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## THE $Z$ BOSON

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Precision measurements at the  $Z$ -boson resonance using electron–positron colliding beams began in 1989 at the SLC and at LEP. During 1989–95, the four CERN experiments made high-statistics studies of the  $Z$ . The availability of longitudinally polarized electron beams at the SLC since 1993 enabled a precision determination of the effective electroweak mixing angle  $\sin^2\bar{\theta}_W$  that is competitive with the CERN results on this parameter.

The  $Z$ -boson properties reported in this section may broadly be categorized as:

- The standard ‘lineshape’ parameters of the  $Z$  consisting of its mass,  $M_Z$ , its total width,  $\Gamma_Z$ , and its partial decay widths,  $\Gamma(\text{hadrons})$ , and  $\Gamma(\ell\bar{\ell})$  where  $\ell = e, \mu, \tau, \nu$ ;
- $Z$  asymmetries in leptonic decays and extraction of  $Z$  couplings to charged and neutral leptons;
- The  $b$ - and  $c$ -quark-related partial widths and charge asymmetries which require special techniques;
- Determination of  $Z$  decay modes and the search for modes that violate known conservation laws;
- Average particle multiplicities in hadronic  $Z$  decay;
- $Z$  anomalous couplings.

Details on  $Z$ -parameter determination and the study of  $Z \rightarrow b\bar{b}, c\bar{c}$  at LEP and SLC are given in this note.

The standard ‘lineshape’ parameters of the  $Z$  are determined from an analysis of the production cross sections of these final states in  $e^+e^-$  collisions. The  $Z \rightarrow \nu\bar{\nu}(\gamma)$  state is identified directly by detecting single photon production and indirectly by subtracting the visible partial widths from the total width. Inclusion in this analysis of the forward-backward asymmetry of charged leptons,  $A_{FB}^{(0,\ell)}$ , of the  $\tau$  polarization,  $P(\tau)$ , and its forward-backward asymmetry,  $P(\tau)^{fb}$ , enables the separate determination of the effective vector ( $\bar{g}_V$ ) and axial vector ( $\bar{g}_A$ ) couplings of the  $Z$  to these leptons and the ratio ( $\bar{g}_V/\bar{g}_A$ ) which is related to the effective electroweak mixing angle  $\sin^2\bar{\theta}_W$  (see the “Electroweak Model and Constraints on New Physics” Review).

Determination of the  $b$ - and  $c$ -quark-related partial widths and charge asymmetries involves tagging the  $b$  and  $c$  quarks. Traditionally this was done by requiring the presence of a prompt lepton in the event with high momentum and high transverse momentum (with respect to the accompanying jet). Precision vertex measurement with high-resolution detectors enabled one to do impact parameter and lifetime tagging. Neural-network techniques have also been used to classify events as  $b$  or non- $b$  on a statistical basis using event–shape variables. Finally, the presence of a charmed meson ( $D/D^*$ ) has been used to tag heavy quarks.

### ***Z-parameter determination***

LEP was run at energy points on and around the  $Z$  mass (88–94 GeV) constituting an energy ‘scan.’ The shape of the cross-section variation around the  $Z$  peak can be described by a Breit-Wigner *ansatz* with an energy-dependent

total width [1–3]. The **three** main properties of this distribution, viz., the **position** of the peak, the **width** of the distribution, and the **height** of the peak, determine respectively the values of  $M_Z$ ,  $\Gamma_Z$ , and  $\Gamma(e^+e^-) \times \Gamma(f\bar{f})$ , where  $\Gamma(e^+e^-)$  and  $\Gamma(f\bar{f})$  are the electron and fermion partial widths of the  $Z$ . The quantitative determination of these parameters is done by writing analytic expressions for these cross sections in terms of the parameters and fitting the calculated cross sections to the measured ones by varying these parameters, taking properly into account all the errors. Single-photon exchange ( $\sigma_\gamma^0$ ) and  $\gamma$ - $Z$  interference ( $\sigma_{\gamma Z}^0$ ) are included, and the large ( $\sim 25\%$ ) initial-state radiation (ISR) effects are taken into account by convoluting the analytic expressions over a ‘Radiator Function’ [1–5]  $H(s, s')$ . Thus for the process  $e^+e^- \rightarrow f\bar{f}$ :

$$\sigma_f(s) = \int H(s, s') \sigma_f^0(s') ds' \quad (1)$$

$$\sigma_f^0(s) = \sigma_Z^0 + \sigma_\gamma^0 + \sigma_{\gamma Z}^0 \quad (2)$$

$$\sigma_Z^0 = \frac{12\pi}{M_Z^2} \frac{\Gamma(e^+e^-)\Gamma(f\bar{f})}{\Gamma_Z^2} \frac{s \Gamma_Z^2}{(s - M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2} \quad (3)$$

$$\sigma_\gamma^0 = \frac{4\pi\alpha^2(s)}{3s} Q_f^2 N_c^f \quad (4)$$

$$\begin{aligned} \sigma_{\gamma Z}^0 = & -\frac{2\sqrt{2}\alpha(s)}{3} (Q_f G_F N_c^f \mathcal{G}_V^e \mathcal{G}_V^f) \\ & \times \frac{(s - M_Z^2)M_Z^2}{(s - M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2} \end{aligned} \quad (5)$$

where  $Q_f$  is the charge of the fermion,  $N_c^f = 3(1)$  for quark (lepton) and  $\mathcal{G}_V^f$  is the neutral vector coupling of the  $Z$  to the fermion-antifermion pair  $f\bar{f}$ .

Since  $\sigma_{\gamma Z}^0$  is expected to be much less than  $\sigma_Z^0$ , the LEP Collaborations have generally calculated the interference term in the framework of the Standard Model. This fixing of  $\sigma_{\gamma Z}^0$  leads to a tighter constraint on  $M_Z$  and consequently a smaller error on its fitted value.

In the above framework, the QED radiative corrections have been explicitly taken into account by convoluting over the ISR and allowing the electromagnetic coupling constant to run [9]:  $\alpha(s) = \alpha/(1 - \Delta\alpha)$ . On the other hand, weak radiative corrections that depend upon the assumptions of the electroweak theory and on the values of  $M_{\text{top}}$  and  $M_{\text{Higgs}}$  are accounted for by **absorbing them into the couplings**, which are then called the *effective* couplings  $\mathcal{G}_V$  and  $\mathcal{G}_A$  (or alternatively the effective parameters of the  $\star$  scheme of Kennedy and Lynn [10]).

$\mathcal{G}_V^f$  and  $\mathcal{G}_A^f$  are complex numbers with a small imaginary part. As experimental data does not allow simultaneous extraction of both real and imaginary parts of the effective couplings, the convention  $g_A^f = \text{Re}(\mathcal{G}_A^f)$  and  $g_V^f = \text{Re}(\mathcal{G}_V^f)$  is used and the imaginary parts are added in the fitting code [4].

Defining

$$A_f = 2 \frac{g_V^f \cdot g_A^f}{(g_V^f)^2 + (g_A^f)^2} \quad (6)$$

the lowest-order expressions for the various lepton-related asymmetries on the  $Z$  pole are [6–8]  $A_{FB}^{(0,\ell)} = (3/4)A_e A_f$ ,  $P(\tau) = -A_\tau$ ,  $P(\tau)^{fb} = -(3/4)A_e$ ,  $A_{LR} = A_e$ . The full analysis takes into account the energy dependence of the asymmetries. Experimentally  $A_{LR}$  is defined as  $(\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$  where  $\sigma_{L(R)}$  are the  $e^+e^- \rightarrow Z$  production cross sections with left-(right)-handed electrons.

The definition of the partial decay width of the  $Z$  to  $f\bar{f}$  includes the effects of QED and QCD final state corrections

as well as the contribution due to the imaginary parts of the couplings:

$$\Gamma(f\bar{f}) = \frac{G_F M_Z^3}{6\sqrt{2}\pi} N_c^f (|\mathcal{G}_A^f|^2 R_A^f + |\mathcal{G}_V^f|^2 R_V^f) + \Delta_{ew/QCD} \quad (7)$$

where  $R_V^f$  and  $R_A^f$  are radiator factors to account for final state QED and QCD corrections as well as effects due to nonzero fermion masses, and  $\Delta_{ew/QCD}$  represents the non-factorizable electroweak/QCD corrections.

### ***S-matrix approach to the Z***

While practically all experimental analyses of LEP/SLC data have followed the ‘Breit-Wigner’ approach described above, an alternative S-matrix-based analysis is also possible. The  $Z$ , like all unstable particles, is associated with a complex pole in the S matrix. The pole position is process independent and gauge invariant. The mass,  $\bar{M}_Z$ , and width,  $\bar{\Gamma}_Z$ , can be defined in terms of the pole in the energy plane via [11–14]

$$\bar{s} = \bar{M}_Z^2 - i\bar{M}_Z\bar{\Gamma}_Z \quad (8)$$

leading to the relations

$$\begin{aligned} \bar{M}_Z &= M_Z / \sqrt{1 + \Gamma_Z^2 / M_Z^2} \\ &\approx M_Z - 34.1 \text{ MeV} \end{aligned} \quad (9)$$

$$\begin{aligned} \bar{\Gamma}_Z &= \Gamma_Z / \sqrt{1 + \Gamma_Z^2 / M_Z^2} \\ &\approx \Gamma_Z - 0.9 \text{ MeV} . \end{aligned} \quad (10)$$

Some authors [15] choose to define the  $Z$  mass and width via

$$\bar{s} = (\bar{M}_Z - \frac{i}{2}\bar{\Gamma}_Z)^2 \quad (11)$$

which yields  $\overline{M}_Z \approx M_Z - 26 \text{ MeV}$ ,  $\overline{\Gamma}_Z \approx \Gamma_Z - 1.2 \text{ MeV}$ .

The L3 and OPAL Collaborations at LEP (ACCIARRI 00Q and ACKERSTAFF 97C) have analyzed their data using the S-matrix approach as defined in Eq. (8), in addition to the conventional one. They observe a downward shift in the  $Z$  mass as expected.

### ***Handling the large-angle $e^+e^-$ final state***

Unlike other  $f\bar{f}$  decay final states of the  $Z$ , the  $e^+e^-$  final state has a contribution not only from the  $s$ -channel but also from the  $t$ -channel and  $s$ - $t$  interference. The full amplitude is not amenable to fast calculation, which is essential if one has to carry out minimization fits within reasonable computer time. The usual procedure is to calculate the non- $s$  channel part of the cross section separately using the Standard Model programs ALIBABA [16] or TOPAZ0 [17] with the measured value of  $M_{\text{top}}$ , and  $M_{\text{Higgs}} = 150 \text{ GeV}$  and add it to the  $s$ -channel cross section calculated as for other channels. This leads to two additional sources of error in the analysis: firstly, the theoretical calculation in ALIBABA itself is known to be accurate to  $\sim 0.5\%$ , and secondly, there is uncertainty due to the error on  $M_{\text{top}}$  and the unknown value of  $M_{\text{Higgs}}$  (100–1000 GeV). These errors are propagated into the analysis by including them in the systematic error on the  $e^+e^-$  final state. As these errors are common to the four LEP experiments, this is taken into account when performing the LEP average.

### ***Errors due to uncertainty in LEP energy determination*** [18–23]

The systematic errors related to the LEP energy measurement can be classified as:

- The absolute energy scale error;
- Energy-point-to-energy-point errors due to the non-linear response of the magnets to the exciting currents;
- Energy-point-to-energy-point errors due to possible higher-order effects in the relationship between the dipole field and beam energy;
- Energy reproducibility errors due to various unknown uncertainties in temperatures, tidal effects, corrector settings, RF status, *etc.*

Precise energy calibration was done outside normal data taking using the resonant depolarization technique. Run-time energies were determined every 10 minutes by measuring the relevant machine parameters and using a model which takes into account all the known effects, including leakage currents produced by trains in the Geneva area and the tidal effects due to gravitational forces of the Sun and the Moon. The LEP Energy Working Group has provided a covariance matrix from the determination of LEP energies for the different running periods during 1993–1995 [18].

### *Choice of fit parameters*

The LEP Collaborations have chosen the following primary set of parameters for fitting:  $M_Z$ ,  $\Gamma_Z$ ,  $\sigma_{\text{hadron}}^0$ ,  $R(\text{lepton})$ ,  $A_{FB}^{(0,\ell)}$ , where  $R(\text{lepton}) = \Gamma(\text{hadrons})/\Gamma(\text{lepton})$ ,  $\sigma_{\text{hadron}}^0 = 12\pi\Gamma(e^+e^-)\Gamma(\text{hadrons})/M_Z^2\Gamma_Z^2$ . With a knowledge of these fitted parameters and their covariance matrix, any other parameter can be derived. The main advantage of these parameters is that they form the **least correlated** set of parameters, so that it becomes easy to combine results from the different LEP experiments.

Thus, the most general fit carried out to cross section and asymmetry data determines the **nine parameters**:  $M_Z$ ,  $\Gamma_Z$ ,  $\sigma_{\text{hadron}}^0$ ,  $R(e)$ ,  $R(\mu)$ ,  $R(\tau)$ ,  $A_{FB}^{(0,e)}$ ,  $A_{FB}^{(0,\mu)}$ ,  $A_{FB}^{(0,\tau)}$ . Assumption of lepton universality leads to a **five-parameter fit** determining  $M_Z$ ,  $\Gamma_Z$ ,  $\sigma_{\text{hadron}}^0$ ,  $R(\text{lepton})$ ,  $A_{FB}^{(0,\ell)}$ .

### ***Combining results from LEP and SLC experiments***

With steady increase in statistics over the years and improved understanding of the common systematic errors between LEP experiments, the procedures for combining results have evolved continuously [24]. The Line Shape Sub-group of the LEP Electroweak Working Group investigated the effects of these common errors and devised a combination procedure for the precise determination of the  $Z$  parameters from LEP experiments [25]. Using these procedures this note also gives the results after combining the final parameter sets from the four experiments and these are the results quoted as the fit results in the  $Z$  listings below. Transformation of variables leads to values of derived parameters like partial decay widths and branching ratios to hadrons and leptons. Finally, transforming the LEP combined nine parameter set to  $(M_Z, \Gamma_Z, \sigma_{\text{hadron}}^0, g_A^f, g_V^f, f = e, \mu, \tau)$  using the average values of lepton asymmetry parameters  $(A_e, A_\mu, A_\tau)$  as constraints, leads to the best fitted values of the vector and axial-vector couplings  $(g_V, g_A)$  of the charged leptons to the  $Z$ .

Brief remarks on the handling of common errors and their magnitudes are given below. The identified common errors are those coming from

- (a) LEP energy calibration uncertainties, and
- (b) the theoretical uncertainties in (i) the luminosity determination using small angle Bhabha scattering, (ii) estimating



the non-s channel contribution to large angle Bhabha scattering, (iii) the calculation of QED radiative effects, and (iv) the parametrization of the cross section in terms of the parameter set used.

### ***Common LEP energy errors***

All the collaborations incorporate in their fit the full LEP energy error matrix as provided by the LEP energy group for their intersection region [18]. The effect of these errors is separated out from that of other errors by carrying out fits with energy errors scaled up and down by  $\sim 10\%$  and redoing the fits. From the observed changes in the overall error matrix the covariance matrix of the common energy errors is determined. Common LEP energy errors lead to uncertainties on  $M_Z$ ,  $\Gamma_Z$ , and  $\sigma_{\text{hadron}}^\circ$  of 1.7, 1.2 MeV, and 0.011 nb respectively.

### ***Common luminosity errors***

BHLUMI 4.04 [26] is used by all LEP collaborations for small angle Bhabha scattering leading to a common uncertainty in their measured cross sections of 0.061% [27]. BHLUMI does not include a correction for production of light fermion pairs. OPAL explicitly correct for this effect and reduce their luminosity uncertainty to 0.054% which is taken fully correlated with the other experiments. The other three experiments among themselves have a common uncertainty of 0.061%.

### ***Common non-s channel uncertainties***

The same standard model programs ALIBABA [16] and TOPAZ0 [17] are used to calculate the non-s channel contribution to the large angle Bhabha scattering [28]. As this contribution is a function of the  $Z$  mass, which itself is a variable in the fit, it is parametrized as a function of  $M_Z$  by each collaboration to properly track this contribution as  $M_Z$  varies

in the fit. The common errors on  $R_e$  and  $A_{FB}^{0,e}$  are 0.024 and 0.0014 respectively and are correlated between them.

### ***Common theoretical uncertainties: QED***

There are large initial state photon and fermion pair radiation effects near the  $Z$  resonance for which the best currently available evaluations include contributions up to  $\mathcal{O}(\alpha^3)$ . To estimate the remaining uncertainties different schemes are incorporated in the standard model programs ZFITTER [5], TOPAZ0 [17] and MIZA [29]. Comparing the different options leads to error estimates of 0.3 and 0.2 MeV on  $M_Z$  and  $\Gamma_Z$  respectively and of 0.02% on  $\sigma_{\text{hadron}}^\circ$ .

### ***Common theoretical uncertainties: parametrization of lineshape and asymmetries***

To estimate uncertainties arising from ambiguities in the model-independent parametrization of the differential cross-section near the  $Z$  resonance, results from TOPAZ0 and ZFITTER were compared by using ZFITTER to fit the cross sections and asymmetries calculated using TOPAZ0. The resulting uncertainties on  $M_Z$ ,  $\Gamma_Z$ ,  $\sigma_{\text{hadron}}^\circ$ ,  $R(\text{lepton})$  and  $A_{FB}^{0,\ell}$  are 0.1 MeV, 0.1 MeV, 0.001 nb, 0.004, and 0.0001 respectively.

Thus the overall theoretical errors on  $M_Z$ ,  $\Gamma_Z$ ,  $\sigma_{\text{hadron}}^\circ$  are 0.3 MeV, 0.2 MeV, and 0.008 nb respectively; on each  $R(\text{lepton})$  is 0.004 and on each  $A_{FB}^{0,\ell}$  is 0.0001. Within the set of three  $R(\text{lepton})$ 's and the set of three  $A_{FB}^{0,\ell}$ 's the respective errors are fully correlated.

All the theory related errors mentioned above utilize standard model programs which need the Higgs mass and running electromagnetic coupling constant as inputs; uncertainties on these inputs will also lead to common errors. All LEP collaborations used the same set of inputs for standard model calculations:  $M_Z = 91.187$  GeV, the

Fermi constant  $G_F = (1.16637 \pm 0.00001) \times 10^{-5} \text{ GeV}^{-2}$  [30],  $\alpha^{(5)}(M_Z) = 1/128.877 \pm 0.090$  [31],  $\alpha_s(M_Z) = 0.119$  [32],  $M_{\text{top}} = 174.3 \pm 5.1 \text{ GeV}$  [32] and  $M_{\text{Higgs}} = 150 \text{ GeV}$ . The only observable effect, on  $M_Z$ , is due to the variation of  $M_{\text{Higgs}}$  between 100–1000 GeV (due to the variation of the  $\gamma/Z$  interference term which is taken from the standard model):  $M_Z$  changes by +0.23 MeV per unit change in  $\log_{10} M_{\text{Higgs}}/\text{GeV}$ , which is not an error but a correction to be applied once  $M_{\text{Higgs}}$  is determined. The effect is much smaller than the error on  $M_Z$  ( $\pm 2.1 \text{ MeV}$ ).

### ***Methodology of combining the LEP experimental results***

The LEP experimental results actually used for combination are slightly modified from those published by the experiments (which are given in the Listings below). This has been done in order to facilitate the procedure by making the inputs more consistent. These modified results are given explicitly in [25]. The main differences compared to the published results are

(a) consistent use of ZFITTER 6.23 and TOPAZ0. The published ALEPH results used ZFITTER 6.10. (b) use of the combined energy error matrix which makes a difference of 0.1 MeV on the  $M_Z$  and  $\Gamma_Z$  for L3 only as at that intersection the RF modeling uncertainties are the largest.

Thus, nine-parameter sets from all four experiments with their covariance matrices are used together with all the common errors correlations. A grand covariance matrix,  $V$ , is constructed and a combined nine-parameter set is obtained by minimizing  $\chi^2 = \Delta^T V^{-1} \Delta$ , where  $\Delta$  is the vector of residuals of the combined parameter set to the results of individual experiments.

### ***Study of $Z \rightarrow b\bar{b}$ and $Z \rightarrow c\bar{c}$***

In the sector of  $c$ - and  $b$ -physics the LEP experiments have measured the ratios of partial widths  $R_b = \Gamma(Z \rightarrow b\bar{b})/\Gamma(Z \rightarrow \text{hadrons})$  and  $R_c = \Gamma(Z \rightarrow c\bar{c})/\Gamma(Z \rightarrow \text{hadrons})$  and the forward-backward (charge) asymmetries  $A_{FB}^{b\bar{b}}$  and  $A_{FB}^{c\bar{c}}$ . The final state coupling parameters  $A_b$  and  $A_c$  have been obtained from the left-right forward-backward asymmetry at SLD. Several of the analyses have also determined other quantities, in particular the semileptonic branching ratios,  $B(b \rightarrow \ell^-)$ ,  $B(b \rightarrow c \rightarrow \ell^+)$ , and  $B(c \rightarrow \ell^+)$ , the average  $B^0\bar{B}^0$  mixing parameter  $\bar{\chi}$  and the probabilities for a  $c$ -quark to fragment into a  $D^+$ , a  $D_s$ , a  $D^{*+}$ , or a charmed baryon. The latter measurements do not concern properties of the  $Z$  boson and hence they do not appear in the listing below. However, for completeness, we will report at the end of this minireview their values as obtained fitting the data contained in the Z section. All these quantities are correlated with the electroweak parameters, and since the mixture of  $b$  hadrons is different from the one at the  $\Upsilon(4S)$ , their values might differ from those measured at the  $\Upsilon(4S)$ .

All the above quantities are correlated to each other since:

- Several analyses (for example the lepton fits) determine more than one parameter simultaneously;
- Some of the electroweak parameters depend explicitly on the values of other parameters (for example  $R_b$  depends on  $R_c$ );
- Common tagging and analysis techniques produce common systematic uncertainties.

The LEP Electroweak Heavy Flavour Working Group has developed [33] a procedure for combining the measurements taking into account known sources of correlation. The combining procedure determines twelve parameters: the four parameters of interest in the electroweak sector,  $R_b$ ,  $R_c$ ,  $A_{FB}^{b\bar{b}}$ , and  $A_{FB}^{c\bar{c}}$  and, in addition,  $B(b \rightarrow \ell^-)$ ,  $B(b \rightarrow c \rightarrow \ell^+)$ ,  $B(c \rightarrow \ell^+)$ ,  $\bar{\chi}$ ,  $f(D^+)$ ,  $f(D_s)$ ,  $f(c_{\text{baryon}})$  and  $P(c \rightarrow D^{*+}) \times B(D^{*+} \rightarrow \pi^+ D^0)$ , to take into account their correlations with the electroweak parameters. Before the fit both the peak and off-peak asymmetries are translated to the common energy  $\sqrt{s} = 91.26$  GeV using the predicted energy dependence from ZFITTER [5].

### ***Summary of the measurements and of the various kinds of analysis***

The measurements of  $R_b$  and  $R_c$  fall into two classes. In the first, named single-tag measurement, a method for selecting  $b$  and  $c$  events is applied and the number of tagged events is counted. The second technique, named double-tag measurement, is based on the following principle: if the number of events with a single hemisphere tagged is  $N_t$  and with both hemispheres tagged is  $N_{tt}$ , then given a total number of  $N_{\text{had}}$  hadronic  $Z$  decays one has:

$$\frac{N_t}{2N_{\text{had}}} = \varepsilon_b R_b + \varepsilon_c R_c + \varepsilon_{uds}(1 - R_b - R_c) \quad (12)$$

$$\frac{N_{tt}}{N_{\text{had}}} = C_b \varepsilon_b^2 R_b + C_c \varepsilon_c^2 R_c + C_{uds} \varepsilon_{uds}^2 (1 - R_b - R_c) \quad (13)$$

where  $\varepsilon_b$ ,  $\varepsilon_c$ , and  $\varepsilon_{uds}$  are the tagging efficiencies per hemisphere for  $b$ ,  $c$ , and light quark events, and  $C_q \neq 1$  accounts for the fact that the tagging efficiencies between the hemispheres may be correlated. In tagging the  $b$  one has  $\varepsilon_b \gg \varepsilon_c \gg \varepsilon_{uds}$ ,  $C_b \approx 1$ .

Neglecting the  $c$  and  $uds$  background and the hemisphere correlations, these equations give:

$$\varepsilon_b = 2N_{tt}/N_t \quad (14)$$

$$R_b = N_t^2 / (4N_{tt}N_{\text{had}}) . \quad (15)$$

The double-tagging method has thus the great advantage that the tagging efficiency is directly derived from the data, reducing the systematic error of the measurement. The backgrounds, dominated by  $c\bar{c}$  events, obviously complicate this simple picture, and their level must still be inferred by other means. The rate of charm background in these analyses depends explicitly on the value of  $R_c$ . The correlations in the tagging efficiencies between the hemispheres (due for instance to correlations in momentum between the  $b$  hadrons in the two hemispheres) are small but nevertheless lead to further systematic uncertainties.

The measurements in the  $b$ - and  $c$ -sector can be essentially grouped in the following categories:

- Lifetime (and lepton) double-tagging measurements of  $R_b$ . These are the most precise measurements of  $R_b$  and obviously dominate the combined result. The main sources of systematics come from the charm contamination and from estimating the hemisphere  $b$ -tagging efficiency correlation. The charm rejection has been improved (and hence the systematic errors reduced) by using either the information of the secondary vertex invariant mass or the information from the energy of all particles at the secondary vertex and their rapidity;
- Analyses with  $D/D^{*\pm}$  to measure  $R_c$ . These measurements make use of several different tagging

- techniques (inclusive/exclusive double tag, exclusive double tag, reconstruction of all weakly decaying charmed states) and no assumptions are made on the energy dependence of charm fragmentation;
- Lepton fits which use hadronic events with one or more leptons in the final state to measure  $A_{FB}^{b\bar{b}}$  and  $A_{FB}^{c\bar{c}}$ . Each analysis usually gives several other electroweak parameters. The dominant sources of systematics are due to lepton identification, to other semileptonic branching ratios and to the modeling of the semileptonic decay;
  - Measurements of  $A_{FB}^{b\bar{b}}$  using lifetime tagged events with a hemisphere charge measurement. Their contribution to the combined result has roughly the same weight as the lepton fits;
  - Analyses with  $D/D^{*\pm}$  to measure  $A_{FB}^{c\bar{c}}$  or simultaneously  $A_{FB}^{b\bar{b}}$  and  $A_{FB}^{c\bar{c}}$ ;
  - Measurements of  $A_b$  and  $A_c$  from SLD, using several tagging methods (lepton, kaon,  $D/D^*$ , and vertex mass). These quantities are directly extracted from a measurement of the left–right forward–backward asymmetry in  $c\bar{c}$  and  $b\bar{b}$  production using a polarized electron beam.

### ***Averaging procedure***

All the measurements are provided by the LEP Collaborations in the form of tables with a detailed breakdown of the systematic errors of each measurement and its dependence on other electroweak parameters.

The averaging proceeds via the following steps:

- Define and propagate a consistent set of external inputs such as branching ratios, hadron lifetimes, fragmentation models *etc.* All the measurements are also consistently checked to ensure that all use a common set of assumptions (for instance since the QCD corrections for the forward–backward asymmetries are strongly dependent on the experimental conditions, the data are corrected before combining);
- Form the full (statistical and systematic) covariance matrix of the measurements. The systematic correlations between different analyses are calculated from the detailed error breakdown in the measurement tables. The correlations relating several measurements made by the same analysis are also used;
- Take into account any explicit dependence of a measurement on the other electroweak parameters. As an example of this dependence we illustrate the case of the double-tag measurement of  $R_b$ , where  $c$ -quarks constitute the main background. The normalization of the charm contribution is not usually fixed by the data and the measurement of  $R_b$  depends on the assumed value of  $R_c$ , which can be written as:

$$R_b = R_b^{\text{meas}} + a(R_c) \frac{(R_c - R_c^{\text{used}})}{R_c}, \quad (16)$$

where  $R_b^{\text{meas}}$  is the result of the analysis which assumed a value of  $R_c = R_c^{\text{used}}$  and  $a(R_c)$  is the constant which gives the dependence on  $R_c$ ;

- Perform a  $\chi^2$  minimization with respect to the combined electroweak parameters.



After the fit the average peak asymmetries  $A_{FB}^{c\bar{c}}$  and  $A_{FB}^{b\bar{b}}$  are corrected for the energy shift from 91.26 GeV to  $M_Z$  and for QED (initial state radiation),  $\gamma$  exchange, and  $\gamma Z$  interference effects to obtain the corresponding pole asymmetries  $A_{FB}^{0,c}$  and  $A_{FB}^{0,b}$ .

This averaging procedure, using the fourteen parameters described above and applied to the data contained in the Z particle listing below, gives the following results:

$$R_b^0 = 0.21643 \pm 0.00072$$

$$R_c^0 = 0.1689 \pm 0.0047$$

$$A_{FB}^{0,b} = 0.1001 \pm 0.0017$$

$$A_{FB}^{0,c} = 0.0704 \pm 0.0036$$

$$A_b = 0.926 \pm 0.024$$

$$A_c = 0.666 \pm 0.036$$

$$B(b \rightarrow \ell^-) = 0.1069 \pm 0.0021$$

$$B(b \rightarrow c \rightarrow \ell^+) = 0.0801 \pm 0.0018$$

$$B(c \rightarrow \ell^+) = 0.0980 \pm 0.0033$$

$$\bar{\chi} = 0.1251 \pm 0.0040$$

$$f(D^+) = 0.237 \pm 0.016$$

$$f(D_s) = 0.119 \pm 0.025$$

$$f(c_{\text{baryon}}) = 0.090 \pm 0.022$$

$$P(c \rightarrow D^{*+}) \times B(D^{*+} \rightarrow \pi^+ D^0) = 0.1648 \pm 0.0056$$

## References

1. R.N. Cahn, Phys. Rev. **D36**, 2666 (1987).
2. F.A. Berends *et al.*, “Z Physics at LEP 1”, CERN Report 89-08 (1989), Vol. 1, eds. G. Altarelli, R. Kleiss, and C. Verzegnassi, p. 89.
3. A. Borrelli *et al.*, Nucl. Phys. **B333**, 357 (1990).
4. D. Bardin and G. Passarino, “Upgrading of Precision Calculations for Electroweak Observables,” [hep-ph/9803425](#); D. Bardin, G. Passarino, and M. Grünewald, “Precision Calculation Project Report,” [hep-ph/9902452](#).
5. D. Bardin *et al.*, Z. Phys. **C44**, 493 (1989); Comp. Phys. Comm. **59**, 303 (1990); D. Bardin *et al.*, Nucl. Phys. **B351**, 1 (1991); Phys. Lett. **B255**, 290 (1991) and CERN-TH/6443/92 (1992); Comp. Phys. Comm. **133**, 229 (2001).
6. M. Consoli *et al.*, “Z Physics at LEP 1”, CERN Report 89-08 (1989), Vol. 1, eds. G. Altarelli, R. Kleiss, and C. Verzegnassi, p. 7.
7. M. Bohm *et al.*, *ibid*, p. 203.
8. S. Jadach *et al.*, *ibid*, p. 235.
9. G. Burgers *et al.*, *ibid*, p. 55.
10. D.C. Kennedy and B.W. Lynn, SLAC-PUB 4039 (1986, revised 1988).
11. R. Stuart, Phys. Lett. **B262**, 113 (1991).
12. A. Sirlin, Phys. Rev. Lett. **67**, 2127 (1991).
13. A. Leike, T. Riemann, and J. Rose, Phys. Lett. **B273**, 513 (1991).
14. See also D. Bardin *et al.*, Phys. Lett. **B206**, 539 (1988).
15. S. Willenbrock and G. Valencia, Phys. Lett. **B259**, 373 (1991).
16. W. Beenakker, F.A. Berends, and S.C. van der Marck, Nucl. Phys. **B349**, 323 (1991).
17. G. Montagna *et al.*, Nucl. Phys. **B401**, 3 (1993); Comp. Phys. Comm. **76**, 328 (1993); Comp. Phys. Comm. **93**, 120 (1996);

- G. Montagna *et al.*, Comp. Phys. Comm. **117**, 278 (1999).
18. R. Assmann *et al.* (Working Group on LEP Energy), Eur. Phys. J. **C6**, 187 (1999).
  19. R. Assmann *et al.* (Working Group on LEP Energy), Z. Phys. **C66**, 567 (1995).
  20. L. Arnaudon *et al.* (Working Group on LEP Energy and LEP Collaborations), Phys. Lett. **B307**, 187 (1993).
  21. L. Arnaudon *et al.* (Working Group on LEP Energy), CERN-PPE/92-125 (1992).
  22. L. Arnaudon *et al.*, Phys. Lett. **B284**, 431 (1992).
  23. R. Bailey *et al.*, ‘LEP Energy Calibration’ CERN-SL-90-95-AP, Proceedings of the “2<sup>nd</sup> European Particle Accelerator Conference,” Nice, France, 12–16 June 1990, pp. 1765-1767.
  24. The LEP Collaborations: ALEPH, DELPHI, L3, OPAL, the LEP Electroweak Working Group, and the SLD Heavy Flavour Group:  
CERN-EP/2002-091 (2002); CERN-EP/2001-098 (2001);  
CERN-EP/2001-021 (2001); CERN-EP/2000-016 (1999);  
CERN-EP/99-15 (1998); CERN-PPE/97-154 (1997);  
CERN-PPE/96-183 (1996); CERN-PPE/95-172 (1995);  
CERN-PPE/94-187 (1994); CERN-PPE/93-157 (1993).
  25. The LEP Collaborations ALEPH, DELPHI, L3, OPAL, and the Line Shape Sub-group of the LEP Electroweak Working Group: CERN-EP/2000-153, [hep-ex/0101027](http://arxiv.org/abs/hep-ex/0101027) (to be published as part of a review in Physics Reports).
  26. S. Jadach *et al.*, BHLUMI 4.04, Comp. Phys. Comm. **102**, 229 (1997);  
S. Jadach and O. Nicosini, Event generators for Bhabha scattering, in Physics at LEP2, CERN-96-01 Vol. 2, February 1996.
  27. B.F.L. Ward *et al.*, Phys. Lett. **B450**, 262 (1999).
  28. W. Beenakker and G. Passarino, Phys. Lett. **B425**, 199 (1998).
  29. L. Garrido *et al.*, Z. Phys. **C49**, 645 (1991);

- M. Martinez and F. Teubert, Z. Phys. **C65**, 267 (1995), updated with results summarized in S. Jadach, B. Pietrzyk and M. Skrzypek, Phys. Lett. **B456**, 77 (1999) and Reports of the working group on precision calculations for the Z resonance, CERN 95-03, ed. D. Bardin, W. Hollik, and G. Passarino, and references therein.
30. T. van Ritbergen, R. Stuart, Phys. Lett. **B437**, 201 (1998); Phys. Rev. Lett. **81**, 488 (1999).
  31. S. Eidelman and F. Jegerlehner, Z. Phys. **C67**, 585 (1995); M. Steinhauser, Phys. Lett. **B249**, 158 (1998).
  32. Particle Data Group (D.E. Groom *et al.*), Eur. Phys. J. **C15**, 1 (2000).
  33. The LEP Experiments: ALEPH, DELPHI, L3, and OPAL Nucl. Instrum. Methods **A378**, 101 (1996).

## Z MASS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson"). 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 a Breit-Wigner resonance parameter. 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 ACKERSTAFF 97C 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. • • •

91.1875 ± 0.0039	3.97M	<sup>5</sup> ACCIARRI	00Q L3	$E_{cm}^{ee} = \text{LEP1} +$ 130–189 GeV
91.185 ± 0.010		<sup>6</sup> ACKERSTAFF	97C OPAL	$E_{cm}^{ee} = \text{LEP1}$ + 130–136 GeV + 161 GeV
91.151 ± 0.008		<sup>7</sup> MIYABAYASHI	95 TOPZ	$E_{cm}^{ee} = 57.8 \text{ GeV}$
91.187 ± 0.007 ± 0.006	1.16M	<sup>8</sup> ABREU	94 DLPH	Repl. by ABREU 00F
91.195 ± 0.006 ± 0.007	1.19M	<sup>8</sup> ACCIARRI	94 L3	Repl. by ACCIARRI 00C
91.182 ± 0.007 ± 0.006	1.33M	<sup>8</sup> AKERS	94 OPAL	Repl. by ABBIENDI 01A
91.187 ± 0.007 ± 0.006	1.27M	<sup>8</sup> BUSKULIC	94 ALEP	Repl. by BARATE 00C
91.74 ± 0.28 ± 0.93	156	<sup>9</sup> ALITTI	92B UA2	$E_{cm}^{pp} = 630 \text{ GeV}$
90.9 ± 0.3 ± 0.2	188	<sup>10</sup> ABE	89C CDF	$E_{cm}^{pp} = 1.8 \text{ TeV}$
91.14 ± 0.12	480	<sup>11</sup> ABRAMS	89B MRK2	$E_{cm}^{ee} = 89–93 \text{ GeV}$
93.1 ± 1.0 ± 3.0	24	<sup>12</sup> ALBAJAR	89 UA1	$E_{cm}^{pp} = 546,630 \text{ GeV}$

<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> 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>6</sup> ACKERSTAFF 97C obtain this using the S-matrix formalism for a combined fit to their cross-section and asymmetry data at the Z peak (AKERS 94) and their data at 130, 136, and 161 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit-Wigner fits.

<sup>7</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>8</sup> The second error of 6.3 MeV is due to a common LEP energy uncertainty.

<sup>9</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>10</sup> First error of ABE 89 is combination of statistical and systematic contributions; second is mass scale uncertainty.

<sup>11</sup> ABRAMS 89B uncertainty includes 35 MeV due to the absolute energy measurement.

<sup>12</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 on the Z boson").

VALUE (GeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>2.4952 ± 0.0023 OUR FIT</b>				
2.4948 ± 0.0041	4.57M	13 ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
2.4876 ± 0.0041	4.08M	14 ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
2.5024 ± 0.0042	3.96M	15 ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
2.4951 ± 0.0043	4.57M	16 BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
2.5025 ± 0.0041	3.97M	17 ACCIARRI	00Q L3	$E_{cm}^{ee} = \text{LEP1} + 130-189$ GeV
2.50 ± 0.21 ± 0.06		18 ABREU	96R DLPH	$E_{cm}^{ee} = 91.2$ GeV
2.483 ± 0.011 ± 0.0045	1.16M	19 ABREU	94 DLPH	Repl. by ABREU 00F
2.494 ± 0.009 ± 0.0045	1.19M	19 ACCIARRI	94 L3	Repl. by ACCIARRI 00C
2.483 ± 0.011 ± 0.0045	1.33M	19 AKERS	94 OPAL	Repl. by ABBIENDI 01A
2.501 ± 0.011 ± 0.0045	1.27M	19 BUSKULIC	94 ALEP	Repl. by BARATE 00C
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	20 ABRAMS	89B MRK2	$E_{cm}^{ee} = 89-93$ GeV
2.7 $\begin{smallmatrix} +1.2 \\ -1.0 \end{smallmatrix}$ ± 1.3	24	21 ALBAJAR	89 UA1	$E_{cm}^{p\bar{p}} = 546,630$ GeV
2.7 ± 2.0 ± 1.0	25	22 ANSARI	87 UA2	$E_{cm}^{p\bar{p}} = 546,630$ GeV

<sup>13</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>14</sup> The error includes 1.2 MeV due to LEP energy uncertainty.

<sup>15</sup> The error includes 1.3 MeV due to LEP energy uncertainty.

<sup>16</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>17</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>18</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>19</sup> The second error of 4.5 MeV is due to a common LEP energy uncertainty.

<sup>20</sup> ABRAMS 89B uncertainty includes 50 MeV due to the miniSAM background subtraction error.

<sup>21</sup> ALBAJAR 89 result is from a total sample of 33  $Z \rightarrow e^+ e^-$  events.

<sup>22</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/ Confidence level
$\Gamma_1$ $e^+ e^-$	( 3.363 $\pm$ 0.004 ) %	
$\Gamma_2$ $\mu^+ \mu^-$	( 3.366 $\pm$ 0.007 ) %	
$\Gamma_3$ $\tau^+ \tau^-$	( 3.370 $\pm$ 0.008 ) %	
$\Gamma_4$ $\ell^+ \ell^-$	[a] ( 3.3658 $\pm$ 0.0023 ) %	
$\Gamma_5$ invisible	(20.00 $\pm$ 0.06 ) %	
$\Gamma_6$ hadrons	(69.91 $\pm$ 0.06 ) %	
$\Gamma_7$ $(u\bar{u} + c\bar{c})/2$	(10.1 $\pm$ 1.1 ) %	
$\Gamma_8$ $(d\bar{d} + s\bar{s} + b\bar{b})/3$	(16.6 $\pm$ 0.6 ) %	
$\Gamma_9$ $c\bar{c}$	(11.81 $\pm$ 0.33 ) %	
$\Gamma_{10}$ $b\bar{b}$	(15.13 $\pm$ 0.05 ) %	
$\Gamma_{11}$ $b\bar{b}b\bar{b}$	( 3.6 $\pm$ 1.3 ) $\times 10^{-4}$	
$\Gamma_{12}$ $g g g$	< 1.1	% CL=95%
$\Gamma_{13}$ $\pi^0 \gamma$	< 5.2	$\times 10^{-5}$ CL=95%
$\Gamma_{14}$ $\eta \gamma$	< 5.1	$\times 10^{-5}$ CL=95%
$\Gamma_{15}$ $\omega \gamma$	< 6.5	$\times 10^{-4}$ CL=95%
$\Gamma_{16}$ $\eta'(958) \gamma$	< 4.2	$\times 10^{-5}$ CL=95%
$\Gamma_{17}$ $\gamma \gamma$	< 5.2	$\times 10^{-5}$ CL=95%
$\Gamma_{18}$ $\gamma \gamma \gamma$	< 1.0	$\times 10^{-5}$ CL=95%
$\Gamma_{19}$ $\pi^\pm W^\mp$	[b] < 7	$\times 10^{-5}$ CL=95%
$\Gamma_{20}$ $\rho^\pm W^\mp$	[b] < 8.3	$\times 10^{-5}$ CL=95%
$\Gamma_{21}$ $J/\psi(1S) X$	( 3.51 $^{+0.23}_{-0.25}$ ) $\times 10^{-3}$	S=1.1
$\Gamma_{22}$ $\psi(2S) X$	( 1.60 $\pm$ 0.29 ) $\times 10^{-3}$	
$\Gamma_{23}$ $\chi_{c1}(1P) X$	( 2.9 $\pm$ 0.7 ) $\times 10^{-3}$	
$\Gamma_{24}$ $\chi_{c2}(1P) X$	< 3.2	$\times 10^{-3}$ CL=90%
$\Gamma_{25}$ $\Upsilon(1S) X + \Upsilon(2S) X + \Upsilon(3S) X$	( 1.0 $\pm$ 0.5 ) $\times 10^{-4}$	
$\Gamma_{26}$ $\Upsilon(1S) X$	< 4.4	$\times 10^{-5}$ CL=95%
$\Gamma_{27}$ $\Upsilon(2S) X$	< 1.39	$\times 10^{-4}$ CL=95%
$\Gamma_{28}$ $\Upsilon(3S) X$	< 9.4	$\times 10^{-5}$ CL=95%
$\Gamma_{29}$ $(D^0/\bar{D}^0) X$	(20.7 $\pm$ 2.0 ) %	
$\Gamma_{30}$ $D^\pm X$	(12.2 $\pm$ 1.7 ) %	
$\Gamma_{31}$ $D^*(2010)^\pm X$	[b] (11.4 $\pm$ 1.3 ) %	
$\Gamma_{32}$ $D_{s1}(2536)^\pm X$	( 3.6 $\pm$ 0.8 ) $\times 10^{-3}$	
$\Gamma_{33}$ $D_{sJ}(2573)^\pm X$	( 5.8 $\pm$ 2.2 ) $\times 10^{-3}$	
$\Gamma_{34}$ $D^{*J}(2629)^\pm X$	searched for	
$\Gamma_{35}$ $B X$		
$\Gamma_{36}$ $B^* X$		
$\Gamma_{37}$ $B_s^0 X$	seen	
$\Gamma_{38}$ $B_c^+ X$	searched for	
$\Gamma_{39}$ anomalous $\gamma$ + hadrons	[c] < 3.2	$\times 10^{-3}$ CL=95%

$\Gamma_{40}$	$e^+ e^- \gamma$		[c] < 5.2	$\times 10^{-4}$	CL=95%
$\Gamma_{41}$	$\mu^+ \mu^- \gamma$		[c] < 5.6	$\times 10^{-4}$	CL=95%
$\Gamma_{42}$	$\tau^+ \tau^- \gamma$		[c] < 7.3	$\times 10^{-4}$	CL=95%
$\Gamma_{43}$	$\ell^+ \ell^- \gamma \gamma$		[d] < 6.8	$\times 10^{-6}$	CL=95%
$\Gamma_{44}$	$q \bar{q} \gamma \gamma$		[d] < 5.5	$\times 10^{-6}$	CL=95%
$\Gamma_{45}$	$\nu \bar{\nu} \gamma \gamma$		[d] < 3.1	$\times 10^{-6}$	CL=95%
$\Gamma_{46}$	$e^\pm \mu^\mp$	LF	[b] < 1.7	$\times 10^{-6}$	CL=95%
$\Gamma_{47}$	$e^\pm \tau^\mp$	LF	[b] < 9.8	$\times 10^{-6}$	CL=95%
$\Gamma_{48}$	$\mu^\pm \tau^\mp$	LF	[b] < 1.2	$\times 10^{-5}$	CL=95%
$\Gamma_{49}$	$p e$	L,B	< 1.8	$\times 10^{-6}$	CL=95%
$\Gamma_{50}$	$p \mu$	L,B	< 1.8	$\times 10^{-6}$	CL=95%

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

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

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

[d] 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 on the Z Boson.'

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<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>23</sup> ABE	95J SLD	$E_{cm}^{ee} = 91.31$ GeV

<sup>23</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 on the Z Boson.'

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<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 on the Z Boson.'

<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

### $\Gamma(\ell^+\ell^-)$

$\Gamma_4$

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 on the Z Boson.'

<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

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

$\Gamma_5$

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>24</sup>	ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
498.1± 3.2	<sup>24</sup>	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
499.1± 2.9	<sup>24</sup>	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
499.1± 2.5	<sup>24</sup>	BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

<sup>24</sup> This is an indirect determination of  $\Gamma(\text{invisible})$  from a fit to the visible Z decay modes.

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

$\Gamma_6$

This parameter is not directly used in the 5-parameter fit assuming lepton universality, but is derived using the fit results. See the 'Note on the Z Boson.'

<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	$E_{cm}^{ee} = 88-94$ GeV
1738.1 ± 4.0	3.70M	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
1751.1 ± 3.8	3.54M	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
1744.0 ± 3.4	4.07M	BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ 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 on the Z boson").

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

$\Gamma_6/\Gamma_1$

<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>25</sup> ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
20.88 ± 0.12	117.8k	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
20.816 ± 0.089	124.4k	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
20.677 ± 0.075		<sup>26</sup> BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
20.74 ± 0.18	31.4k	ABREU	94 DLPH	Repl. by ABREU 00F
20.96 ± 0.15	38k	ACCIARRI	94 L3	Repl. by ACCIA- RRI 00C
20.83 ± 0.16	42k	AKERS	94 OPAL	Repl. by ABBIENDI 01A
20.59 ± 0.15	45.8k	BUSKULIC	94 ALEP	Repl. by BARATE 00C
27.0 $\begin{smallmatrix} +11.7 \\ -8.8 \end{smallmatrix}$	12	<sup>27</sup> ABRAMS	89D MRK2	$E_{cm}^{ee} = 89-93$ GeV

<sup>25</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>26</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>27</sup> ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

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

$\Gamma_6/\Gamma_2$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson").

<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>28</sup> ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
20.65 ± 0.08	157.6k	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
20.861 ± 0.097	113.4k	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
20.799 ± 0.056		<sup>29</sup> BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

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

20.54 ±0.14	45.6k	ABREU	94	DLPH	Repl. by ABREU 00F
21.02 ±0.16	34k	ACCIARRI	94	L3	Repl. by ACCIA-RRI 00C
20.78 ±0.11	57k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.83 ±0.15	46.4k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
18.9 $\begin{smallmatrix} +7.1 \\ -5.3 \end{smallmatrix}$	13	<sup>30</sup> ABRAMS	89D	MRK2	$E_{cm}^{ee} = 89-93$ GeV

<sup>28</sup> ABBIENDI 01A error includes approximately 0.050 due to statistics and 0.027 due to event selection systematics.

<sup>29</sup> BARATE 00C error includes approximately 0.053 due to statistics and 0.021 due to experimental systematics.

<sup>30</sup> ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

### $\Gamma(\text{hadrons})/\Gamma(\tau^+\tau^-)$ $\Gamma_6/\Gamma_3$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the "Note on the Z boson").

<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>31</sup> ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
20.84 ± 0.13	104.0k	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
20.792 ± 0.133	103.0k	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
20.707 ± 0.062		<sup>32</sup> BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

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

20.68 ±0.18	25k	ABREU	94	DLPH	Repl. by ABREU 00F
20.80 ±0.20	25k	ACCIARRI	94	L3	Repl. by ACCIA-RRI 00C
21.01 ±0.15	47k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.70 ±0.16	45.1k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
15.2 $\begin{smallmatrix} +4.8 \\ -3.9 \end{smallmatrix}$	21	<sup>33</sup> ABRAMS	89D	MRK2	$E_{cm}^{ee} = 89-93$ GeV

<sup>31</sup> ABBIENDI 01A error includes approximately 0.055 due to statistics and 0.071 due to event selection systematics.

<sup>32</sup> BARATE 00C error includes approximately 0.054 due to statistics and 0.033 due to experimental systematics.

<sup>33</sup> ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

### $\Gamma(\text{hadrons})/\Gamma(\ell^+\ell^-)$ $\Gamma_6/\Gamma_4$

$\ell$  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>34</sup> ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
20.730 ± 0.060	379.4k	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
20.810 ± 0.060	340.8k	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
20.725 ± 0.039	500k	<sup>35</sup> BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

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

20.62 ±0.10	102k	ABREU	94	DLPH	Repl. by ABREU 00F
20.93 ±0.10	97k	ACCIARRI	94	L3	Repl. by ACCIARRI 00C
20.835 ±0.086	146k	AKERS	94	OPAL	Repl. by ABBIENDI 01A
20.69 ±0.09	137.3k	BUSKULIC	94	ALEP	Repl. by BARATE 00C
18.9 $\begin{smallmatrix} +3.6 \\ -3.2 \end{smallmatrix}$	46	ABRAMS	89B	MRK2	$E_{cm}^{ee} = 89-93$ GeV

<sup>34</sup> ABBIENDI 01A error includes approximately 0.034 due to statistics and 0.027 due to event selection systematics.

<sup>35</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.

**$\Gamma(\text{hadrons})/\Gamma_{\text{total}}$**   **$\Gamma_6/\Gamma$**

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (%) DOCUMENT ID  
**69.911 ± 0.056 OUR FIT**

**$\Gamma(e^+ e^-)/\Gamma_{\text{total}}$**   **$\Gamma_1/\Gamma$**

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (%) DOCUMENT ID  
**3.3632 ± 0.0042 OUR FIT**

**$\Gamma(\mu^+ \mu^-)/\Gamma_{\text{total}}$**   **$\Gamma_2/\Gamma$**

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (%) DOCUMENT ID  
**3.3662 ± 0.0066 OUR FIT**

**$\Gamma(\tau^+ \tau^-)/\Gamma_{\text{total}}$**   **$\Gamma_3/\Gamma$**

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (%) DOCUMENT ID  
**3.3696 ± 0.0083 OUR FIT**

**$\Gamma(\ell^+ \ell^-)/\Gamma_{\text{total}}$**   **$\Gamma_4/\Gamma$**

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

Our fit result assumes lepton universality.

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE (%) DOCUMENT ID  
**3.3658 ± 0.0023 OUR FIT**

**$\Gamma(\text{invisible})/\Gamma_{\text{total}}$**   **$\Gamma_5/\Gamma$**

See the data, the note, and the fit result for the partial width,  $\Gamma_5$ , above.

VALUE (%) DOCUMENT ID  
**20.000 ± 0.055 OUR FIT**

$\Gamma(\mu^+ \mu^-)/\Gamma(e^+ e^-)$   $\Gamma_2/\Gamma_1$

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE DOCUMENT ID  
**1.0009 ± 0.0028 OUR FIT**

$\Gamma(\tau^+ \tau^-)/\Gamma(e^+ e^-)$   $\Gamma_3/\Gamma_1$

This parameter is not directly used in the overall fit but is derived using the fit results; see the 'Note on the Z Boson.'

VALUE DOCUMENT ID  
**1.0019 ± 0.0032 OUR FIT**

$\Gamma((u\bar{u} + c\bar{c})/2)/\Gamma(\text{hadrons})$   $\Gamma_7/\Gamma_6$

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 ( $>5$  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.

VALUE DOCUMENT ID TECN COMMENT  
**0.145 ± 0.015 OUR AVERAGE**

0.160 ± 0.019 ± 0.019	36	ACKERSTAFF 97T	OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
0.137 <sup>+0.038</sup> <sub>-0.054</sub>	37	ABREU	95X DLPH	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
0.139 ± 0.026	38	ACTON	93F OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
0.137 ± 0.033	39	ADRIANI	93 L3	$E_{\text{cm}}^{ee} = 91.2$ GeV

<sup>36</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>37</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>38</sup> ACTON 93F use the LEP 92 value of  $\Gamma(\text{hadrons}) = 1740 \pm 12$  MeV and  $\alpha_s = 0.122^{+0.006}_{-0.005}$ .

<sup>39</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  $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$ .

$\Gamma((d\bar{d} + s\bar{s} + b\bar{b})/3)/\Gamma(\text{hadrons})$   $\Gamma_8/\Gamma_6$

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 ( $>5$  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.

VALUE DOCUMENT ID TECN COMMENT  
**0.237 ± 0.009 OUR AVERAGE**

0.230 ± 0.010 ± 0.010	40	ACKERSTAFF 97T	OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
0.243 <sup>+0.036</sup> <sub>-0.026</sub>	41	ABREU	95X DLPH	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
0.241 ± 0.017	42	ACTON	93F OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
0.243 ± 0.022	43	ADRIANI	93 L3	$E_{\text{cm}}^{ee} = 91.2$ GeV

- <sup>40</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>41</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>42</sup> ACTON 93F use the LEP 92 value of  $\Gamma(\text{hadrons}) = 1740 \pm 12$  MeV and  $\alpha_s = 0.122^{+0.006}_{-0.005}$ .
- <sup>43</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  $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$ .

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

$\Gamma_9/\Gamma_6$

OUR FIT is obtained by a simultaneous fit to several *c*- and *b*-quark measurements as explained in the "Note on the Z boson." As a cross check we have also performed a weighted average of the  $R_c$  measurements. Taking into account the various common systematic errors, we obtain  $R_c = 0.1679 \pm 0.0059$ .

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>0.1689±0.0047 OUR FIT</b>			
0.1665±0.0051±0.0081	44 ABREU	00 DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
0.1698±0.0069	45 BARATE	00B ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV
0.180 ±0.011 ±0.013	46 ACKERSTAFF	98E OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV
0.167 ±0.011 ±0.012	47 ALEXANDER	96R OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.1675±0.0062±0.0103	48 BARATE	98T ALEP	Repl. by BARATE 00B
0.1689±0.0095±0.0068	49 BARATE	98T ALEP	Repl. by BARATE 00B
0.1623±0.0085±0.0209	50 ABREU	95D DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
0.142 ±0.008 ±0.014	51 AKERS	95O OPAL	Repl. by ACKERSTAFF 98E
0.165 ±0.005 ±0.020	52 BUSKULIC	94G ALEP	Repl. by BARATE 00B

- <sup>44</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>45</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>46</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.

- 47 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.
- 48 BARATE 98T perform a simultaneous fit to the  $p$  and  $p_T$  spectra of electrons from hadronic  $Z$  decays. The semileptonic branching ratio  $B(c \rightarrow e)$  is taken as  $0.098 \pm 0.005$  and the systematic error includes an uncertainty of  $\pm 0.0084$  due to this.
- 49 BARATE 98T obtain this result combining two double-tagging techniques. Searching for a  $D$  meson in each hemisphere by full reconstruction in an exclusive decay mode gives  $R_c = 0.173 \pm 0.014 \pm 0.0009$ . The same tag in combination with inclusive identification using the slow pion from the  $D^{*+} \rightarrow D^0 \pi^+$  decay in the opposite hemisphere yields  $R_c = 0.166 \pm 0.012 \pm 0.009$ . The  $R_b$  dependence is given by  $R_c = 0.1689 - 0.023 \times (R_b - 0.2159)$ . The three measurements of BARATE 98T are combined with BUSKULIC 94G to give the average  $R_c = 0.1681 \pm 0.0054 \pm 0.0062$ .
- 50 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.
- 51 AKERS 95O use the presence of a  $D^{*\pm}$  to tag  $Z \rightarrow c\bar{c}$  with  $D^* \rightarrow D^0 \pi$  and  $D^0 \rightarrow K\pi$ . They measure  $P_c * \Gamma(c\bar{c}) / \Gamma(\text{hadrons})$  to be  $(1.006 \pm 0.055 \pm 0.061) \times 10^{-3}$ , where  $P_c$  is the product branching ratio  $B(c \rightarrow D^*)B(D^* \rightarrow D^0 \pi)B(D^0 \rightarrow K\pi)$ . Assuming that  $P_c$  remains unchanged with energy, they use its value  $(7.1 \pm 0.5) \times 10^{-3}$  determined at CESR/PETRA to obtain  $\Gamma(c\bar{c}) / \Gamma(\text{hadrons})$ . The second error of AKERS 95O includes an uncertainty of  $\pm 0.011$  from the uncertainty on  $P_c$ .
- 52 BUSKULIC 94G perform a simultaneous fit to the  $p$  and  $p_T$  spectra of both single and dilepton events.

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

$\Gamma_{10} / \Gamma_6$

OUR FIT is obtained by a simultaneous fit to several  $c$ - and  $b$ -quark measurements as explained in the "Note on the  $Z$  boson." As a cross check we have also performed a weighted average of the  $R_b$  measurements taking into account the various common systematic errors. For  $R_c = 0.1689$  (as given by OUR FIT above), we obtain  $R_b = 0.21622 \pm 0.00076$ . For an expected Standard Model value of  $R_c = 0.1723$ , our weighted average gives  $R_b = 0.21614 \pm 0.00076$ .

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

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.21643 ± 0.00072 OUR FIT</b>			
0.2174 ± 0.0015 ± 0.0028	53 ACCIARRI	00 L3	$E_{cm}^{ee} = 89-93$ GeV
0.2178 ± 0.0011 ± 0.0013	54 ABBIENDI	99B OPAL	$E_{cm}^{ee} = 88-94$ GeV
0.21634 ± 0.00067 ± 0.00060	55 ABREU	99B DLPH	$E_{cm}^{ee} = 88-94$ GeV
0.2142 ± 0.0034 ± 0.0015	56 ABE	98D SLD	$E_{cm}^{ee} = 91.2$ GeV
0.2159 ± 0.0009 ± 0.0011	57 BARATE	97F ALEP	$E_{cm}^{ee} = 88-94$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.2175 ± 0.0014 ± 0.0017	58 ACKERSTAFF	97K OPAL	Repl. by ABBIENDI 99B
0.2167 ± 0.0011 ± 0.0013	59 BARATE	97E ALEP	$E_{cm}^{ee} = 88-94$ GeV
0.229 ± 0.011	60 ABE	96E SLD	Repl. by ABE 98D
0.2216 ± 0.0016 ± 0.0021	61 ABREU	96 DLPH	Repl. by ABREU 99B
0.2145 ± 0.0089 ± 0.0067	62 ABREU	95D DLPH	$E_{cm}^{ee} = 88-94$ GeV
0.219 ± 0.006 ± 0.005	63 BUSKULIC	94G ALEP	$E_{cm}^{ee} = 88-94$ GeV
0.251 ± 0.049 ± 0.030	64 JACOBSEN	91 MRK2	$E_{cm}^{ee} = 91$ GeV

- 53 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.
- 54 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.
- 55 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  $-0.024 \times (R_c - 0.172)$ .
- 56 ABE 98D use a double tag based on 3D impact parameter with reconstruction of secondary vertices. The charm background is reduced by requiring the invariant mass at the secondary vertex to be above 2 GeV. The systematic error includes an uncertainty of  $\pm 0.0002$  due to the uncertainty on  $R_c$ .
- 57 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  $-0.019 \times (R_c - 0.172)$ .
- 58 ACKERSTAFF 97K use lepton and/or separated decay vertex to tag independently each hemisphere. Comparing the numbers of single- and double-tagged events, they determine the  $b$ -tagging efficiency directly from the data.
- 59 BARATE 97E combine a lifetime tag with a mass cut based on the mass difference between  $c$  hadrons and  $b$  hadrons. Included in BARATE 97F.
- 60 ABE 96E obtain this value by combining results from three different  $b$ -tagging methods (2D impact parameter, 3D impact parameter, and 3D displaced vertex).
- 61 ABREU 96 obtain this result combining several analyses (double lifetime tag, mixed tag and multivariate analysis). This value is obtained assuming  $R_c = \Gamma(c\bar{c})/\Gamma(\text{hadrons}) = 0.172$ . For a value of  $R_c$  different from this by an amount  $\Delta R_c$  the change in the value is given by  $-0.087 \cdot \Delta R_c$ .
- 62 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.
- 63 BUSKULIC 94G perform a simultaneous fit to the  $p$  and  $p_T$  spectra of both single and dilepton events.
- 64 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 ( $\pm 0.014$ ).

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

$\Gamma_{11}/\Gamma_6$

VALUE (units $10^{-4}$ )	DOCUMENT ID	TECN	COMMENT
<b><math>5.2 \pm 1.9</math></b> OUR AVERAGE			
$3.6 \pm 1.7 \pm 2.7$	65 ABBIENDI	01G OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV
$6.0 \pm 1.9 \pm 1.4$	66 ABREU	99U DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV

- 65 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.
- 66 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  $b\bar{b}$ .

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

$\Gamma_{12}/\Gamma_6$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<b><math>&lt; 1.6 \times 10^{-2}</math></b>	95	67 ABREU	96S DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV

- 67 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  $1.5 \times 10^{-2}$ .



$\Gamma(\pi^0\gamma)/\Gamma_{\text{total}}$   $\Gamma_{13}/\Gamma$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>&lt;5.2 × 10<sup>-5</sup></b>	95	<sup>68</sup> ACCIARRI	95G L3	$E_{\text{cm}}^{ee} = 88-94$ GeV
<5.5 × 10 <sup>-5</sup>	95	ABREU	94B DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
<2.1 × 10 <sup>-4</sup>	95	DECAMP	92 ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV
<1.4 × 10 <sup>-4</sup>	95	AKRAWY	91F OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>68</sup> This limit is for both decay modes  $Z \rightarrow \pi^0\gamma/\gamma\gamma$  which are indistinguishable in ACCIARRI 95G.

$\Gamma(\eta\gamma)/\Gamma_{\text{total}}$   $\Gamma_{14}/\Gamma$

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

$\Gamma(\omega\gamma)/\Gamma_{\text{total}}$   $\Gamma_{15}/\Gamma$

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

$\Gamma(\eta'(958)\gamma)/\Gamma_{\text{total}}$   $\Gamma_{16}/\Gamma$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>&lt;4.2 × 10<sup>-5</sup></b>	95	DECAMP	92 ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV

$\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_{17}/\Gamma$

This decay would violate the Landau-Yang theorem.

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>&lt;5.2 × 10<sup>-5</sup></b>	95	<sup>69</sup> ACCIARRI	95G L3	$E_{\text{cm}}^{ee} = 88-94$ GeV
<5.5 × 10 <sup>-5</sup>	95	ABREU	94B DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
<1.4 × 10 <sup>-4</sup>	95	AKRAWY	91F OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>69</sup> This limit is for both decay modes  $Z \rightarrow \pi^0\gamma/\gamma\gamma$  which are indistinguishable in ACCIARRI 95G.

$\Gamma(\gamma\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_{18}/\Gamma$

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>&lt;1.0 × 10<sup>-5</sup></b>	95	<sup>70</sup> ACCIARRI	95C L3	$E_{\text{cm}}^{ee} = 88-94$ GeV
<1.7 × 10 <sup>-5</sup>	95	<sup>70</sup> ABREU	94B DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
<6.6 × 10 <sup>-5</sup>	95	AKRAWY	91F OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>70</sup> Limit derived in the context of composite  $Z$  model.

$\Gamma(\pi^\pm W^\mp)/\Gamma_{\text{total}}$   $\Gamma_{19}/\Gamma$

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

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>&lt;7 × 10<sup>-5</sup></b>	95	DECAMP	92 ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV

**$\Gamma(\rho^\pm W^\mp)/\Gamma_{\text{total}}$**   **$\Gamma_{20}/\Gamma$**

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

<u>VALUE</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>&lt;8.3 \times 10^{-5}</math></b>	95	DECAMP	92 ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV

**$\Gamma(J/\psi(1S)X)/\Gamma_{\text{total}}$**   **$\Gamma_{21}/\Gamma$**

<u>VALUE (units <math>10^{-3}</math>)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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**$3.51^{+0.23}_{-0.25}$  OUR AVERAGE** Error includes scale factor of 1.1.

3.21 ± 0.21<sup>+0.19</sup><sub>-0.28</sub>      553      71 ACCIARRI      99F L3       $E_{\text{cm}}^{ee} = 88-94$  GeV

3.9 ± 0.2 ± 0.3      511      72 ALEXANDER      96B OPAL       $E_{\text{cm}}^{ee} = 88-94$  GeV

3.73 ± 0.39 ± 0.36      153      73 ABREU      94P DLPH       $E_{\text{cm}}^{ee} = 88-94$  GeV

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

3.40 ± 0.23 ± 0.27      441      74 ACCIARRI      97J L3      Repl. by ACCIARRI 99F

71 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  $(2.1 \pm 0.6 \pm 0.4^{+0.4}_{-0.2}(\text{theor.})) \times 10^{-4}$ .

72 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).

73 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.

74 ACCIARRI 97J combine  $\mu^+ \mu^-$  and  $e^+ e^- J/\psi(1S)$  decay channels and take into account the common systematic error.

**$\Gamma(\psi(2S)X)/\Gamma_{\text{total}}$**   **$\Gamma_{22}/\Gamma$**

<u>VALUE (units <math>10^{-3}</math>)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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**$1.60 \pm 0.29$  OUR AVERAGE**

1.6 ± 0.5 ± 0.3      39      75 ACCIARRI      97J L3       $E_{\text{cm}}^{ee} = 88-94$  GeV

1.6 ± 0.3 ± 0.2      46.9      76 ALEXANDER      96B OPAL       $E_{\text{cm}}^{ee} = 88-94$  GeV

1.60 ± 0.73 ± 0.33      5.4      77 ABREU      94P DLPH       $E_{\text{cm}}^{ee} = 88-94$  GeV

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

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

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

**$\Gamma(\chi_{c1}(1P)X)/\Gamma_{\text{total}}$**   **$\Gamma_{23}/\Gamma$**

<u>VALUE (units <math>10^{-3}</math>)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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**$2.9 \pm 0.7$  OUR AVERAGE**

2.7 ± 0.6 ± 0.5      33      78 ACCIARRI      97J L3       $E_{\text{cm}}^{ee} = 88-94$  GeV

5.0 ± 2.1<sup>+1.5</sup><sub>-0.9</sub>      6.4      79 ABREU      94P DLPH       $E_{\text{cm}}^{ee} = 88-94$  GeV

78 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  $\chi_{c2}$ .

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

$\Gamma(\chi_{c2}(1P)X)/\Gamma_{\text{total}}$   $\Gamma_{24}/\Gamma$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<3.2 \times 10^{-3}$	90	<sup>80</sup> ACCIARRI	97J L3	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>80</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  $\chi_{c2}$ .

$\Gamma(\Upsilon(1S)X + \Upsilon(2S)X + \Upsilon(3S)X)/\Gamma_{\text{total}}$   $\Gamma_{25}/\Gamma = (\Gamma_{26} + \Gamma_{27} + \Gamma_{28})/\Gamma$

VALUE (units $10^{-4}$ )	EVTS	DOCUMENT ID	TECN	COMMENT
$1.0 \pm 0.4 \pm 0.22$	6.4	<sup>81</sup> ALEXANDER	96F OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>81</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.

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<4.4 \times 10^{-5}$	95	<sup>82</sup> ACCIARRI	99F L3	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>82</sup> ACCIARRI 99F search for  $\Upsilon(1S)$  through its decay into  $\ell^+ \ell^-$  ( $\ell = e$  or  $\mu$ ).

$\Gamma(\Upsilon(2S)X)/\Gamma_{\text{total}}$   $\Gamma_{27}/\Gamma$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<13.9 \times 10^{-5}$	95	<sup>83</sup> ACCIARRI	97R L3	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>83</sup> ACCIARRI 97R search for  $\Upsilon(2S)$  through its decay into  $\ell^+ \ell^-$  ( $\ell = e$  or  $\mu$ ).

$\Gamma(\Upsilon(3S)X)/\Gamma_{\text{total}}$   $\Gamma_{28}/\Gamma$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<9.4 \times 10^{-5}$	95	<sup>84</sup> ACCIARRI	97R L3	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>84</sup> ACCIARRI 97R search for  $\Upsilon(3S)$  through its decay into  $\ell^+ \ell^-$  ( $\ell = e$  or  $\mu$ ).

$\Gamma((D^0/\bar{D}^0)X)/\Gamma(\text{hadrons})$   $\Gamma_{29}/\Gamma_6$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.296 \pm 0.019 \pm 0.021$	369	<sup>85</sup> ABREU	93i DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>85</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).

$\Gamma(D^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{30}/\Gamma_6$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$0.174 \pm 0.016 \pm 0.018$	539	<sup>86</sup> ABREU	93i DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>86</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).

$\Gamma(D^*(2010)^\pm X)/\Gamma(\text{hadrons})$   $\Gamma_{31}/\Gamma_6$

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

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b><math>0.163 \pm 0.019</math> OUR AVERAGE</b>		Error includes scale factor of 1.3.		
$0.155 \pm 0.010 \pm 0.013$	358	<sup>87</sup> ABREU	93i DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
$0.21 \pm 0.04$	362	<sup>88</sup> DECAMP	91J ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>87</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>88</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  $B(D^*(2010)^+ \rightarrow D^0\pi^+) = (68.1 \pm 1.6)\%$ .

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

$\Gamma_{32} / \Gamma_6$

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

VALUE (%)	EVTS	DOCUMENT ID	TECN	COMMENT
<b><math>0.52 \pm 0.09 \pm 0.06</math></b>	92	<sup>89</sup> HEISTER	02B ALEP	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>89</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.

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

$\Gamma_{33} / \Gamma_6$

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

VALUE (%)	EVTS	DOCUMENT ID	TECN	COMMENT
<b><math>0.83 \pm 0.29^{+0.07}_{-0.13}</math></b>	64	<sup>90</sup> HEISTER	02B ALEP	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>90</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.

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

$\Gamma_{34} / \Gamma_6$

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

VALUE	DOCUMENT ID	TECN	COMMENT
<b>searched for</b>	<sup>91</sup> ABBIENDI	01N OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>91</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  $Z \rightarrow D^{*'}(2629)^\pm \times B(D^{*'}(2629)^\pm \rightarrow D^{*+} \pi^+ \pi^-) < 3.1 \times 10^{-3}$ .

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

$\Gamma_{37} / \Gamma_6$

VALUE	DOCUMENT ID	TECN	COMMENT
seen	<sup>92</sup> ABREU	92M DLPH	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
seen	<sup>93</sup> ACTON	92N OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV
seen	<sup>94</sup> BUSKULIC	92E ALEP	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

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

<sup>93</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>94</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  $B(\bar{b} \rightarrow B_S^0) \times B(B_S^0 \rightarrow D_S^- \ell^+ \nu_\ell X) = 0.040 \pm 0.011^{+0.010}_{-0.012}$ .

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

$\Gamma_{38}/\Gamma_6$

VALUE	DOCUMENT ID	TECN	COMMENT
searched for	95 ACKERSTAFF 98O	OPAL	$E_{cm}^{ee} = 88-94$ GeV
searched for	96 ABREU	97E DLPH	$E_{cm}^{ee} = 88-94$ GeV
searched for	97 BARATE	97H ALEP	$E_{cm}^{ee} = 88-94$ GeV

95 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  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) = (3.8^{+5.0}_{-2.4} \pm 0.5) \times 10^{-5}$ . Interpreted as background, the 90% CL bounds are  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) < 1.06 \times 10^{-4}$ ,  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi a_1^+)/\Gamma(\text{hadrons}) < 5.29 \times 10^{-4}$ ,  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 6.96 \times 10^{-5}$ .

96 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:  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}$ ,  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < (5.8-5.0) \times 10^{-5}$ ,  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi (3\pi)^+)/\Gamma(\text{hadrons}) < 1.75 \times 10^{-4}$ , where the ranges are due to the predicted  $B_C$  lifetime (0.4-1.4) ps.

97 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:  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \pi^+)/\Gamma(\text{hadrons}) < 3.6 \times 10^{-5}$  and  $\Gamma(B_C^+ X) \times B(B_C \rightarrow J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 5.2 \times 10^{-5}$ .

### $\Gamma(B^* X)/[\Gamma(BX) + \Gamma(B^* X)]$

$\Gamma_{36}/(\Gamma_{35} + \Gamma_{36})$

As the experiments assume different values of the  $b$ -baryon contribution, our average should be taken with caution. If we assume a common baryon production fraction of  $(11.8 \pm 2.0)\%$  as given in the 2002 edition of this Review OUR AVERAGE becomes  $0.75 \pm 0.04$ .

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b>0.75 ± 0.04 OUR AVERAGE</b>				
0.760 ± 0.036 ± 0.083		98 ACKERSTAFF 97M	OPAL	$E_{cm}^{ee} = 88-94$ GeV
0.771 ± 0.026 ± 0.070		99 BUSKULIC	96D ALEP	$E_{cm}^{ee} = 88-94$ GeV
0.72 ± 0.03 ± 0.06		100 ABREU	95R DLPH	$E_{cm}^{ee} = 88-94$ GeV
0.76 ± 0.08 ± 0.06	1378	101 ACCIARRI	95B L3	$E_{cm}^{ee} = 88-94$ GeV

98 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  $B_s$ .

99 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>100</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>101</sup> ACCIARRI 95B assume a 9.4%  $b$ -baryon contribution. The value refers to a  $b$ -flavored mixture of  $B_u$ ,  $B_d$ , and  $B_s$ .

**$\Gamma(\text{anomalous } \gamma + \text{hadrons})/\Gamma_{\text{total}}$**   **$\Gamma_{39}/\Gamma$**   
 Limits on additional sources of prompt photons beyond expectations for final-state bremsstrahlung.

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<3.2 \times 10^{-3}$	95	<sup>102</sup> AKRAWY	90J OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>102</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.

**$\Gamma(e^+ e^- \gamma)/\Gamma_{\text{total}}$**   **$\Gamma_{40}/\Gamma$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<5.2 \times 10^{-4}$	95	<sup>103</sup> ACTON	91B OPAL	$E_{\text{cm}}^{ee} = 91.2$ GeV

<sup>103</sup> ACTON 91B looked for isolated photons with  $E > 2\%$  of beam energy ( $> 0.9$  GeV).

**$\Gamma(\mu^+ \mu^- \gamma)/\Gamma_{\text{total}}$**   **$\Gamma_{41}/\Gamma$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<5.6 \times 10^{-4}$	95	<sup>104</sup> ACTON	91B OPAL	$E_{\text{cm}}^{ee} = 91.2$ GeV

<sup>104</sup> ACTON 91B looked for isolated photons with  $E > 2\%$  of beam energy ( $> 0.9$  GeV).

**$\Gamma(\tau^+ \tau^- \gamma)/\Gamma_{\text{total}}$**   **$\Gamma_{42}/\Gamma$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<7.3 \times 10^{-4}$	95	<sup>105</sup> ACTON	91B OPAL	$E_{\text{cm}}^{ee} = 91.2$ GeV

<sup>105</sup> ACTON 91B looked for isolated photons with  $E > 2\%$  of beam energy ( $> 0.9$  GeV).

**$\Gamma(\ell^+ \ell^- \gamma \gamma)/\Gamma_{\text{total}}$**   **$\Gamma_{43}/\Gamma$**

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<6.8 \times 10^{-6}$	95	<sup>106</sup> ACTON	93E OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>106</sup> For  $m_{\gamma\gamma} = 60 \pm 5$  GeV.

**$\Gamma(q \bar{q} \gamma \gamma)/\Gamma_{\text{total}}$**   **$\Gamma_{44}/\Gamma$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<5.5 \times 10^{-6}$	95	<sup>107</sup> ACTON	93E OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>107</sup> For  $m_{\gamma\gamma} = 60 \pm 5$  GeV.

**$\Gamma(\nu \bar{\nu} \gamma \gamma)/\Gamma_{\text{total}}$**   **$\Gamma_{45}/\Gamma$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<3.1 \times 10^{-6}$	95	<sup>108</sup> ACTON	93E OPAL	$E_{\text{cm}}^{ee} = 88\text{--}94$ GeV

<sup>108</sup> For  $m_{\gamma\gamma} = 60 \pm 5$  GeV.

**$\Gamma(e^\pm \mu^\mp)/\Gamma(e^+ e^-)$**   **$\Gamma_{46}/\Gamma_1$**

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	$E_{\text{cm}}^{P\bar{P}} = 546,630$ GeV

$\Gamma(e^\pm \mu^\mp)/\Gamma_{\text{total}}$   $\Gamma_{46}/\Gamma$

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<2.5 \times 10^{-6}$	95	ABREU	97C DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
<b><math>&lt;1.7 \times 10^{-6}</math></b>	95	AKERS	95W OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV
$<0.6 \times 10^{-5}$	95	ADRIANI	93I L3	$E_{\text{cm}}^{ee} = 88-94$ GeV
$<2.6 \times 10^{-5}$	95	DECAMP	92 ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV

$\Gamma(e^\pm \tau^\mp)/\Gamma_{\text{total}}$   $\Gamma_{47}/\Gamma$

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

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<2.2 \times 10^{-5}$	95	ABREU	97C DLPH	$E_{\text{cm}}^{ee} = 88-94$ GeV
<b><math>&lt;9.8 \times 10^{-6}</math></b>	95	AKERS	95W OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV
$<1.3 \times 10^{-5}$	95	ADRIANI	93I L3	$E_{\text{cm}}^{ee} = 88-94$ GeV
$<1.2 \times 10^{-4}$	95	DECAMP	92 ALEP	$E_{\text{cm}}^{ee} = 88-94$ GeV

$\Gamma(\mu^\pm \tau^\mp)/\Gamma_{\text{total}}$   $\Gamma_{48}/\Gamma$

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

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

$\Gamma(pe)/\Gamma_{\text{total}}$   $\Gamma_{49}/\Gamma$

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>109</sup> ABBIENDI	99I OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>109</sup> ABBIENDI 99I give the 95%CL limit on the partial width  $\Gamma(Z^0 \rightarrow pe) < 4.6$  KeV and we have transformed it into a branching ratio.

$\Gamma(p\mu)/\Gamma_{\text{total}}$   $\Gamma_{50}/\Gamma$

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>110</sup> ABBIENDI	99I OPAL	$E_{\text{cm}}^{ee} = 88-94$ GeV

<sup>110</sup> ABBIENDI 99I give the 95%CL limit on the partial width  $\Gamma(Z^0 \rightarrow p\mu) < 4.4$  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	$E_{\text{cm}}^{ee} = 91.2$ GeV

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

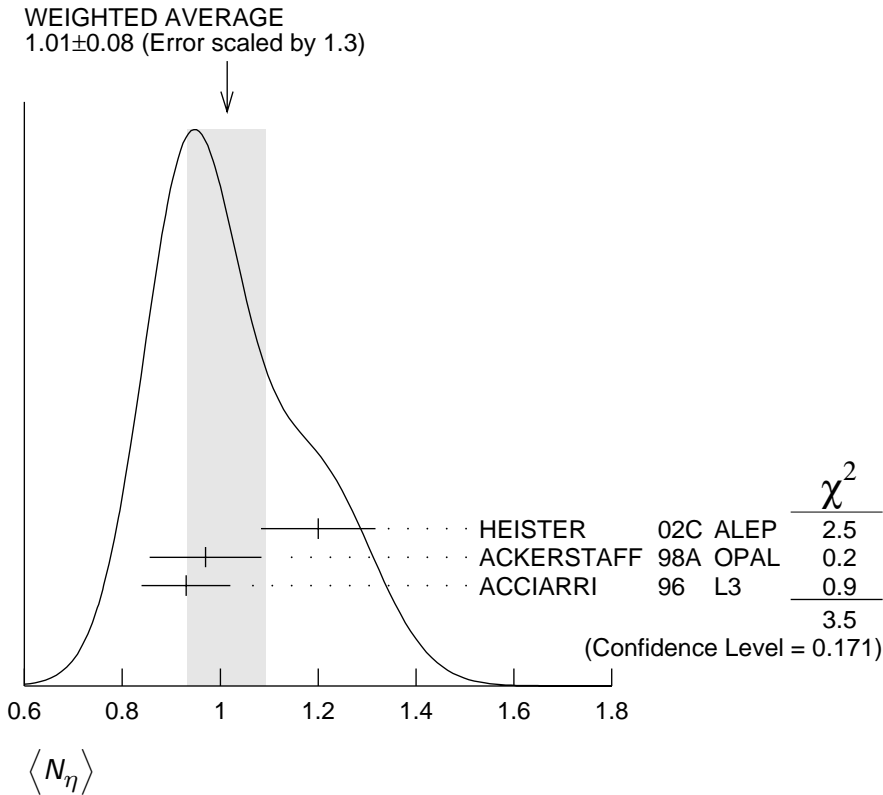
VALUE	DOCUMENT ID	TECN	COMMENT
<b>16.99±0.20 OUR AVERAGE</b>			
16.84±0.37	ABE	99E SLD	$E_{cm}^{ee} = 91.2$ GeV
17.26±0.10±0.88	ABREU	98L DLPH	$E_{cm}^{ee} = 91.2$ GeV
17.04±0.31	BARATE	98V ALEP	$E_{cm}^{ee} = 91.2$ GeV
17.05±0.43	AKERS	94P OPAL	$E_{cm}^{ee} = 91.2$ GeV

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

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

$\langle N_\eta \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
<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>2.40 ± 0.06 ± 0.43</b>	ACKERSTAFF 98A	OPAL	$E_{cm}^{ee} = 91.2$ GeV

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

<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	$E_{cm}^{ee} = 91.2$ GeV
1.04 ± 0.04 ± 0.14	ACKERSTAFF 98A	OPAL	$E_{cm}^{ee} = 91.2$ GeV
1.17 ± 0.09 ± 0.15	ACCIARRI	97D L3	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ GeV
0.25 ± 0.04	<sup>111</sup> ACCIARRI	97D L3	$E_{cm}^{ee} = 91.2$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.068 ± 0.018 ± 0.016	<sup>112</sup> BUSKULIC	92D ALEP	$E_{cm}^{ee} = 91.2$ GeV

<sup>111</sup>ACCIARRI 97D obtain this value averaging over the two decay channels  $\eta' \rightarrow \pi^+ \pi^- \eta$  and  $\eta' \rightarrow \rho^0 \gamma$ .

<sup>112</sup>BUSKULIC 92D obtain this value for  $x > 0.1$ .

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

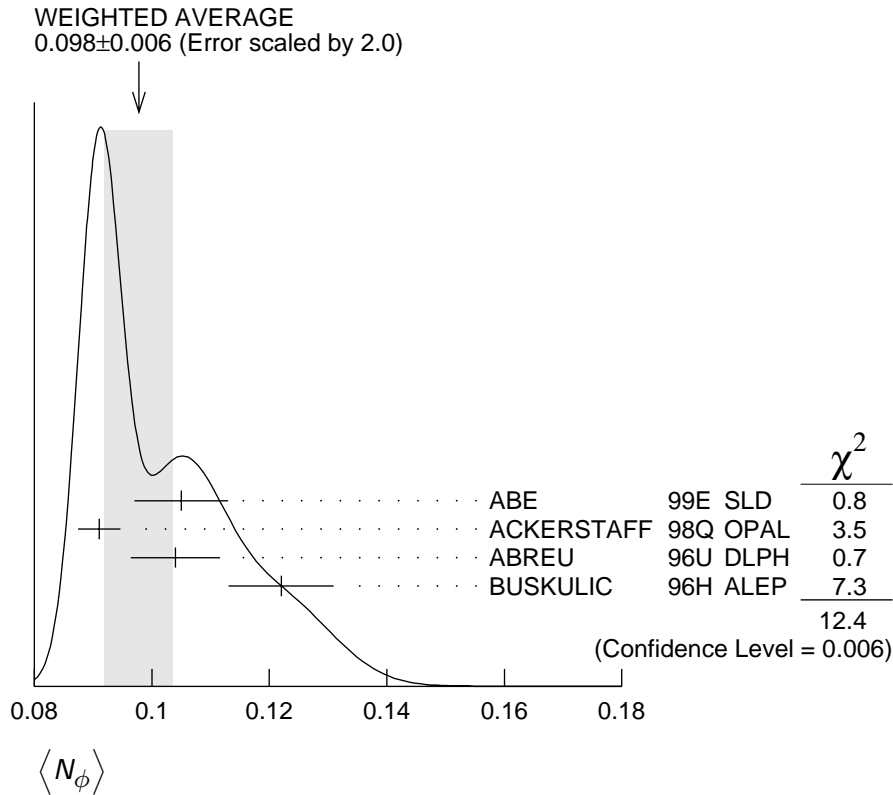
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.147 ± 0.011 OUR AVERAGE</b>			
0.164 ± 0.021	ABREU	99J DLPH	$E_{cm}^{ee} = 91.2$ GeV
0.141 ± 0.007 ± 0.011	ACKERSTAFF 98Q	OPAL	$E_{cm}^{ee} = 91.2$ GeV

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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.27 ± 0.04 ± 0.10</b>	ACKERSTAFF 98A	OPAL	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ GeV
0.091 ± 0.002 ± 0.003	ACKERSTAFF 98Q	OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.104 ± 0.003 ± 0.007	ABREU	96U DLPH	$E_{cm}^{ee} = 91.2$ GeV
0.122 ± 0.004 ± 0.008	BUSKULIC	96H ALEP	$E_{cm}^{ee} = 91.2$ 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>113</sup> ABDALLAH 03H DLPH		$E_{cm}^{ee} = 91.2$ GeV
	<sup>113</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>114</sup> ABDALLAH 03H DLPH		$E_{cm}^{ee} = 91.2$ GeV
	<sup>114</sup> ABDALLAH 03H		assume a $K\bar{K}\pi$ branching ratio of 100%.

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

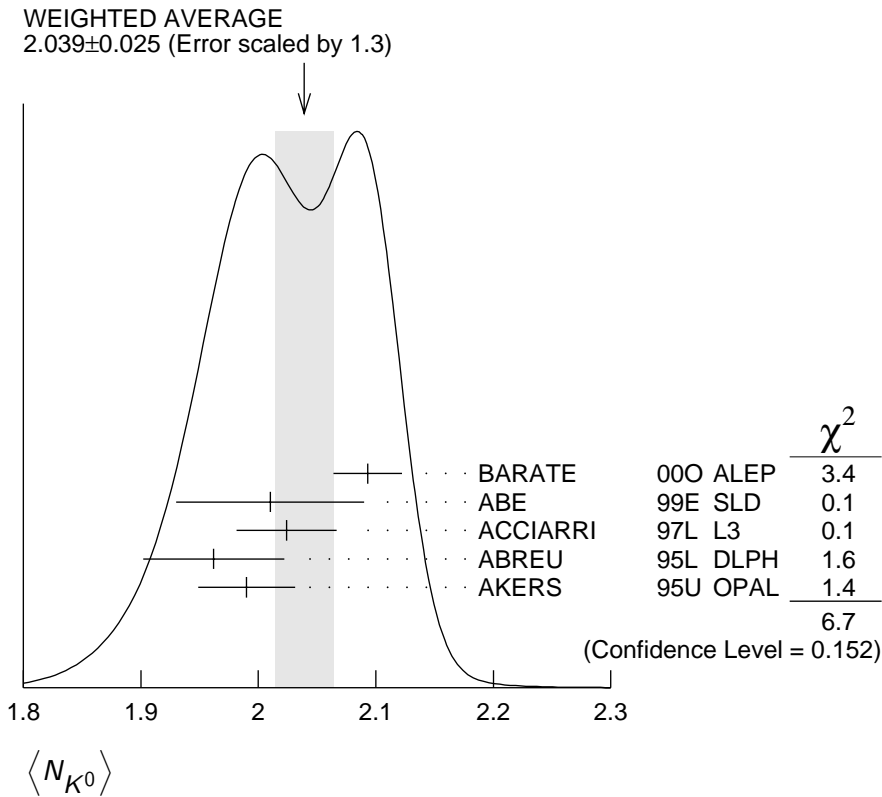
VALUE	DOCUMENT ID	TECN	COMMENT
<b><math>0.012 \pm 0.006</math></b>	ABREU 99J DLPH		$E_{cm}^{ee} = 91.2$ GeV

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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>2.25 ± 0.05 OUR AVERAGE</b>			
2.22 ± 0.16	ABE	99E 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

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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<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	00O 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



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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<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. • • •

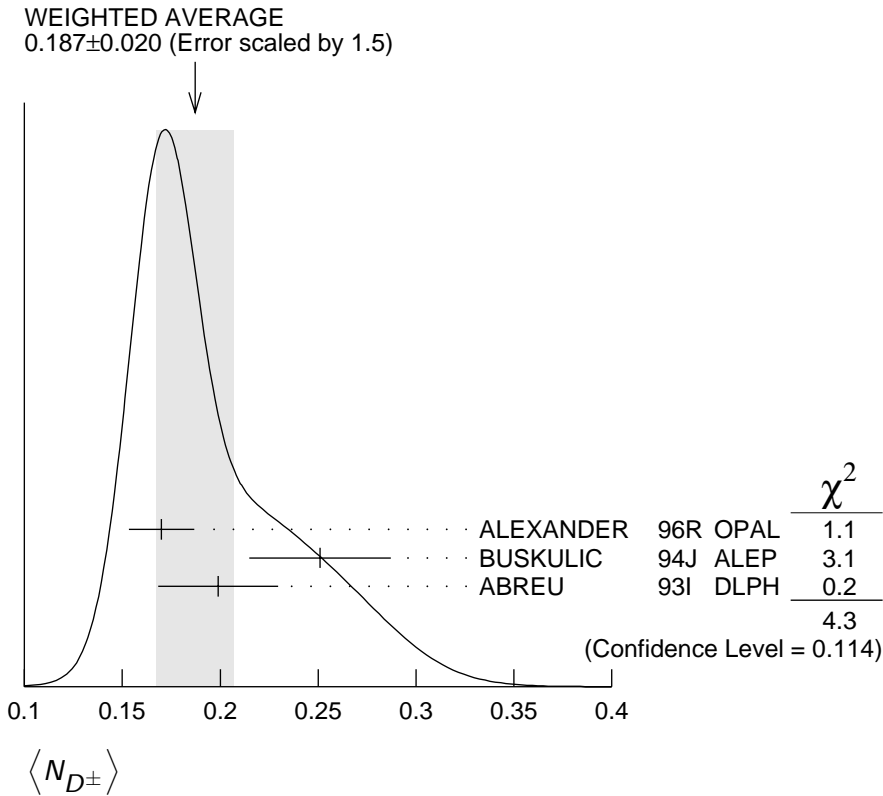
0.19 ±0.04 ±0.06	<sup>115</sup> AKERS	95X OPAL	$E_{cm}^{ee} = 91.2$ GeV
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<sup>115</sup> AKERS 95X obtain this value for  $x < 0.3$ .

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

<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>116</sup> ABREU	93I DLPH	$E_{cm}^{ee} = 91.2$ GeV

<sup>116</sup> See ABREU 95 (erratum).



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

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.462 ± 0.026 OUR AVERAGE</b>			
0.465 ± 0.017 ± 0.027	ALEXANDER	96R OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.518 ± 0.052 ± 0.035	BUSKULIC	94J ALEP	$E_{cm}^{ee} = 91.2$ GeV
0.403 ± 0.038 ± 0.044	<sup>117</sup> ABREU	93i DLPH	$E_{cm}^{ee} = 91.2$ GeV

<sup>117</sup> See ABREU 95 (erratum).

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

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.131 ± 0.010 ± 0.018</b>	ALEXANDER	96R OPAL	$E_{cm}^{ee} = 91.2$ GeV

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

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.183 ± 0.008 OUR AVERAGE</b>			
0.1854 ± 0.0041 ± 0.0091	<sup>118</sup> ACKERSTAFF	98E OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.187 ± 0.015 ± 0.013	BUSKULIC	94J ALEP	$E_{cm}^{ee} = 91.2$ GeV
0.171 ± 0.012 ± 0.016	<sup>119</sup> ABREU	93i DLPH	$E_{cm}^{ee} = 91.2$ GeV

<sup>118</sup> ACKERSTAFF 98E systematic error includes an uncertainty of ±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>119</sup> See ABREU 95 (erratum).

$\langle N_{D_{s1}(2536)^+} \rangle$

VALUE (units $10^{-3}$ )	DOCUMENT ID	TECN	COMMENT
<b>• • • We do not use the following data for averages, fits, limits, etc. • • •</b>			
$2.9^{+0.7}_{-0.6} \pm 0.2$	<sup>120</sup> ACKERSTAFF	97W OPAL	$E_{cm}^{ee} = 91.2$ GeV

<sup>120</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.

$\langle N_{B^*} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.28 ± 0.01 ± 0.03</b>	<sup>121</sup> ABREU	95R DLPH	$E_{cm}^{ee} = 91.2$ GeV

<sup>121</sup> ABREU 95R quote this value for a flavor-averaged excited state.

$\langle N_{J/\psi(1S)} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.0056 ± 0.0003 ± 0.0004</b>	<sup>122</sup> ALEXANDER	96B OPAL	$E_{cm}^{ee} = 91.2$ GeV

<sup>122</sup> ALEXANDER 96B identify  $J/\psi(1S)$  from the decays into lepton pairs.

$\langle N_{\psi(2S)} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.0023 ± 0.0004 ± 0.0003</b>	ALEXANDER	96B OPAL	$E_{cm}^{ee} = 91.2$ GeV

$\langle N_p \rangle$

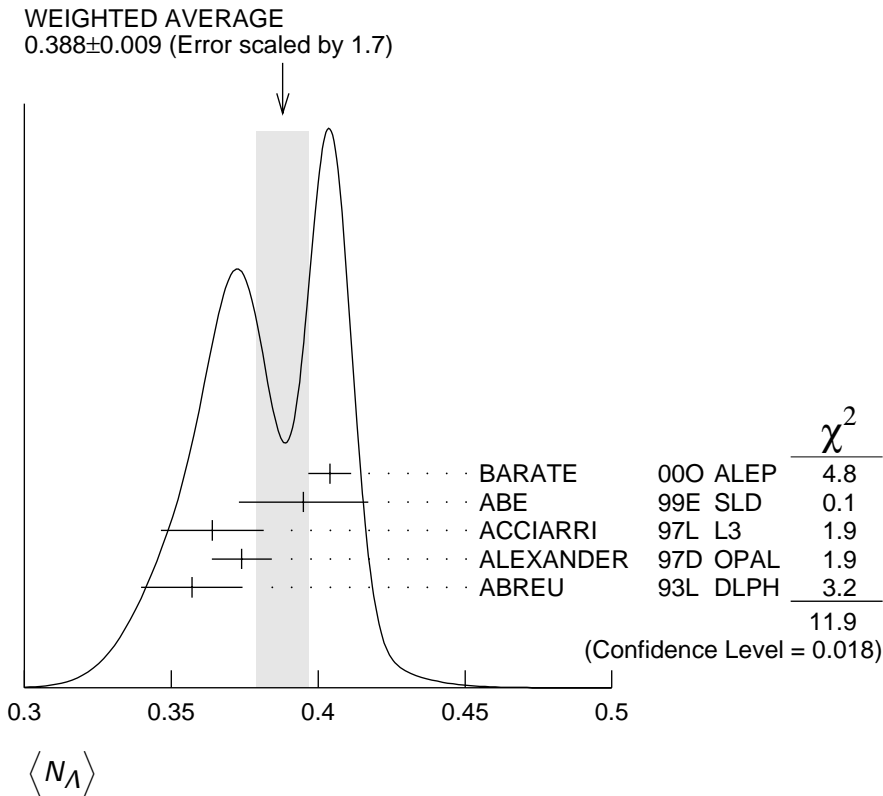
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1.04 ± 0.04 OUR AVERAGE</b>			
1.03 ± 0.13	ABE	99E SLD	$E_{cm}^{ee} = 91.2$ GeV
1.08 ± 0.04 ± 0.03	ABREU	98L DLPH	$E_{cm}^{ee} = 91.2$ GeV
1.00 ± 0.07	BARATE	98V ALEP	$E_{cm}^{ee} = 91.2$ GeV
0.92 ± 0.11	AKERS	94P OPAL	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ GeV
0.0213 ± 0.0021 ± 0.0019	ALEXANDER	97D OPAL	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ GeV
0.099 ± 0.008 ± 0.013	ALEXANDER	97E OPAL	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ GeV
0.083 ± 0.006 ± 0.009	ALEXANDER	97E OPAL	$E_{cm}^{ee} = 91.2$ 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>123</sup> ALEXANDER	97E OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.170 ± 0.014 ± 0.061	ABREU	95O DLPH	$E_{cm}^{ee} = 91.2$ GeV

<sup>123</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	$E_{cm}^{ee} = 91.2$ GeV
0.071 ± 0.012 ± 0.013	ALEXANDER	97E OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.070 ± 0.010 ± 0.010	ADAM	96B DLPH	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ 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	$E_{cm}^{ee} = 91.2$ 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>			
0.0259 ± 0.0004 ± 0.0009	ALEXANDER	97D OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.0250 ± 0.0009 ± 0.0021	ABREU	95O DLPH	$E_{cm}^{ee} = 91.2$ GeV

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

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.0053 ± 0.0013 OUR AVERAGE</b>	Error includes scale factor of 3.2.		
0.0068 ± 0.0005 ± 0.0004	ALEXANDER	97D OPAL	$E_{cm}^{ee} = 91.2$ GeV
0.0041 ± 0.0004 ± 0.0004	ABREU	95O DLPH	$E_{cm}^{ee} = 91.2$ 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

$\langle N_{charged} \rangle$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>21.07 ± 0.11 OUR AVERAGE</b>			
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 on the Z boson"). 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.

<u>VALUE (nb)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>41.541±0.037 OUR FIT</b>				
41.501±0.055	4.10M	<sup>124</sup> ABBIENDI	01A OPAL	$E_{cm}^{ee} = 88-94$ GeV
41.578±0.069	3.70M	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
41.535±0.055	3.54M	ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
41.559±0.058	4.07M	<sup>125</sup> BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
41.23 ±0.20	1.05M	ABREU	94 DLPH	Repl. by ABREU 00F
41.39 ±0.26	1.09M	ACCIARRI	94 L3	Repl. by ACCIARRI 00C
41.70 ±0.23	1.19M	AKERS	94 OPAL	Repl. by ABBIENDI 01A
41.60 ±0.16	1.27M	BUSKULIC	94 ALEP	Repl. by BARATE 00C
42 ±4	450	ABRAMS	89B MRK2	$E_{cm}^{ee} = 89.2-93.0$ GeV
<sup>124</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>125</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 TO CHARGED LEPTONS

These quantities are the effective vector couplings of the  $Z$  to charged leptons. 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). The 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 "Note on the  $Z$  boson" for details.

$g_V^e$				
<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>-0.03816±0.00047 OUR FIT</b>				
-0.0346 ±0.0023	137.0K	<sup>126</sup> ABBIENDI	010 OPAL	$E_{cm}^{ee} = 88-94$ GeV
-0.0412 ±0.0027	124.4k	<sup>127</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
-0.0400 ±0.0037		BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
-0.0414 ±0.0020		<sup>128</sup> ABE	95J SLD	$E_{cm}^{ee} = 91.31$ GeV
<sup>126</sup> ABBIENDI 010 use their measurement of the $\tau$ polarization in addition to the lineshape and forward-backward lepton asymmetries.				
<sup>127</sup> ACCIARRI 00C use their measurement of the $\tau$ polarization in addition to forward-backward lepton asymmetries.				
<sup>128</sup> ABE 95J obtain this result combining polarized Bhabha results with the $A_{LR}$ measurement of ABE 94C. The Bhabha results alone give $-0.0507 \pm 0.0096 \pm 0.0020$ .				

### $g_V^\mu$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
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**-0.0367 ± 0.0023 OUR FIT**

-0.0388 <sup>+0.0060</sup> <sub>-0.0064</sub>	182.8K	<sup>129</sup> ABBIENDI	01O OPAL	$E_{cm}^{ee} = 88-94$ GeV
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-0.0386 ± 0.0073	113.4k	<sup>130</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
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-0.0362 ± 0.0061		BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
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• • • We do not use the following data for averages, fits, limits, etc. • • •

-0.0413 ± 0.0060	66143	<sup>131</sup> ABBIENDI	01K OPAL	$E_{cm}^{ee} = 89-93$ GeV
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<sup>129</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>130</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

<sup>131</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
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**-0.0366 ± 0.0010 OUR FIT**

-0.0365 ± 0.0023	151.5K	<sup>132</sup> ABBIENDI	01O OPAL	$E_{cm}^{ee} = 88-94$ GeV
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-0.0384 ± 0.0026	103.0k	<sup>133</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
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-0.0361 ± 0.0068		BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
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<sup>132</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>133</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
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**-0.03783 ± 0.00041 OUR FIT**

-0.0358 ± 0.0014	471.3K	<sup>134</sup> ABBIENDI	01O OPAL	$E_{cm}^{ee} = 88-94$ GeV
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-0.0397 ± 0.0020	379.4k	<sup>135</sup> ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
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-0.0397 ± 0.0017	340.8k	<sup>136</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
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-0.0383 ± 0.0018	500k	BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
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<sup>134</sup> ABBIENDI 01O use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>135</sup> Using forward-backward lepton asymmetries.

<sup>136</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

## Z AXIAL-VECTOR COUPLINGS TO CHARGED LEPTONS

These quantities are the effective axial-vector couplings of the  $Z$  to charged leptons. 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).

The 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 "Note on the Z boson" for details.

### $g_A^e$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b>-0.50111 ± 0.00035 OUR FIT</b>				
-0.50062 ± 0.00062	137.0K	<sup>137</sup> ABBIENDI	010 OPAL	$E_{cm}^{ee} = 88-94$ GeV
-0.5015 ± 0.0007	124.4k	<sup>138</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
-0.50166 ± 0.00057		BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV
-0.4977 ± 0.0045		<sup>139</sup> ABE	95J SLD	$E_{cm}^{ee} = 91.31$ GeV

<sup>137</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>138</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

<sup>139</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>140</sup> ABBIENDI	010 OPAL	$E_{cm}^{ee} = 88-94$ GeV
-0.5009 ± 0.0014	113.4k	<sup>141</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
-0.50046 ± 0.00093		BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

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

-0.520 ± 0.015      66143      <sup>142</sup> ABBIENDI      01K OPAL       $E_{cm}^{ee} = 89-93$  GeV

<sup>140</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>141</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

<sup>142</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>143</sup> ABBIENDI	010 OPAL	$E_{cm}^{ee} = 88-94$ GeV
-0.5023 ± 0.0017	103.0k	<sup>144</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
-0.50216 ± 0.00100		BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

<sup>143</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>144</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><math>-0.50123 \pm 0.00026</math></b>				<b>OUR FIT</b>
$-0.50089 \pm 0.00045$	471.3K	<sup>145</sup> ABBIENDI	010 OPAL	$E_{cm}^{ee} = 88-94$ GeV
$-0.5007 \pm 0.0005$	379.4k	ABREU	00F DLPH	$E_{cm}^{ee} = 88-94$ GeV
$-0.50153 \pm 0.00053$	340.8k	<sup>146</sup> ACCIARRI	00C L3	$E_{cm}^{ee} = 88-94$ GeV
$-0.50150 \pm 0.00046$	500k	BARATE	00C ALEP	$E_{cm}^{ee} = 88-94$ GeV

<sup>145</sup> ABBIENDI 010 use their measurement of the  $\tau$  polarization in addition to the lineshape and forward-backward lepton asymmetries.

<sup>146</sup> ACCIARRI 00C use their measurement of the  $\tau$  polarization in addition to forward-backward lepton asymmetries.

## Z COUPLINGS TO NEUTRAL LEPTONS

These quantities are the effective couplings of the  $Z$  to neutral leptons.  $\nu_e e$  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.

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

VALUE	DOCUMENT ID	TECN	COMMENT
<b><math>0.528 \pm 0.085</math></b>	<sup>147</sup> VILAIN	94 CHM2	From $\nu_\mu e$ and $\nu_e e$ scattering

<sup>147</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><math>0.502 \pm 0.017</math></b>	<sup>148</sup> VILAIN	94 CHM2	From $\nu_\mu e$ scattering

<sup>148</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 on the  $Z$  Boson.'

### $A_e$

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>149</sup> ABBIENDI	01O OPAL	$E_{cm}^{ee} = 88-94$ GeV
0.1516 ± 0.0021	559000	<sup>150</sup> ABE	01B SLD	$E_{cm}^{ee} = 91.24$ GeV
0.1504 ± 0.0068 ± 0.0008		<sup>151</sup> HEISTER	01 ALEP	$E_{cm}^{ee} = 88-94$ GeV
0.1382 ± 0.0116 ± 0.0005	105000	<sup>152</sup> ABREU	00E DLPH	$E_{cm}^{ee} = 88-94$ GeV
0.1678 ± 0.0127 ± 0.0030	137092	<sup>153</sup> ACCIARRI	98H L3	$E_{cm}^{ee} = 88-94$ GeV
0.162 ± 0.041 ± 0.014	89838	<sup>154</sup> ABE	97 SLD	$E_{cm}^{ee} = 91.27$ GeV
0.202 ± 0.038 ± 0.008		<sup>155</sup> ABE	95J SLD	$E_{cm}^{ee} = 91.31$ GeV

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

0.15138 ± 0.00216	537000	<sup>156</sup> ABE	00B SLD	Repl. by ABE 01B
0.152 ± 0.012	4527	<sup>157</sup> ABE	97N SLD	Repl. by ABE 01B
0.129 ± 0.014 ± 0.005	89075	<sup>158</sup> ALEXANDER	96U OPAL	Repl. by ABBI- ENDI 01O
0.136 ± 0.027 ± 0.003		<sup>153</sup> ABREU	95I DLPH	Repl. by ABREU 00E
0.129 ± 0.016 ± 0.005	33000	<sup>159</sup> BUSKULIC	95Q ALEP	Repl. by HEIS- TER 01
0.157 ± 0.020 ± 0.005	86000	<sup>153</sup> ACCIARRI	94E L3	Repl. by ACCIA- RRI 98H

<sup>149</sup> ABBIENDI 01O 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>150</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>151</sup> HEISTER 01 obtain this result fitting the  $\tau$  polarization as a function of the polar production angle of the  $\tau$ .

<sup>152</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>153</sup> Derived from the measurement of forward-backward  $\tau$  polarization asymmetry.

<sup>154</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>155</sup> ABE 95J obtain this result from polarized Bhabha scattering.

<sup>156</sup> ABE 00B obtain this value measuring the left-right  $Z$  boson cross-section asymmetry. This is equivalent to an effective weak mixing angle of  $\sin^2 \theta_W^{\text{eff}} = 0.23097 \pm 0.00027$ .

<sup>157</sup> ABE 97N obtain this direct measurement using the left-right cross section asymmetry and the left-right forward-backward asymmetry in leptonic decays of the  $Z$  boson obtained with a polarized electron beam.

<sup>158</sup> ALEXANDER 96U measure the  $\tau$ -lepton polarization and the forward-backward polarization asymmetry.

<sup>159</sup> BUSKULIC 95Q obtain this result fitting the  $\tau$  polarization as a function of the polar  $\tau$  production angle.

## $A_\mu$

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>160</sup> ABE	01B SLD	$E_{cm}^{ee} = 91.24$ GeV

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

0.102±0.034	3788	<sup>161</sup> ABE	97N SLD	Repl. by ABE 01B
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<sup>160</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>161</sup> ABE 97N obtain this direct measurement using the left-right cross section asymmetry and the left-right forward-backward asymmetry in  $\mu^+\mu^-$  decays of the  $Z$  boson obtained with a polarized electron beam.

## $A_\tau$

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>162</sup> ABBIENDI	010 OPAL	$E_{cm}^{ee} = 88-94$ GeV
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0.136 ±0.015	16083	<sup>163</sup> ABE	01B SLD	$E_{cm}^{ee} = 91.24$ GeV
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0.1451±0.0052±0.0029		<sup>164</sup> HEISTER	01 ALEP	$E_{cm}^{ee} = 88-94$ GeV
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0.1359±0.0079±0.0055	105000	<sup>165</sup> ABREU	00E DLPH	$E_{cm}^{ee} = 88-94$ GeV
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0.1476±0.0088±0.0062	137092	ACCIARRI	98H L3	$E_{cm}^{ee} = 88-94$ GeV
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• • • We do not use the following data for averages, fits, limits, etc. • • •

0.195 ±0.034	3748	<sup>166</sup> ABE	97N SLD	Repl. by ABE 01B
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0.134 ±0.009 ±0.010	89075	<sup>167</sup> ALEXANDER	96U OPAL	Repl. by ABBI- ENDI 010
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0.148 ±0.017 ±0.014		ABREU	95I DLPH	Repl. by ABREU 00E
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0.136 ±0.012 ±0.009	33000	<sup>168</sup> BUSKULIC	95Q ALEP	Repl. by HEIS- TER 01
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0.150 ±0.013 ±0.009	86000	ACCIARRI	94E L3	Repl. by ACCIA- RRI 98H
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<sup>162</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>163</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>164</sup> HEISTER 01 obtain this result fitting the  $\tau$  polarization as a function of the polar production angle of the  $\tau$ .

<sup>165</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>166</sup> ABE 97N obtain this direct measurement using the left-right cross section asymmetry and the left-right forward-backward asymmetry in  $\tau^+\tau^-$  decays of the  $Z$  boson obtained with a polarized electron beam.

- 167 ALEXANDER 96U measure the  $\tau$ -lepton polarization and the forward-backward polarization asymmetry.  
 168 BUSKULIC 95Q obtain this result fitting the  $\tau$  polarization as a function of the polar  $\tau$  production angle.

### $A_s$

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.

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b>0.895 ± 0.066 ± 0.062</b>	2870	169 ABE	00D SLD	$E_{cm}^{ee} = 91.2$ GeV

- 169 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."

VALUE	DOCUMENT ID	TECN	COMMENT
<b>0.666 ± 0.036 OUR FIT</b>			
0.583 ± 0.055 ± 0.055	170 ABE	02G SLD	$E_{cm}^{ee} = 91.24$ GeV
0.688 ± 0.041	171 ABE	01C SLD	$E_{cm}^{ee} = 91.25$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.642 ± 0.110 ± 0.063	172 ABE	99O SLD	Repl. by ABE 02G
0.73 ± 0.22 ± 0.10	173 ABE,K	95 SLD	Repl. by ABE 01C

- 170 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  $A_c$ .  
 171 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.  
 172 ABE 99O 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  $A_c$ .  
 173 ABE,K 95 tag  $Z \rightarrow c\bar{c}$  events using  $D^{*+}$  and  $D^+$  meson production. To take care of the  $b\bar{b}$  contamination in their analysis they use  $A_b^D = 0.64 \pm 0.11$  (which is  $A_b$  from  $D^*/D$  tagging). This is obtained by starting with a Standard Model value of 0.935, assigning it an estimated error of  $\pm 0.105$  to cover LEP and SLD measurements, and finally taking into account  $B$ - $\bar{B}$  mixing ( $1 - 2\chi_{mix} = 0.72 \pm 0.09$ ).

### $A_b$

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."

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>0.926±0.024 OUR FIT</b>				
0.907±0.020±0.024	48028	174 ABE	03F SLD	$E_{\text{cm}}^{ee} = 91.24$ GeV
0.919±0.030±0.024		175 ABE	02G SLD	$E_{\text{cm}}^{ee} = 91.24$ GeV
0.855±0.088±0.102	7473	176 ABE	99L SLD	$E_{\text{cm}}^{ee} = 91.27$ GeV
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
0.910±0.068±0.037		177 ABE	99O SLD	Repl. by ABE 02G
0.911±0.045±0.045	11092	178 ABE	98I SLD	Repl. by ABE 03F
174 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).				
175 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 $A_c$ .				
176 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 $K^\pm$ .				
177 ABE 99O 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 $A_c$ .				
178 ABE 98I obtain an enriched sample of $b\bar{b}$ events tagging with an inclusive vertex mass cut. A momentum-weighted track charge is used to identify the sign of the charge of the underlying $b$ quark.				

### 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  $P_\tau$ .

### $C_{TT}$

<u>VALUE</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<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><math>0.08 \pm 0.13 \pm 0.04</math></b>	120k	179 BARATE	97D ALEP	$E_{cm}^{ee} = 91.2$ GeV

179 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." 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,  $M_{top}=174.3$  GeV,  $M_{Higgs}=150$  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 on the Z boson"). 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.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID	TECN
<b><math>1.45 \pm 0.25</math> OUR FIT</b>				
0.89±0.44	1.57	91.2	180 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	181 BARATE	00C ALEP
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
2.5 ±0.9	1.57	91.2	ABREU	94 DLPH
1.04±0.92	1.57	91.2	ACCIARRI	94 L3
0.62±0.80	1.57	91.2	AKERS	94 OPAL
1.85±0.66	1.57	91.2	BUSKULIC	94 ALEP

180 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.

181 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 on the Z boson"). 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	182 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	183 BARATE	00C ALEP
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
9 ± 30	-1.3	20	184 ABREU	95M DLPH
7 ± 26	-8.3	40	184 ABREU	95M DLPH
-11 ± 33	-24.1	57	184 ABREU	95M DLPH
-62 ± 17	-44.6	69	184 ABREU	95M DLPH
-56 ± 10	-63.5	79	184 ABREU	95M DLPH
-13 ± 5	-34.4	87.5	184 ABREU	95M DLPH
1.4 ± 0.5	1.57	91.2	ABREU	94 DLPH
1.79 ± 0.61	1.57	91.2	ACCIARRI	94 L3
0.99 ± 0.42	1.57	91.2	AKERS	94 OPAL
1.46 ± 0.48	1.57	91.2	BUSKULIC	94 ALEP
-29.0 <sup>+5.0</sup> / <sub>-4.8</sub> ± 0.5	-32.1	56.9	185 ABE	90I VNS
- 9.9 ± 1.5 ± 0.5	-9.2	35	HEGNER	90 JADE
0.05 ± 0.22	0.026	91.14	186 ABRAMS	89D MRK2
-43.4 ± 17.0	-24.9	52.0	187 BACALA	89 AMY
-11.0 ± 16.5	-29.4	55.0	187 BACALA	89 AMY
-30.0 ± 12.4	-31.2	56.0	187 BACALA	89 AMY
-46.2 ± 14.9	-33.0	57.0	187 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 <sup>+2.2</sup> / <sub>-2.3</sub> ± 0.5	-8.9	35.0	BRAUNSCH...	88D TASS
-17.6 <sup>+4.4</sup> / <sub>-4.3</sub> ± 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

182 ABBIENDI 01A error is almost entirely on account of statistics.

183 BARATE 00C error is almost entirely on account of statistics.

184 ABREU 95M perform this measurement using radiative muon-pair events associated with high-energy isolated photons.

185 ABE 90I measurements in the range  $50 \leq \sqrt{s} \leq 60.8$  GeV.

186 ABRAMS 89D asymmetry includes both 9  $\mu^+\mu^-$  and 15  $\tau^+\tau^-$  events.

187 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 on the Z boson”). 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. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID	TECN
<b>1.88 ± 0.17 OUR FIT</b>				
1.45 ± 0.30	1.57	91.2	188 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	189 BARATE	00C ALEP
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
2.2 ± 0.7	1.57	91.2	ABREU	94 DLPH
2.65 ± 0.88	1.57	91.2	ACCIARRI	94 L3
2.05 ± 0.52	1.57	91.2	AKERS	94 OPAL
1.97 ± 0.56	1.57	91.2	BUSKULIC	94 ALEP
–32.8 <sup>+6.4</sup> <sub>–6.2</sub> ± 1.5	–32.1	56.9	190 ABE	90I VNS
– 8.1 ± 2.0 ± 0.6	–9.2	35	HEGNER	90 JADE
–18.4 ± 19.2	–24.9	52.0	191 BACALA	89 AMY
–17.7 ± 26.1	–29.4	55.0	191 BACALA	89 AMY
–45.9 ± 16.6	–31.2	56.0	191 BACALA	89 AMY
–49.5 ± 18.0	–33.0	57.0	191 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

188 ABBIENDI 01A error includes approximately 0.26 due to statistics and 0.14 due to event selection systematics.

189 BARATE 00C error includes approximately 0.26 due to statistics and 0.11 due to experimental systematics.

190 ABE 90I measurements in the range  $50 \leq \sqrt{s} \leq 60.8$  GeV.

191 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 on the Z boson.”

<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>192</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>193</sup> BARATE	00C ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.77 ± 0.37	1.57	91.2	ABREU	94 DLPH
1.84 ± 0.45	1.57	91.2	ACCIARRI	94 L3
1.28 ± 0.30	1.57	91.2	AKERS	94 OPAL
1.71 ± 0.33	1.57	91.2	BUSKULIC	94 ALEP

<sup>192</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>193</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>194</sup> ACKERSTAFF	97T OPAL

<sup>194</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>195</sup> ABREU	00B DLPH
6.8 ± 3.5 ± 1.1	10.1	91.2	<sup>196</sup> ACKERSTAFF	97T OPAL
• • • We do not use the following data for averages, fits, limits, etc. • • •				
13.1 ± 3.5 ± 1.3	10.1	91.2	<sup>197</sup> ABREU	95G DLPH

- 195 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.
- 196 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.
- 197 ABREU 95G require the presence of a high-momentum charged kaon or  $\Lambda^0$  to tag the  $s$  quark. An unresolved  $s$ - and  $d$ -quark asymmetry of  $(11.2 \pm 3.1 \pm 5.4)\%$  is obtained by tagging the presence of a high-energy neutron or neutral kaon in the hadron calorimeter. Superseded by ABREU 00B.

—————  $A_{FB}^{(0,c)}$  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 on the Z boson," refers to the **Z pole** asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies. As a cross check we have also performed a weighted average of the "near peak" measurements taking into account the various common systematic errors. Applying to this combined "peak" measurement QED and energy-dependence corrections, our weighted average gives a pole asymmetry of  $(6.98 \pm 0.42)\%$ , the Standard Model prediction being 7.25%.

ASYMMETRY (%)	STD. MODEL	$\sqrt{s}$ (GeV)	DOCUMENT ID	TECN
<b>7.04 ± 0.36 OUR FIT</b>				
5.68 ± 0.54 ± 0.39	6.3	91.25	198 ABBIENDI	03P OPAL
6.45 ± 0.57 ± 0.37	6.10	91.21	199 HEISTER	02H ALEP
6.59 ± 0.94 ± 0.35	6.2	91.235	200 ABREU	99Y DLPH
6.3 ± 0.9 ± 0.3	6.1	91.22	201 BARATE	98O ALEP
6.3 ± 1.2 ± 0.6	6.1	91.22	202 ALEXANDER	97C OPAL
8.3 ± 2.2 ± 1.6	6.4	91.27	203 ABREU	95K DLPH
8.3 ± 3.8 ± 2.7	6.2	91.24	204 ADRIANI	92D L3
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
− 6.8 ± 2.5 ± 0.9	− 3.0	89.51	198 ABBIENDI	03P OPAL
14.6 ± 2.0 ± 0.8	12.2	92.95	198 ABBIENDI	03P OPAL
− 12.4 ± 15.9 ± 2.0	− 9.6	88.38	199 HEISTER	02H ALEP
− 2.3 ± 2.6 ± 0.2	− 3.8	89.38	199 HEISTER	02H ALEP
− 0.3 ± 8.3 ± 0.6	0.9	90.21	199 HEISTER	02H ALEP
10.6 ± 7.7 ± 0.7	9.6	92.05	199 HEISTER	02H ALEP
11.9 ± 2.1 ± 0.6	12.2	92.94	199 HEISTER	02H ALEP
12.1 ± 11.0 ± 1.0	14.2	93.90	199 HEISTER	02H ALEP
− 4.96 ± 3.68 ± 0.53	− 3.5	89.434	200 ABREU	99Y DLPH
11.80 ± 3.18 ± 0.62	12.3	92.990	200 ABREU	99Y DLPH
− 1.0 ± 4.3 ± 1.0	− 3.9	89.37	201 BARATE	98O ALEP
11.0 ± 3.3 ± 0.8	12.3	92.96	201 BARATE	98O ALEP
3.9 ± 5.1 ± 0.9	− 3.4	89.45	202 ALEXANDER	97C OPAL
15.8 ± 4.1 ± 1.1	12.4	93.00	202 ALEXANDER	97C OPAL
− 12.9 ± 7.8 ± 5.5	− 13.6	35	BEHREND	90D CELL

7.7 ± 13.4 ± 5.0	− 22.1	43	BEHREND	90D CELL
− 12.8 ± 4.4 ± 4.1	− 13.6	35	ELSEN	90 JADE
− 10.9 ± 12.9 ± 4.6	− 23.2	44	ELSEN	90 JADE
− 14.9 ± 6.7	− 13.3	35	OULD-SAADA	89 JADE

198 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.

199 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.

200 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).

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

202 ALEXANDER 97C identify the  $b$  and  $c$  events using a  $D/D^*$  tag.

203 ABREU 95K identify  $c$  and  $b$  quarks using both electron and muon semileptonic decays.

204 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 on the  $Z$  boson,” refers to the **Z pole** asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies. As a cross check we have also performed a weighted average of the “near peak” measurements taking into account the various common systematic errors. Applying to this combined “peak” measurement QED and energy-dependence corrections, our weighted average gives a pole asymmetry of  $(10.14 \pm 0.18)\%$ , the Standard Model prediction being 10.15%. For the jet-charge measurements (where the QCD effects are included since they represent an inherent part of the analysis), we use the corrections given by the authors.

<u>ASYMMETRY (%)</u>	<u>STD. MODEL</u>	<u><math>\sqrt{s}</math> (GeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<b>10.01 ± 0.17 OUR FIT</b>				
9.72 ± 0.42 ± 0.15	9.67	91.25	205 ABBIENDI	03P OPAL
9.77 ± 0.36 ± 0.18	9.69	91.26	206 ABBIENDI	02I OPAL
9.52 ± 0.41 ± 0.17	9.59	91.21	207 HEISTER	02H ALEP
10.00 ± 0.27 ± 0.11	9.63	91.232	208 HEISTER	01D ALEP
9.82 ± 0.47 ± 0.16	9.69	91.26	209 ABREU	99M DLPH
7.62 ± 1.94 ± 0.85	9.64	91.235	210 ABREU	99Y DLPH
9.60 ± 0.66 ± 0.33	9.69	91.26	211 ACCIARRI	99D L3
9.31 ± 1.01 ± 0.55	9.65	91.24	212 ACCIARRI	98U L3
9.4 ± 2.7 ± 2.2	9.61	91.22	213 ALEXANDER	97C OPAL
10.4 ± 1.3 ± 0.5	9.70	91.27	214 ABREU	95K DLPH
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
4.7 ± 1.8 ± 0.1	5.9	89.51	205 ABBIENDI	03P OPAL
10.3 ± 1.5 ± 0.2	12.0	92.95	205 ABBIENDI	03P OPAL
5.82 ± 1.53 ± 0.12	5.9	89.50	206 ABBIENDI	02I OPAL

12.21 ± 1.23 ± 0.25	12.0	92.91	206	ABBIENDI	02I	OPAL
−13.1 ± 13.5 ± 1.0	3.2	88.38	207	HEISTER	02H	ALEP
5.5 ± 1.9 ± 0.1	5.6	89.38	207	HEISTER	02H	ALEP
− 0.4 ± 6.7 ± 0.8	7.5	90.21	207	HEISTER	02H	ALEP
11.1 ± 6.4 ± 0.5	11.0	92.05	207	HEISTER	02H	ALEP
10.4 ± 1.5 ± 0.3	12.0	92.94	207	HEISTER	02H	ALEP
13.8 ± 9.3 ± 1.1	12.9	93.90	207	HEISTER	02H	ALEP
4.36 ± 1.19 ± 0.11	5.8	89.472	208	HEISTER	01D	ALEP
11.72 ± 0.97 ± 0.11	12.0	92.950	208	HEISTER	01D	ALEP
6.8 ± 1.8 ± 0.13	6.0	89.55	209	ABREU	99M	DLPH
12.3 ± 1.6 ± 0.27	12.0	92.94	209	ABREU	99M	DLPH
5.67 ± 7.56 ± 1.17	5.7	89.434	210	ABREU	99Y	DLPH
8.82 ± 6.33 ± 1.22	12.1	92.990	210	ABREU	99Y	DLPH
6.11 ± 2.93 ± 0.43	5.9	89.50	211	ACCIARRI	99D	L3
13.71 ± 2.40 ± 0.44	12.2	93.10	211	ACCIARRI	99D	L3
4.95 ± 5.23 ± 0.40	5.8	89.45	212	ACCIARRI	98U	L3
11.37 ± 3.99 ± 0.65	12.1	92.99	212	ACCIARRI	98U	L3
− 8.6 ± 10.8 ± 2.9	5.8	89.45	213	ALEXANDER	97C	OPAL
− 2.1 ± 9.0 ± 2.6	12.1	93.00	213	ALEXANDER	97C	OPAL
−71 ± 34 + − 8	−58	58.3		SHIMONAKA	91	TOPZ
−22.2 ± 7.7 ± 3.5	−26.0	35		BEHREND	90D	CELL
−49.1 ± 16.0 ± 5.0	−39.7	43		BEHREND	90D	CELL
−28 ± 11	−23	35		BRAUNSCH...	90	TASS
−16.6 ± 7.7 ± 4.8	−24.3	35		ELSEN	90	JADE
−33.6 ± 22.2 ± 5.2	−39.9	44		ELSEN	90	JADE
3.4 ± 7.0 ± 3.5	−16.0	29.0		BAND	89	MAC
−72 ± 28 ± 13	−56	55.2		SAGAWA	89	AMY

205 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.

206 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.

207 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.

208 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  $+0.103 (A_{FB}^C - 0.0651) - 0.440 (R_b - 0.21585)$ .

209 ABREU 99M tag  $Z \rightarrow b\bar{b}$  events using lifetime and vertex charge. The original quark charge is obtained from the charge flow, the difference between the forward and backward hemisphere charges.

210 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).

211 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.

- 212 ACCIARRI 98U tag  $Z \rightarrow b\bar{b}$  events using lifetime and measure the jet charge using the hemisphere charge.
- 213 ALEXANDER 97C identify the  $b$  and  $c$  events using a  $D/D^*$  tag.
- 214 ABREU 95K identify  $c$  and  $b$  quarks using both electron and muon semileptonic decays. The systematic error includes an uncertainty of  $\pm 0.3$  due to the mixing correction ( $\chi = 0.115 \pm 0.011$ ).

## 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. MODEL</u>	<u><math>\sqrt{s}</math> (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>215</sup> ABREU	92I DLPH
$4.0 \pm 0.4 \pm 0.63$	4.0	91.3	<sup>216</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>215</sup> ABREU 92I has 0.14 systematic error due to uncertainty of quark fragmentation.

<sup>216</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. MODEL</u>	<u><math>\sqrt{s}</math> (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

Revised February 2002 by C. Caso (University of Genova) and A. Gurtu (Tata Institute).

In the reaction  $e^+e^- \rightarrow Z\gamma$ , deviations from the Standard Model for the  $Z\gamma\gamma^*$  and  $Z\gamma Z^*$  couplings may be described in terms of 8 parameters,  $h_i^V$  ( $i = 1, 4; V = \gamma, Z$ ) [1]. The parameters  $h_i^\gamma$  describe the  $Z\gamma\gamma^*$  couplings and the parameters  $h_i^Z$



the  $Z\gamma Z^*$  couplings. In this formalism  $h_1^V$  and  $h_2^V$  lead to  $CP$ -violating and  $h_3^V$  and  $h_4^V$  to  $CP$ -conserving effects. All these anomalous contributions to the cross section increase rapidly with center-of-mass energy. In order to ensure unitarity, these parameters are usually described by a form-factor representation,  $h_i^V(s) = h_{i0}^V/(1 + s/\Lambda^2)^n$ , where  $\Lambda$  is the energy scale for the manifestation of a new phenomenon and  $n$  is a sufficiently large power. By convention one uses  $n = 3$  for  $h_{1,3}^V$  and  $n = 4$  for  $h_{2,4}^V$ . Usually limits on  $h_i^V$ 's are put assuming some value of  $\Lambda$  (sometimes  $\infty$ ).

Above the  $e^+e^- \rightarrow ZZ$  threshold, deviations from the Standard Model for the  $ZZ\gamma^*$  and  $ZZZ^*$  couplings may be described by means of four anomalous couplings  $f_i^V$  ( $i = 4, 5; V = \gamma, Z$ ) [2]. As above, the parameters  $f_i^\gamma$  describe the  $Z\gamma\gamma^*$  couplings and the parameters  $f_i^Z$  the  $ZZZ^*$  couplings. The anomalous couplings  $f_5^V$  lead to violation of  $C$  and  $P$  symmetries while  $f_4^V$  introduces  $CP$  violation.

All these couplings  $h_i^V$  and  $f_i^V$  are zero at tree level in the Standard Model.

## References

1. U. Baur and E.L. Berger Phys. Rev. **D47**, 4889 (1993).
2. K. Hagiwara *et al.*, Nucl. Phys. **B282**, 253 (1987).

## $h_i^V$

Combining the LEP results properly taking into account the correlations the following 95% CL limits are derived:

(See EP Preprint Summer 2003: CERN-EP/2003-091 and hep-ex/0312023, December 2003, on <http://lepewwg.web.cern.ch/LEPEWWG/stanmod/>)

$$\begin{array}{ll}
 -0.13 < h_1^Z < +0.13, & -0.078 < h_2^Z < +0.071, \\
 -0.20 < h_3^Z < +0.07, & -0.05 < h_4^Z < +0.12, \\
 -0.056 < h_1^\gamma < +0.055, & -0.045 < h_2^\gamma < +0.025, \\
 -0.049 < h_3^\gamma < -0.008, & -0.002 < h_4^\gamma < +0.034.
 \end{array}$$

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

	217 ABBIENDI,G	00C OPAL
	218 ACCIARRI	00O L3
	219 ABBOTT	98M D0
	220 ABREU	98K DLPH

217 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:  $h_1^Z = 0.000 \pm 0.100$  ( $-0.190, 0.190$ ),  $h_2^Z = 0.000 \pm 0.068$  ( $-0.128, 0.128$ ),  $h_3^Z = -0.074_{-0.103}^{+0.102}$  ( $-0.269, 0.119$ ),  $h_4^Z = 0.046 \pm 0.068$  ( $-0.084, 0.175$ ),  $h_1^\gamma = 0.000 \pm 0.061$  ( $-0.115, 0.115$ ),  $h_2^\gamma = 0.000 \pm 0.041$  ( $-0.077, 0.077$ ),  $h_3^\gamma = -0.080_{-0.041}^{+0.039}$  ( $-0.164, -0.006$ ),  $h_4^\gamma = 0.064_{-0.030}^{+0.033}$  ( $+0.007, +0.134$ ). The results are derived assuming that only one coupling at a time is different from zero.

218 ACCIARRI 00O study 189 GeV  $e^+e^- \rightarrow q\bar{q}\gamma$  and  $e^+e^- \rightarrow \nu\bar{\nu}\gamma$  events to derive 95% CL limits on  $h_i^V$ . For deriving each limit the others are fixed at zero. They report:  $-0.26 < h_1^Z < 0.09$ ,  $-0.10 < h_2^Z < 0.16$ ,  $-0.26 < h_3^Z < 0.21$ ,  $-0.11 < h_4^Z < 0.19$ ,  $-0.20 < h_1^\gamma < 0.08$ ,  $-0.11 < h_2^\gamma < 0.11$ ,  $-0.11 < h_3^\gamma < 0.03$ ,  $-0.02 < h_4^\gamma < 0.10$ .

219 ABBOTT 98M study  $p\bar{p} \rightarrow Z\gamma + X$ , with  $Z \rightarrow e^+e^-, \mu^+\mu^-, \bar{\nu}\nu$  at 1.8 TeV, to obtain 95% CL limits at  $\Lambda = 750$  GeV:  $|h_{30}^Z| < 0.36$ ,  $|h_{40}^Z| < 0.05$  (keeping  $|h_{30}^\gamma| < 0.37$ ,  $|h_{40}^\gamma| < 0.05$  (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  $h_i^Z = 0$ ).

220 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 results properly taking into account the correlations the following 95% CL limits are derived:

(See EP Preprint Summer 2003: CERN-EP/2003-091 and hep-ex/0312023, December 2003, on <http://lepewwg.web.cern.ch/LEPEWWG/stanmod/>)

$$\begin{aligned} -0.30 < f_4^Z < +0.30, & & -0.34 < f_5^Z < +0.38, \\ -0.17 < f_4^\gamma < +0.19, & & -0.32 < f_5^\gamma < +0.36. \end{aligned}$$

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

	221 ABBIENDI	04C OPAL
	222 ACHARD	03D L3

- <sup>221</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>222</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

Revised November 2003 by C. Caso (University of Genova) and A. Gurtu (Tata Institute).

The Standard Model predictions for  $WWWW$ ,  $WWZZ$ ,  $WWZ\gamma$ ,  $WW\gamma\gamma$ , and  $ZZ\gamma\gamma$  couplings are small at LEP, but expected to become important at a TeV Linear Collider. Outside the Standard Model framework such possible couplings,  $a_0, a_c, a_n$ , are expressed in terms of the following dimension-6 operators [1,2];

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

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

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

At LEP the processes studied in search of these quartic couplings are  $e^+e^- \rightarrow WW\gamma$ ,  $e^+e^- \rightarrow \gamma\gamma\nu\bar{\nu}$ , and  $e^+e^- \rightarrow Z\gamma\gamma$  and limits are set on the quantities  $a_0^W/\Lambda^2, a_c^W/\Lambda^2, a_n/\Lambda^2$ . The characteristics of the first process depend on all the three couplings whereas those of the latter two depend only on the two  $CP$ -conserving couplings. The sensitive measured variables are the cross sections for these processes as well as the energy and angular distributions of the photon and recoil mass to the photon pair.

## References

1. G. Belanger and F. Boudjema, Phys. Lett. **B288**, 201 (1992).
2. J.W. Stirling and A. Werthenbach, Eur. Phys. J. **C14**, 103 (2000);  
J.W. Stirling and A. Werthenbach, Phys. Lett. **B466**, 369 (1999);  
A. Denner *et al.*, Eur. Phys. J. **C20**, 201 (2001);  
G. Montagna *et al.*, Phys. Lett. **B515**, 197 (2001).
3. G. Belanger *et al.*, Eur. Phys. J. **C13**, 103 (2000).

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

Combining published and unpublished preliminary LEP results the following 95% CL intervals for the QGCs associated with the  $ZZ\gamma\gamma$  vertex are derived:

(See EP Preprint Summer 2003: CERN-EP/2003-091 and hep-ex/0312023, December 2003, on <http://lepewwg.web.cern.ch/LEPEWWG/stanmod/>)

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

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

VALUE \_\_\_\_\_ DOCUMENT ID \_\_\_\_\_ TECN \_\_\_\_\_

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

223 ACHARD 02G L3

223 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  $>5$  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  $a_0/\Lambda^2 = 0.00^{+0.02}_{-0.01}$  GeV $^{-2}$  and  $a_c/\Lambda^2 = 0.03^{+0.01}_{-0.02}$  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  $-0.02$  GeV $^{-2} < a_0/\Lambda^2 < 0.03$  GeV $^{-2}$  and  $-0.07$  GeV $^{-2} < a_c/\Lambda^2 < 0.05$  GeV $^{-2}$ .

## Z REFERENCES

ABBIENDI	04C	EPJ C32 303	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	03P	PL B577 18	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABDALLAH	03H	PL B569 129	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
ABE	03F	PRL 90 141804	K. Abe <i>et al.</i>	(SLD Collab.)
ACHARD	03D	PL B572 133	P. Achard <i>et al.</i>	(L3 Collab.)
ABBIENDI	02I	PL B546 29	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABE	02G	PRL 88 151801	K. Abe <i>et al.</i>	(SLD Collab.)
ACHARD	02G	PL B540 43	P. Achard <i>et al.</i>	(L3 Collab.)
HEISTER	02B	PL B526 34	A. Heister <i>et al.</i>	(ALEPH Collab.)
HEISTER	02C	PL B528 19	A. Heister <i>et al.</i>	(ALEPH Collab.)
HEISTER	02H	EPJ C24 177	A. Heister <i>et al.</i>	(ALEPH Collab.)
ABBIENDI	01A	EPJ C19 587	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	01G	EPJ C18 447	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	01K	PL B516 1	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	01N	EPJ C20 445	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	01O	EPJ C21 1	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABE	01B	PRL 86 1162	K. Abe <i>et al.</i>	(SLD Collab.)
ABE	01C	PR D63 032005	K. Abe <i>et al.</i>	(SLD Collab.)
ACCIARRI	01E	PL B505 47	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	01I	PL B497 23	M. Acciarri <i>et al.</i>	(L3 Collab.)
HEISTER	01	EPJ C20 401	A. Heister <i>et al.</i>	(ALEPH Collab.)
HEISTER	01D	EPJ C22 201	A. Heister <i>et al.</i>	(ALEPH Collab.)
ABBIENDI	00N	PL B476 256	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI,G	00C	EPJ C17 553	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABE	00B	PRL 84 5945	K. Abe <i>et al.</i>	(SLD Collab.)
ABE	00D	PRL 85 5059	K. Abe <i>et al.</i>	(SLD Collab.)
ABREU	00	EPJ C12 225	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	00B	EPJ C14 613	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	00E	EPJ C14 585	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	00F	EPJ C16 371	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	00P	PL B475 429	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	00	EPJ C13 47	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00C	EPJ C16 1	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00J	PL B479 79	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00O	PL B489 55	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	00Q	PL B489 93	M. Acciarri <i>et al.</i>	(L3 Collab.)
BARATE	00B	EPJ C16 597	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	00C	EPJ C14 1	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	00O	EPJ C16 613	R. Barate <i>et al.</i>	(ALEPH Collab.)
ABBIENDI	99B	EPJ C8 217	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABBIENDI	99I	PL B447 157	G. Abbiendi <i>et al.</i>	(OPAL Collab.)
ABE	99E	PR D59 052001	K. Abe <i>et al.</i>	(SLD Collab.)
ABE	99L	PRL 83 1902	K. Abe <i>et al.</i>	(SLD Collab.)
ABE	99O	PRL 83 3384	K. Abe <i>et al.</i>	(SLD Collab.)
ABREU	99	EPJ C6 19	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	99B	EPJ C10 415	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	99J	PL B449 364	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	99M	EPJ C9 367	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	99U	PL B462 425	P. Abreu <i>et al.</i>	(DELPHI Collab.)

ABREU	99Y	EPJ C10 219	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	99D	PL B448 152	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	99F	PL B453 94	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	99G	PL B450 281	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	99O	PL B465 363	M. Acciarri <i>et al.</i>	(L3 Collab.)
ABBOTT	98M	PR D57 R3817	B. Abbott <i>et al.</i>	(D0 Collab.)
ABE	98D	PRL 80 660	K. Abe <i>et al.</i>	(SLD Collab.)
ABE	98I	PRL 81 942	K. Abe <i>et al.</i>	(SLD Collab.)
ABREU	98K	PL B423 194	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	98L	EPJ C5 585	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	98G	PL B431 199	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	98H	PL B429 387	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	98U	PL B439 225	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACKERSTAFF	98A	EPJ C5 411	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	98E	EPJ C1 439	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	98O	PL B420 157	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	98Q	EPJ C4 19	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
BARATE	98O	PL B434 415	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	98T	EPJ C4 557	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	98V	EPJ C5 205	R. Barate <i>et al.</i>	(ALEPH Collab.)
ABE	97	PRL 78 17	K. Abe <i>et al.</i>	(SLD Collab.)
ABE	97N	PRL 79 804	K. Abe <i>et al.</i>	(SLD Collab.)
ABREU	97C	ZPHY C73 243	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	97E	PL B398 207	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	97G	PL B404 194	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	97D	PL B393 465	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	97J	PL B407 351	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	97L	PL B407 389	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	97R	PL B413 167	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACKERSTAFF	97C	PL B391 221	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	97K	ZPHY C74 1	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	97M	ZPHY C74 413	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	97S	PL B412 210	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	97T	ZPHY C76 387	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ACKERSTAFF	97W	ZPHY C76 425	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)
ALEXANDER	97C	ZPHY C73 379	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	97D	ZPHY C73 569	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	97E	ZPHY C73 587	G. Alexander <i>et al.</i>	(OPAL Collab.)
BARATE	97D	PL B405 191	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	97E	PL B401 150	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	97F	PL B401 163	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	97H	PL B402 213	R. Barate <i>et al.</i>	(ALEPH Collab.)
BARATE	97J	ZPHY C74 451	R. Barate <i>et al.</i>	(ALEPH Collab.)
ABE	96E	PR D53 1023	K. Abe <i>et al.</i>	(SLD Collab.)
ABREU	96	ZPHY C70 531	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	96R	ZPHY C72 31	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	96S	PL B389 405	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	96U	ZPHY C73 61	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ACCIARRI	96	PL B371 126	M. Acciarri <i>et al.</i>	(L3 Collab.)
ADAM	96	ZPHY C69 561	W. Adam <i>et al.</i>	(DELPHI Collab.)
ADAM	96B	ZPHY C70 371	W. Adam <i>et al.</i>	(DELPHI Collab.)
ALEXANDER	96B	ZPHY C70 197	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	96F	PL B370 185	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	96N	PL B384 343	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	96R	ZPHY C72 1	G. Alexander <i>et al.</i>	(OPAL Collab.)
ALEXANDER	96U	ZPHY C72 365	G. Alexander <i>et al.</i>	(OPAL Collab.)
BUSKULIC	96D	ZPHY C69 393	D. Buskulic <i>et al.</i>	(ALEPH Collab.)
BUSKULIC	96H	ZPHY C69 379	D. Buskulic <i>et al.</i>	(ALEPH Collab.)
ABE	95J	PRL 74 2880	K. Abe <i>et al.</i>	(SLD Collab.)
ABE,K	95	PRL 75 3609	K. Abe <i>et al.</i>	(SLD Collab.)
ABREU	95	ZPHY C65 709 <small>erratum</small>	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95D	ZPHY C66 323	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95G	ZPHY C67 1	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95I	ZPHY C67 183	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95K	ZPHY C65 569	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95L	ZPHY C65 587	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95M	ZPHY C65 603	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95O	ZPHY C67 543	P. Abreu <i>et al.</i>	(DELPHI Collab.)
ABREU	95R	ZPHY C68 353	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	95O	ZPHY C67 27	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	95Q	ZPHY C69 183	D. Buskulic <i>et al.</i>	(ALEPH 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	94	NP B418 403	P. Abreu <i>et al.</i>	(DELPHI 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.)
ACCIARRI	94	ZPHY C62 551	M. Acciarri <i>et al.</i>	(L3 Collab.)
ACCIARRI	94E	PL B341 245	M. Acciarri <i>et al.</i>	(L3 Collab.)
AKERS	94	ZPHY C61 19	R. Akers <i>et al.</i>	(OPAL Collab.)
AKERS	94P	ZPHY C63 181	R. Akers <i>et al.</i>	(OPAL Collab.)
BUSKULIC	94	ZPHY C62 539	D. Buskulic <i>et al.</i>	(ALEPH 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	95	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.)
ACTON	93F	ZPHY C58 405	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.)
LEP	92	PL B276 247	LEP Collabs.	(LEP, ALEPH, DELPHI, L3, OPAL)
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.)
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-SAAD	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	85B	ZPHY C26 507	W. Bartel <i>et al.</i>	(JADE Collab.)
Also	82	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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