, to tag  $p\bar{p} \rightarrow Z\gamma$  events by requiring  $E_T(\gamma) > 7$  GeV, lepton-gamma separation  $\Delta R_{\ell\gamma} > 0.7$ , and di-lepton invariant mass  $> 30$  GeV. The cross section is in agreement with the SM prediction. Using these  $Z\gamma$  events they obtain 95% C.L. limits on each  $h_i^V$ , keeping all others fixed at their SM values. They report:  $-0.083 < h_{30}^Z < 0.082$ ,

- $-0.0053 < h_{40}^Z < 0.0054$ ,  $-0.085 < h_{30}^\gamma < 0.084$ ,  $-0.0053 < h_{40}^\gamma < 0.0054$ , for the form factor scale  $\Lambda = 1.2$  TeV.
- <sup>12</sup> Using data collected at  $\sqrt{s} = 183\text{--}208$ , ABDALLAH 07C select 1,877  $e^+e^- \rightarrow Z\gamma$  events with  $Z \rightarrow q\bar{q}$  or  $\nu\bar{\nu}$ , 171  $e^+e^- \rightarrow ZZ$  events with  $Z \rightarrow q\bar{q}$  or lepton pair (except an explicit  $\tau$  pair), and 74  $e^+e^- \rightarrow Z\gamma^*$  events with a  $q\bar{q}\mu^+\mu^-$  or  $q\bar{q}e^+e^-$  signature, to derive 95% CL limits on  $h_i^V$ . Each limit is derived with other parameters set to zero. They report:  $-0.23 < h_1^Z < 0.23$ ,  $-0.30 < h_3^Z < 0.16$ ,  $-0.14 < h_1^\gamma < 0.14$ ,  $-0.049 < h_3^\gamma < 0.044$ .
- <sup>13</sup> ACHARD 04H select 3515  $e^+e^- \rightarrow Z\gamma$  events with  $Z \rightarrow q\bar{q}$  or  $\nu\bar{\nu}$  at  $\sqrt{s} = 189\text{--}209$  GeV to derive 95% CL limits on  $h_i^V$ . For deriving each limit the other parameters are fixed at zero. They report:  $-0.153 < h_1^Z < 0.141$ ,  $-0.087 < h_2^Z < 0.079$ ,  $-0.220 < h_3^Z < 0.112$ ,  $-0.068 < h_4^Z < 0.148$ ,  $-0.057 < h_1^\gamma < 0.057$ ,  $-0.050 < h_2^\gamma < 0.023$ ,  $-0.059 < h_3^\gamma < 0.004$ ,  $-0.004 < h_4^\gamma < 0.042$ .
- <sup>14</sup> ABBIENDI,G 00C study  $e^+e^- \rightarrow Z\gamma$  events (with  $Z \rightarrow q\bar{q}$  and  $Z \rightarrow \nu\bar{\nu}$ ) at 189 GeV to obtain the central values (and 95% CL limits) of these couplings:  $h_1^Z = 0.000 \pm 0.100$  ( $-0.190, 0.190$ ),  $h_2^Z = 0.000 \pm 0.068$  ( $-0.128, 0.128$ ),  $h_3^Z = -0.074^{+0.102}_{-0.103}$  ( $-0.269, 0.119$ ),  $h_4^Z = 0.046 \pm 0.068$  ( $-0.084, 0.175$ ),  $h_1^\gamma = 0.000 \pm 0.061$  ( $-0.115, 0.115$ ),  $h_2^\gamma = 0.000 \pm 0.041$  ( $-0.077, 0.077$ ),  $h_3^\gamma = -0.080^{+0.039}_{-0.041}$  ( $-0.164, -0.006$ ),  $h_4^\gamma = 0.064^{+0.033}_{-0.030}$  ( $+0.007, +0.134$ ). The results are derived assuming that only one coupling at a time is different from zero.
- <sup>15</sup> ABBOTT 98M study  $p\bar{p} \rightarrow Z\gamma + X$ , with  $Z \rightarrow e^+e^-, \mu^+\mu^-, \nu\bar{\nu}$  at 1.8 TeV, to obtain 95% CL limits at  $\Lambda = 750$  GeV:  $|h_{30}^Z| < 0.36$ ,  $|h_{40}^Z| < 0.05$  (keeping  $h_i^\gamma = 0$ ), and  $|h_{30}^\gamma| < 0.37$ ,  $|h_{40}^\gamma| < 0.05$  (keeping  $h_i^Z = 0$ ). Limits on the  $CP$ -violating couplings are  $|h_{10}^Z| < 0.36$ ,  $|h_{20}^Z| < 0.05$  (keeping  $h_i^\gamma = 0$ ), and  $|h_{10}^\gamma| < 0.37$ ,  $|h_{20}^\gamma| < 0.05$  (keeping  $h_i^Z = 0$ ).
- <sup>16</sup> ABREU 98K determine a 95% CL upper limit on  $\sigma(e^+e^- \rightarrow \gamma + \text{invisible particles}) < 2.5$  pb using 161 and 172 GeV data. This is used to set 95% CL limits on  $|h_{30}^\gamma| < 0.8$  and  $|h_{30}^Z| < 1.3$ , derived at a scale  $\Lambda = 1$  TeV and with  $n = 3$  in the form factor representation.

## $f_i^V$

Combining the LEP-2 results taking into account the correlations, the following 95% CL limits are derived [SCHAEL 13A]:

$$\begin{aligned} -0.28 < f_4^Z < +0.32, & \quad -0.34 < f_5^Z < +0.35, \\ -0.17 < f_4^\gamma < +0.19, & \quad -0.35 < f_5^\gamma < +0.32. \end{aligned}$$

Some of the recent results from the Tevatron and LHC experiments individually surpass the combined LEP-2 results in precision (see below).

| VALUE | DOCUMENT ID   | TECN     | COMMENT                       |
|-------|---|----------|-------------------------------|
| • • • | We do not use the following data for averages, fits, limits, etc. | • • •    |                               |
|       | <sup>1</sup> AABOUD   | 18Q ATLS | $E_{\text{cm}}^{pp} = 13$ TeV |

|    |             |      |      |  |
|----|-------------|------|------|--|
| 2  | SIRUNYAN    | 18BT | CMS  | $E_{\text{cm}}^{pp} = 13$ TeV              |
| 3  | KHACHATRYAN | 15B  | CMS  | $E_{\text{cm}}^{pp} = 8$ TeV               |
| 4  | KHACHATRYAN | 15BC | CMS  | $E_{\text{cm}}^{pp} = 7, 8$ TeV            |
| 5  | AAD         | 13Z  | ATLS | $E_{\text{cm}}^{pp} = 7$ TeV               |
| 6  | CHATRCHYAN  | 13B  | CMS  | $E_{\text{cm}}^{pp} = 7$ TeV               |
| 7  | SCHAEL      | 09   | ALEP | $E_{\text{cm}}^{ee} = 192\text{--}209$ GeV |
| 8  | ABAZOV      | 08K  | D0   | $E_{\text{cm}}^{pp} = 1.96$ TeV            |
| 9  | ABDALLAH    | 07C  | DLPH | $E_{\text{cm}}^{ee} = 183\text{--}208$ GeV |
| 10 | ABBIENDI    | 04C  | OPAL |  |
| 11 | ACHARD      | 03D  | L3   |  |

<sup>1</sup>AABOUD 18Q study  $pp \rightarrow ZZ$  events at  $\sqrt{s} = 13$  TeV with  $Z \rightarrow e^+e^-$  or  $Z \rightarrow \mu^+\mu^-$ . The number of events observed in the  $4e$ ,  $2e2\mu$ , and  $4\mu$  channels is 249, 465, and 303 respectively. Analysing the  $p_T$  spectrum of the leading  $Z$  boson, the following the following 95% C.L. limits are derived in units of  $10^{-4}$ :  $-1.8 < f_4^\gamma < 1.8$ ,  $-1.5 < f_4^Z < 1.5$ ,  $-1.8 < f_5^\gamma < 1.8$ ,  $-1.5 < f_5^Z < 1.5$ .

<sup>2</sup>SIRUNYAN 18BT study  $ppZZ$  events at  $\sqrt{s} = 13$  TeV with  $Z \rightarrow e^+e^-$  or  $Z \rightarrow \mu^+\mu^-$ . The number of events observed in the  $4e$ ,  $2e2\mu$ , and  $4\mu$  channels is 220, 543 and 335 respectively. Analysing the 4-lepton invariant mass spectrum, the following 95% C.L. limits are derived in units of  $10^{-3}$ :  $-1.2 < f_4^\gamma < 1.3$ ,  $-1.2 < f_4^Z < 1.0$ ,  $-1.2 < f_5^\gamma < 1.3$ ,  $-1.0 < f_5^Z < 1.3$ .

<sup>3</sup>KHACHATRYAN 15B study  $ZZ$  production in 8 TeV  $pp$  collisions. In the decay modes  $ZZ \rightarrow 4e$ ,  $4\mu$ ,  $2e2\mu$ , 54, 75, 148 events are observed, with an expected background of  $2.2 \pm 0.9$ ,  $1.2 \pm 0.6$ , and  $2.4 \pm 1.0$  events, respectively. Analysing the 4-lepton invariant mass spectrum in the range from 110 GeV to 1200 GeV, the following 95% C.L. limits are obtained:  $|f_4^Z| < 0.004$ ,  $|f_5^Z| < 0.004$ ,  $|f_4^\gamma| < 0.005$ ,  $|f_5^\gamma| < 0.005$ .

<sup>4</sup>KHACHATRYAN 15BC use the cross section measurement of the final state  $pp \rightarrow ZZ \rightarrow 2\ell 2\nu$ , ( $\ell$  being an electron or a muon) at 7 and 8 TeV to put limits on these triple gauge couplings. Effective mass of the charged lepton pair is required to be in the range 83.5–98.5 GeV and the dilepton  $p_T > 45$  GeV. The reduced missing  $E_T$  is required to be  $> 65$  GeV, which takes into account the fake missing  $E_T$  due to detector effects. The numbers of  $e^+e^-$  and  $\mu^+\mu^-$  events selected are 35 and 40 at 7 TeV and 176 and 271 at 8 TeV respectively. The production cross sections so obtained are in agreement with SM predictions. The following 95% C.L. limits are set:  $-0.0028 < f_4^Z < 0.0032$ ,  $-0.0037 < f_4^\gamma < 0.0033$ ,  $-0.0029 < f_5^Z < 0.0031$ ,  $-0.0033 < f_5^\gamma < 0.0037$ . Combining with previous results (KHACHATRYAN 15B and CHATRCHYAN 13B) which include 7 TeV and 8 TeV data on the final states  $pp \rightarrow ZZ \rightarrow 2\ell 2\ell'$  where  $\ell$  and  $\ell'$  are an electron or a muon, the best limits are  $-0.0022 < f_4^Z < 0.0026$ ,  $-0.0029 < f_4^\gamma < 0.0026$ ,  $-0.0023 < f_5^Z < 0.0023$ ,  $-0.0026 < f_5^\gamma < 0.0027$ .

<sup>5</sup>AAD 13Z study  $ZZ$  production in  $pp$  collisions at  $\sqrt{s} = 7$  TeV. In the  $ZZ \rightarrow \ell^+\ell^-\ell'^+\ell'^-$  final state they observe a total of 66 events with an expected background of  $0.9 \pm 1.3$ . In the  $ZZ \rightarrow \ell^+\ell^-\nu\nu$  final state they observe a total of 87 events with an expected background of  $46.9 \pm 5.2$ . The limits on anomalous TGCs are determined using the observed and expected numbers of these  $ZZ$  events binned in  $p_T^Z$ . The 95% C.L. are as follows: for form factor scale  $\Lambda = \infty$ ,  $-0.015 < f_4^\gamma < 0.015$ ,  $-0.013 < f_4^Z < 0.013$ ,  $-0.016 < f_5^\gamma < 0.015$ ,  $-0.013 < f_5^Z < 0.013$ ; for form factor scale  $\Lambda =$



$$3 \text{ TeV}, -0.022 < f_4^\gamma < 0.023, -0.019 < f_4^Z < 0.019, -0.023 < f_5^\gamma < 0.023, \\ -0.020 < f_5^Z < 0.019.$$

<sup>6</sup> CHATRCHYAN 13B study  $ZZ$  production in  $pp$  collisions and select 54  $ZZ$  candidates in the  $Z$  decay channel with electrons or muons with an expected background of  $1.4 \pm 0.5$  events. The resulting 95% C.L. ranges are:  $-0.013 < f_4^\gamma < 0.015$ ,  $-0.011 < f_4^Z < 0.012$ ,  $-0.014 < f_5^\gamma < 0.014$ ,  $-0.012 < f_5^Z < 0.012$ .

<sup>7</sup> Using data collected in the center of mass energy range 192–209 GeV, SCHAEEL 09 select 318  $e^+e^- \rightarrow ZZ$  events with 319.4 expected from the standard model. Using this data they derive the following 95% CL limits:  $-0.321 < f_4^\gamma < 0.318$ ,  $-0.534 < f_4^Z < 0.534$ ,  $-0.724 < f_5^\gamma < 0.733$ ,  $-1.194 < f_5^Z < 1.190$ .

<sup>8</sup> ABAZOV 08K search for  $ZZ$  and  $Z\gamma^*$  events with  $1 \text{ fb}^{-1} p\bar{p}$  data at  $\sqrt{s} = 1.96 \text{ TeV}$  in  $(ee)(ee)$ ,  $(\mu\mu)(\mu\mu)$ ,  $(ee)(\mu\mu)$  final states requiring the lepton pair masses to be  $> 30 \text{ GeV}$ . They observe 1 event, which is consistent with an expected signal of  $1.71 \pm 0.15$  events and a background of  $0.13 \pm 0.03$  events. From this they derive the following limits, for a form factor ( $\Lambda$ ) value of 1.2 TeV:  $-0.28 < f_{40}^Z < 0.28$ ,  $-0.31 < f_{50}^Z < 0.29$ ,  $-0.26 < f_{40}^\gamma < 0.26$ ,  $-0.30 < f_{50}^\gamma < 0.28$ .

<sup>9</sup> Using data collected at  $\sqrt{s} = 183\text{--}208 \text{ GeV}$ , ABDALLAH 07C select 171  $e^+e^- \rightarrow ZZ$  events with  $Z \rightarrow q\bar{q}$  or lepton pair (except an explicit  $\tau$  pair), and 74  $e^+e^- \rightarrow Z\gamma^*$  events with a  $q\bar{q}\mu^+\mu^-$  or  $q\bar{q}e^+e^-$  signature, to derive 95% CL limits on  $f_i^V$ . Each limit is derived with other parameters set to zero. They report:  $-0.40 < f_4^Z < 0.42$ ,  $-0.38 < f_5^Z < 0.62$ ,  $-0.23 < f_4^\gamma < 0.25$ ,  $-0.52 < f_5^\gamma < 0.48$ .

<sup>10</sup> ABBIENDI 04C study  $ZZ$  production in  $e^+e^-$  collisions in the C.M. energy range 190–209 GeV. They select 340 events with an expected background of 180 events. Including the ABBIENDI 00N data at 183 and 189 GeV (118 events with an expected background of 65 events) they report the following 95% CL limits:  $-0.45 < f_4^Z < 0.58$ ,  $-0.94 < f_5^Z < 0.25$ ,  $-0.32 < f_4^\gamma < 0.33$ , and  $-0.71 < f_5^\gamma < 0.59$ .

<sup>11</sup> ACHARD 03D study  $Z$ -boson pair production in  $e^+e^-$  collisions in the C.M. energy range 200–209 GeV. They select 549 events with an expected background of 432 events. Including the ACCIARRI 99G and ACCIARRI 99O data (183 and 189 GeV respectively, 286 events with an expected background of 241 events) and the 192–202 GeV ACCIARRI 01I results (656 events, expected background of 512 events), they report the following 95% CL limits:  $-0.48 \leq f_4^Z \leq 0.46$ ,  $-0.36 \leq f_5^Z \leq 1.03$ ,  $-0.28 \leq f_4^\gamma \leq 0.28$ , and  $-0.40 \leq f_5^\gamma \leq 0.47$ .

## ANOMALOUS $W/Z$ QUARTIC COUPLINGS

See the related review(s):

[Anomalous  \$W/Z\$  Quartic Couplings \(QGCs\)](#)

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

Combining published and unpublished preliminary LEP results the following 95% CL intervals for the QGCs associated with the  $ZZ\gamma\gamma$  vertex are derived (CERN-PH-EP/2005-051 or hep-ex/0511027):

$$-0.008 < a_0^Z/\Lambda^2 < +0.021 \\ -0.029 < a_c^Z/\Lambda^2 < +0.039$$

Anomalous  $Z$  quartic couplings have also been measured by the Tevatron and LHC experiments. As discussed in the review on "Anomalous  $W/Z$  quartic couplings," the coupling parameters in the Anomalous QGC Lagrangian may relate to processes involving only the  $W$  or only to the  $Z$  or to both. Thus, results on all other AQGCs are reported together in the  $W$  listings.

| <u>VALUE</u> | <u>DOCUMENT ID</u> | <u>TECN</u> |
|--------------|--------------------|-------------|
|--------------|--------------------|-------------|

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

|                       |     |      |
|-----------------------|-----|------|
| <sup>1</sup> ABBIENDI | 04L | OPAL |
| <sup>2</sup> HEISTER  | 04A | ALEP |
| <sup>3</sup> ACHARD   | 02G | L3   |

<sup>1</sup> 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:  $-0.007 < a_0^Z/\Lambda^2 < 0.023 \text{ GeV}^{-2}$ ,  $-0.029 < a_c^Z/\Lambda^2 < 0.029 \text{ GeV}^{-2}$ ,  $-0.020 < a_0^W/\Lambda^2 < 0.020 \text{ GeV}^{-2}$ ,  $-0.052 < a_c^W/\Lambda^2 < 0.037 \text{ GeV}^{-2}$ .

<sup>2</sup> 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:  $-0.012 < a_0^Z/\Lambda^2 < 0.019 \text{ GeV}^{-2}$ ,  $-0.041 < a_c^Z/\Lambda^2 < 0.044 \text{ GeV}^{-2}$ ,  $-0.060 < a_0^W/\Lambda^2 < 0.055 \text{ GeV}^{-2}$ ,  $-0.099 < a_c^W/\Lambda^2 < 0.093 \text{ GeV}^{-2}$ .

<sup>3</sup> ACHARD 02G study  $e^+e^- \rightarrow Z\gamma\gamma \rightarrow q\bar{q}\gamma\gamma$  events using data at center-of-mass energies from 200 to 209 GeV. The photons are required to be isolated, each with energy  $> 5 \text{ GeV}$  and  $|\cos\theta| < 0.97$ , and the di-jet invariant mass to be compatible with that of the  $Z$  boson (74–111 GeV). Cuts on  $Z$  velocity ( $\beta < 0.73$ ) and on the energy of the most energetic photon reduce the backgrounds due to non-resonant production of the  $q\bar{q}\gamma\gamma$  state and due to ISR respectively, yielding a total of 40 candidate events of which 8.6 are expected to be due to background. The energy spectra of the least energetic photon are fitted for all ten center-of-mass energy values from 130 GeV to 209 GeV (as obtained adding to the present analysis 130–202 GeV data of ACCIARRI 01E, for a total of 137 events with an expected background of 34.1 events) to obtain the fitted values  $a_0/\Lambda^2 = 0.00^{+0.02}_{-0.01} \text{ GeV}^{-2}$  and  $a_c/\Lambda^2 = 0.03^{+0.01}_{-0.02} \text{ GeV}^{-2}$ , where the other parameter is kept fixed to its Standard Model value (0). A simultaneous fit to both parameters yields the 95% CL limits  $-0.02 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.03 \text{ GeV}^{-2}$  and  $-0.07 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.05 \text{ GeV}^{-2}$ .

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| ABREU       | 95V | ZPHY C68 541           | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ABREU       | 95W | PL B361 207            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ABREU       | 95X | ZPHY C69 1             | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ACCIARRI    | 95B | PL B345 589            | M. Acciarri <i>et al.</i>              | (L3 Collab.)       |
| ACCIARRI    | 95C | PL B345 609            | M. Acciarri <i>et al.</i>              | (L3 Collab.)       |
| ACCIARRI    | 95G | PL B353 136            | M. Acciarri <i>et al.</i>              | (L3 Collab.)       |
| AKERS       | 95C | ZPHY C65 47            | R. Akers <i>et al.</i>                 | (OPAL Collab.)     |
| AKERS       | 95U | ZPHY C67 389           | R. Akers <i>et al.</i>                 | (OPAL Collab.)     |
| AKERS       | 95W | ZPHY C67 555           | R. Akers <i>et al.</i>                 | (OPAL Collab.)     |
| AKERS       | 95X | ZPHY C68 1             | R. Akers <i>et al.</i>                 | (OPAL Collab.)     |
| AKERS       | 95Z | ZPHY C68 203           | R. Akers <i>et al.</i>                 | (OPAL Collab.)     |
| ALEXANDER   | 95D | PL B358 162            | G. Alexander <i>et al.</i>             | (OPAL Collab.)     |
| BUSKULIC    | 95R | ZPHY C69 15            | D. Buskulic <i>et al.</i>              | (ALEPH Collab.)    |
| MIYABAYASHI | 95  | PL B347 171            | K. Miyabayashi <i>et al.</i>           | (TOPAZ Collab.)    |
| ABE         | 94C | PRL 73 25              | K. Abe <i>et al.</i>                   | (SLD Collab.)      |
| ABREU       | 94B | PL B327 386            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ABREU       | 94P | PL B341 109            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| AKERS       | 94P | ZPHY C63 181           | R. Akers <i>et al.</i>                 | (OPAL Collab.)     |
| BUSKULIC    | 94G | ZPHY C62 179           | D. Buskulic <i>et al.</i>              | (ALEPH Collab.)    |
| BUSKULIC    | 94J | ZPHY C62 1             | D. Buskulic <i>et al.</i>              | (ALEPH Collab.)    |
| VILAIN      | 94  | PL B320 203            | P. Vilain <i>et al.</i>                | (CHARM II Collab.) |
| ABREU       | 93  | PL B298 236            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ABREU       | 93I | ZPHY C59 533           | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| Also        |     | ZPHY C65 709 (erratum) | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ABREU       | 93L | PL B318 249            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ACTON       | 93  | PL B305 407            | P.D. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ACTON       | 93D | ZPHY C58 219           | P.D. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ACTON       | 93E | PL B311 391            | P.D. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ADRIANI     | 93  | PL B301 136            | O. Adriani <i>et al.</i>               | (L3 Collab.)       |
| ADRIANI     | 93I | PL B316 427            | O. Adriani <i>et al.</i>               | (L3 Collab.)       |
| BUSKULIC    | 93L | PL B313 520            | D. Buskulic <i>et al.</i>              | (ALEPH Collab.)    |
| NOVIKOV     | 93C | PL B298 453            | V.A. Novikov, L.B. Okun, M.I. Vysotsky | (ITEP)             |
| ABREU       | 92I | PL B277 371            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ABREU       | 92M | PL B289 199            | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ACTON       | 92B | ZPHY C53 539           | D.P. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ACTON       | 92L | PL B294 436            | P.D. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ACTON       | 92N | PL B295 357            | P.D. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ADEVA       | 92  | PL B275 209            | B. Adeva <i>et al.</i>                 | (L3 Collab.)       |
| ADRIANI     | 92D | PL B292 454            | O. Adriani <i>et al.</i>               | (L3 Collab.)       |
| ALITTI      | 92B | PL B276 354            | J. Alitti <i>et al.</i>                | (UA2 Collab.)      |
| BUSKULIC    | 92D | PL B292 210            | D. Buskulic <i>et al.</i>              | (ALEPH Collab.)    |
| BUSKULIC    | 92E | PL B294 145            | D. Buskulic <i>et al.</i>              | (ALEPH Collab.)    |
| DECAMP      | 92  | PRPL 216 253           | D. Decamp <i>et al.</i>                | (ALEPH Collab.)    |
| ABE         | 91E | PRL 67 1502            | F. Abe <i>et al.</i>                   | (CDF Collab.)      |
| ABREU       | 91H | ZPHY C50 185           | P. Abreu <i>et al.</i>                 | (DELPHI Collab.)   |
| ACTON       | 91B | PL B273 338            | D.P. Acton <i>et al.</i>               | (OPAL Collab.)     |
| ADACHI      | 91  | PL B255 613            | I. Adachi <i>et al.</i>                | (TOPAZ Collab.)    |
| ADEVA       | 91I | PL B259 199            | B. Adeva <i>et al.</i>                 | (L3 Collab.)       |
| AKRAWY      | 91F | PL B257 531            | M.Z. Akrawy <i>et al.</i>              | (OPAL Collab.)     |
| DECAMP      | 91B | PL B259 377            | D. Decamp <i>et al.</i>                | (ALEPH Collab.)    |
| DECAMP      | 91J | PL B266 218            | D. Decamp <i>et al.</i>                | (ALEPH Collab.)    |
| JACOBSEN    | 91  | PRL 67 3347            | R.G. Jacobsen <i>et al.</i>            | (Mark II Collab.)  |
| SHIMONAKA   | 91  | PL B268 457            | A. Shimonaka <i>et al.</i>             | (TOPAZ Collab.)    |
| ABE         | 90I | ZPHY C48 13            | K. Abe <i>et al.</i>                   | (VENUS Collab.)    |
| ABRAMS      | 90  | PRL 64 1334            | G.S. Abrams <i>et al.</i>              | (Mark II Collab.)  |

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|-------------|-----|--------------|-------------------------------|-------------------|
| AKRAWY      | 90J | PL B246 285  | M.Z. Akrawy <i>et al.</i>     | (OPAL Collab.)    |
| BEHREND     | 90D | ZPHY C47 333 | H.J. Behrend <i>et al.</i>    | (CELLO Collab.)   |
| BRAUNSCH... | 90  | ZPHY C48 433 | W. Braunschweig <i>et al.</i> | (TASSO Collab.)   |
| ELSEN       | 90  | ZPHY C46 349 | E. Elsen <i>et al.</i>        | (JADE Collab.)    |
| HEGNER      | 90  | ZPHY C46 547 | S. Hegner <i>et al.</i>       | (JADE Collab.)    |
| STUART      | 90  | PRL 64 983   | D. Stuart <i>et al.</i>       | (AMY Collab.)     |
| ABE         | 89  | PRL 62 613   | F. Abe <i>et al.</i>          | (CDF Collab.)     |
| ABE         | 89C | PRL 63 720   | F. Abe <i>et al.</i>          | (CDF Collab.)     |
| ABE         | 89L | PL B232 425  | K. Abe <i>et al.</i>          | (VENUS Collab.)   |
| ABRAMS      | 89B | PRL 63 2173  | G.S. Abrams <i>et al.</i>     | (Mark II Collab.) |
| ABRAMS      | 89D | PRL 63 2780  | G.S. Abrams <i>et al.</i>     | (Mark II Collab.) |
| ALBAJAR     | 89  | ZPHY C44 15  | C. Albajar <i>et al.</i>      | (UA1 Collab.)     |
| BACALA      | 89  | PL B218 112  | A. Bacala <i>et al.</i>       | (AMY Collab.)     |
| BAND        | 89  | PL B218 369  | H.R. Band <i>et al.</i>       | (MAC Collab.)     |
| GREENSHAW   | 89  | ZPHY C42 1   | T. Greenshaw <i>et al.</i>    | (JADE Collab.)    |
| OULD-SAADA  | 89  | ZPHY C44 567 | F. Ould-Saada <i>et al.</i>   | (JADE Collab.)    |
| SAGAWA      | 89  | PRL 63 2341  | H. Sagawa <i>et al.</i>       | (AMY Collab.)     |
| ADACHI      | 88C | PL B208 319  | I. Adachi <i>et al.</i>       | (TOPAZ Collab.)   |
| ADEVA       | 88  | PR D38 2665  | B. Adeva <i>et al.</i>        | (Mark-J Collab.)  |
| BRAUNSCH... | 88D | ZPHY C40 163 | W. Braunschweig <i>et al.</i> | (TASSO Collab.)   |
| ANSARI      | 87  | PL B186 440  | R. Ansari <i>et al.</i>       | (UA2 Collab.)     |
| BEHREND     | 87C | PL B191 209  | H.J. Behrend <i>et al.</i>    | (CELLO Collab.)   |
| BARTEL      | 86C | ZPHY C30 371 | W. Bartel <i>et al.</i>       | (JADE Collab.)    |
| Also        |     | ZPHY C26 507 | W. Bartel <i>et al.</i>       | (JADE Collab.)    |
| Also        |     | PL 108B 140  | W. Bartel <i>et al.</i>       | (JADE Collab.)    |
| ASH         | 85  | PRL 55 1831  | W.W. Ash <i>et al.</i>        | (MAC Collab.)     |
| BARTEL      | 85F | PL 161B 188  | W. Bartel <i>et al.</i>       | (JADE Collab.)    |
| DERRICK     | 85  | PR D31 2352  | M. Derrick <i>et al.</i>      | (HRS Collab.)     |
| FERNANDEZ   | 85  | PRL 54 1624  | E. Fernandez <i>et al.</i>    | (MAC Collab.)     |
| LEVI        | 83  | PRL 51 1941  | M.E. Levi <i>et al.</i>       | (Mark II Collab.) |
| BEHREND     | 82  | PL 114B 282  | H.J. Behrend <i>et al.</i>    | (CELLO Collab.)   |
| BRANDELIK   | 82C | PL 110B 173  | R. Brandelik <i>et al.</i>    | (TASSO Collab.)   |

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